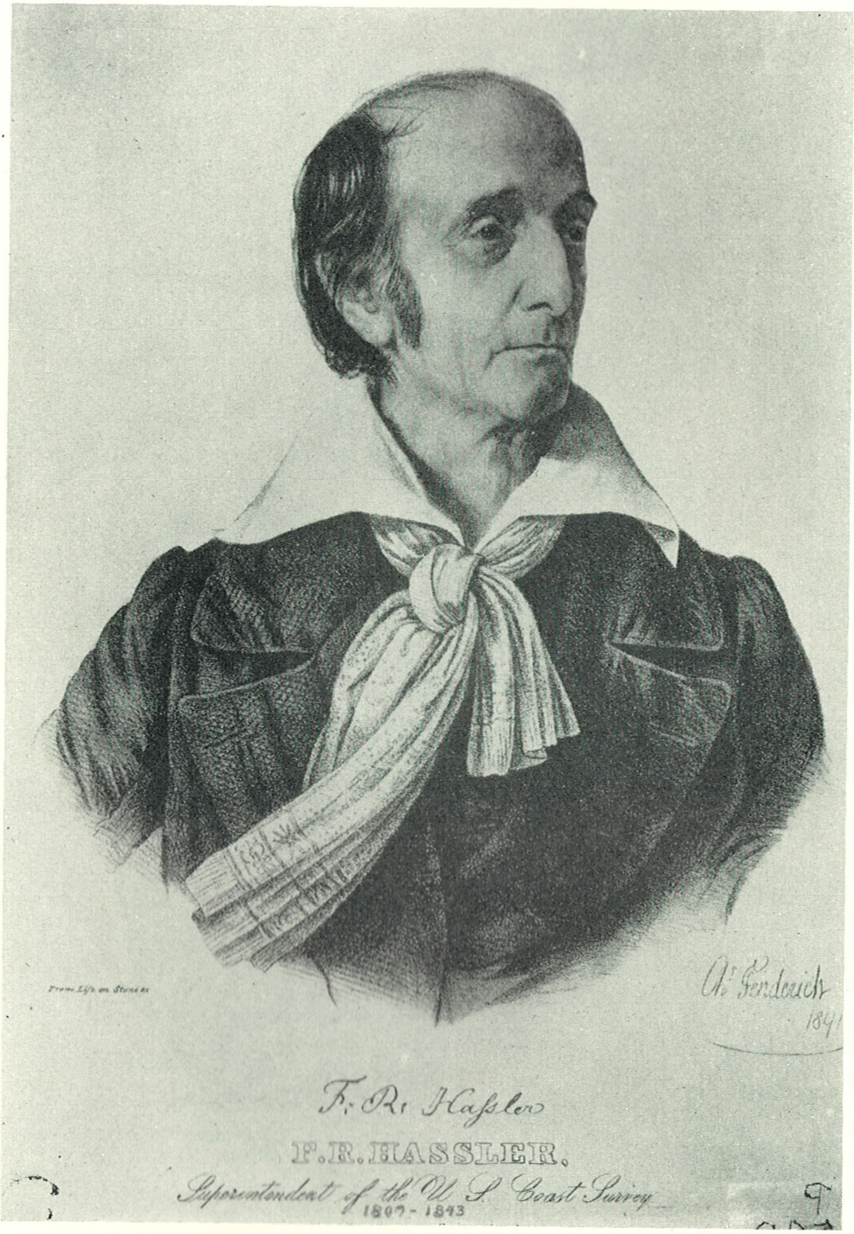
THE COAST AND GEODETIC SURVEY

1807 1957

UNITED STATES COAST AND GEODETIC SURVEY

150 YEARS OF HISTORY

UNITED STATES DEPARTMENT OF COMMERCE



FERDINAND RUDOLPH HASSLER

First Superintendent of the Survey

The Coast and Geodetic Survey 1807–1957

150 YEARS OF HISTORY

by A. Joseph Wraight and Elliott B. Roberts

U. S. DEPARTMENT OF COMMERCE

Sinclair Weeks, *Secretary*

COAST AND GEODETIC SURVEY

H. Arnold Karo, *Director*

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THE SEAL on the covers was used by the Survey before 1903, when the Bureau became a part of the new Department of Commerce and Labor. On the back cover is portrayed the early Survey ship *Experiment*.

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Foreword

In 1957 the Coast and Geodetic Survey completes a century and a half of service. A century and a half of service! Those are simple words, but their meaning is not easy to convey. They mean the charting of 100,000 miles of coast line, the basic mapping of a great continent and its airlanes, and countless hours spent over delicate instruments. They mean hazardous work on sea and mountain, among alligators and rattlesnakes, in blinding storms and exhausting heat, on Arctic ice floes and in tropical swamps. They mean the lifelong service of thousands of quiet and dedicated men, to their country and its commerce.

The accompanying account outlines the Survey's history and lists some of its achievements. It is a matter of pride to salute the Survey, one of the oldest bureaus in the Department of Commerce, for a job well done and for important tasks under way.

SINCLAIR WEEKS,
Secretary of Commerce.

Contents

The Government's Oldest Technical Bureau

I

Taking America's Measurements

THE COAST AND GEODETIC SURVEY, 150 years old on the 10th of February 1957, was the first technical bureau of the Federal Government. It was born out of necessity, given life and ideals by a dedicated public servant—Ferdinand Hassler—and carried forward by Hassler's pupils and successors through 150 years of serving America. In performing its task it has led the world in technical accomplishment, establishing standards and procedures looked on as definitive by all people.

Beginning as the Survey of the Coast, and known in mid-century as the Coast Survey, it became finally the Coast and Geodetic Survey. This is the story, in brief, of the agency with the several names, which will here be called generally the Survey or the Bureau.

Today the Survey is one of the bureaus constituting the United States Department of Commerce, with its main office in the Department's building in Washington. It belongs to a group of bureaus within the Department that serve in the interest of transportation and provide technical services necessary to the national commerce.

The Survey fulfills both functions. It makes surveys and publishes nautical charts of the 2½ million square miles of coastal waters of the Nation and its possessions, in order to provide safety to shipping. It conducts collateral oceanographic and geophysical investigations to provide additional information for mariners and for a wide variety of scientific and technical workers throughout the country. It executes the principal geodetic surveys of the country, not only as a basis for its own charting work, but also as a foundation for topographic and cadastral surveys, mapping, and many engineering works. It prepares and distributes the aeronautical charts of the country and distributes those of foreign areas needed by American civil aviation.

The Survey has rendered substantial services in its specialized fields in every war since its operations began. It has been administered generally by engineers and scientists, and since World War I its staff has included civilian scientists and engineers working with an administrative group of engineer-trained commissioned officers.

SERVICE TO THE CITIZEN

Scientists, mariners, fliers, and private surveyors know the work of the Survey at first hand. The average citizen does not realize, however, that when he plans a fishing trip or a swim he is depending on tide tables that the Bureau prepares, or that his property line is determined in accordance with points it has set by the stars. Local surveyors are guided by "plane coordinates" that the Bureau has fixed.

In the beginning, the Survey charted the depths of America's harbors and the outlines of her coasts. To help seamen use their compasses, it studied the earth's magnetism. North was one thing to a needle off New England, and another to a needle in the Gulf of Mexico. Similarly, "down" was one direction as shown by a plumb at the end of a line suspended near the base of a mountain but might be slightly different in the valley a few miles away. So the Bureau studied the earth's gravity, to make allowances for the attraction the mountain had for the plumb.

The Bureau's scientists wanted to know what effect earthquakes had on their recordings of the earth's magnetism. The seismographs they installed in the magnetic observatories came gradually to be used in the studies of earthquakes themselves. Today the Bureau records a thousand quakes a year and maintains 50 seismographs along the San Andreas Fault in California alone. In the Pacific it operates a sea wave warning system to alert shore residents when a distant quake is likely to swamp their boats and inundate their homes. Builders take its advice in planning structures that will resist such shocks as may be expected in a given area.

The history of the Survey falls roughly into three half-centuries—a period of pioneering, a period of expansion, and the modern period. Until after the Civil War, the work was mainly along the eastern, Gulf of Mexico, and California coasts. In 1871 Congress gave the Survey the additional duty of fixing the basic lines for inland maps. Geodesy became as important as hydrography, the charting of bodies of water.

Geodesy is the kind of surveying that takes into account the size and shape of the earth and checks its calculations by the fixed stars. To calculate the exact location of any point, the survey crews take sightings from two points previously known. The result is a network of triangles that form rectangles and stretch in bands across the country. The lines are imaginary, but the points are marked.

Hikers and mountain climbers know the Survey's bronze markers. For some 150,000 of them, the exact longitude and latitude have been calculated. For the nearly 400,000 others, the exact distance above sea level has been recorded. Anybody curious to know what a given marker designates may find out by writing the Director of the Coast and Geodetic Survey in Washington, giving its name or number and the county and State in which it is located.

In its modern period, the Survey has gone into the air. While it watches the erosion of coasts and harbors and sounds the depths of the continental shelf, it produces the country's aeronautical charts—more than 43 million copies in the fiscal year 1956.

Any history of use to the engineer and the scientist is bound to contain many technical terms. The layman and the student will find a glossary of Survey terms in appendix B.

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II

There Was Only One Hassler

AT THE BEGINNING of the 19th century the Nation consisted of 16 States and some interior territory. Land transportation was difficult, and commerce between the States was largely by coastwise shipping. Foreign trade, essential for the life of the country, was entirely by sea. Commercial fishing along the coasts had become one of the more important industries, providing the capital necessary for the development of other industries. With many ships plying the coast and entering harbors, shipwrecks were common. This resulted in high costs of products, high insurance rates, and conditions generally unfavorable to commerce and industry.

The frequency of shipwreck was due in great part to the lack of adequate charts. There were some maps and other guides for mariners, but they were usually poor, spotty, and unconnected. Vague charts of sections of the coast had been made by the British Government during the colonial period. The *Atlantic Neptune* contained a collection of charts prepared for the British fleet during the Revolutionary War. As early as 1730, Captain Southack of Massachusetts had prepared the *Coasting Pilot,* comprising eight maps covering the coast from New York northward. London reviews of this "pilot" indicated its inadequacy, but, with other similar works, it remained in use because there was nothing better. The *English Pilot* of 1774 and 1794 contained material from scores of mariners but fell far short of filling the needs of shipping. Some harbors had been poorly mapped by individuals or private companies.

The Blunt Company became renowned for the famous *American Coast Pilot,* or *Blunt's Coast Pilot,* first published in 1796. This volume of written text and a few maps was a compilation of available material, including British work, private reports, and soundings and observations of seamen. Though a remarkable collection, it did not eliminate the hazards of navigation.

Charting was obviously a government responsibility. In no other way would comprehensive and reliable results be achieved. This had been recognized for some time by scientific men, including members of the American Philosophical Society, founded by Benjamin Franklin. Thomas Jefferson and others proposed Government action as early as 1800. They were later joined by commercial interests. Several bills were introduced in the Congress for specific construction and other works in several harbor areas, including the Delaware River and Nantucket Harbor.

The first real coastal surveys made by the United States Government covered North Carolina and portions of Louisiana, recently purchased from France. These surveys, ordered early in 1806, did not provide an overall survey of the coasts, though the results were later incorporated into Survey records. The efforts did, however, prepare the way for a bill passed the following year providing for a survey of the entire coast and authorizing a starting amount of $25,000.

HASSLER AND THE SURVEY OF THE COAST

The act of February 10, 1807, authorized the President ". . . to cause a survey to be taken of coasts of the United States, in which shall be designated the islands and shoals and places of anchorage . . . ." President Thomas Jefferson and Secretary of the Treasury Albert Gallatin, men of learning and insight, recognized the necessity of starting this work properly. Jefferson asked the learned scientists of the American Philosophical Society to suggest qualified persons; then he asked those persons to propose methods for undertaking the work.

Proposals were submitted within several months by Robert Patterson, Andrew Ellicott, John Garnett, Isaac Briggs, Joshua Moore, James Madison, and Ferdinand Hassler—all recognized men of accomplishment. The best was that of Hassler's, a Swiss geodesist and scientist of outstanding reputation. It provided for the determination of true geographic position by astronomical means at key points near the coast, networks of precise triangulation between these points, a topographic survey of the coast, and a hydrographic survey of coastal waters controlled by triangulation. On the society's approval, President Jefferson named Hassler first Superintendent of the new bureau, called the Survey of the Coast and lodged in the Treasury Department.

Madison was to be inaugurated as President 2 years later and to play an important part in the Survey's early years.

The appointment of Hassler was extremely fortunate, for it was he who started the Survey on its true scientific course and set standards that still prevail. Though he was proud and intolerant, constantly drawing down official censure upon himself by his irascibility, he nevertheless had an understanding of sound technical procedure and a sense of lasting values. By his strength of will and his sincerity, he successfully resisted those who wanted a quick and cheap job.

Born in Switzerland in 1770, Ferdinand R. Hassler became prominent in his own country. He worked closely with Professor Tralles, founder of the Geodetic Survey of Switzerland, and held such offices as that of attorney general, but he disliked political conditions at home and so came to the United States with his family in 1805. He brought more than 3,000 books on mathematics and science as well as many precision instruments and standards, including an iron meter bar, an original standard of the International Commission on Weights and Measures, which later became the basis for triangulation. Soon he became associated with President Jefferson, Secretary of the Treasury Gallatin, also a Swiss, and other members of the American Philosophical Society. His personality and knowledge had profound impact on all who met him. Men were never indifferent to him. They were either for him or against him.

Hassler could not work without funds or materials, and at first he had neither. Theodolites, copper engraving plates, even chart paper—none were to be found in America. Dissension at home interfered with the release of the appropriated funds, and unsettled political conditions in Europe prevented purchase of instruments and equipment abroad. Nothing was accomplished during his first 4 years with the Survey.

Needing a livelihood, Hassler accepted a position as acting professor of mathematics in the newly created United States Military Academy at West Point, where he stayed from 1807 to 1810. In March 1810 he went to Union College at Schenectady, N. Y., as professor of natural philosophy and mathematics. He remained there until July 1811. At both institutions he had a profound influence on his students. Hassler still remembered his basic mission and carried on correspondence about estimates for the instruments and equipment he would need.

A BEGINNING AND AN ECLIPSE

In April 1811 Secretary Gallatin was able to make available the $25,000 of appropriated funds, and in August of that year Hassler sailed for Europe. In London and Paris he obtained equipment and instruments. Many of these he designed himself, including his famous 24-inch theodolite, a marvel of precision in that day. He purchased many technical books and procured standards of mass, volume, and length, the last of which provided an additional basis for his triangulation.

The War of 1812 prolonged Hassler's stay, and he did not return until late in 1815. This delay and Hassler's impractical zeal caused him to exceed his appropriation, and he had to return at his own expense under severe congressional censure.

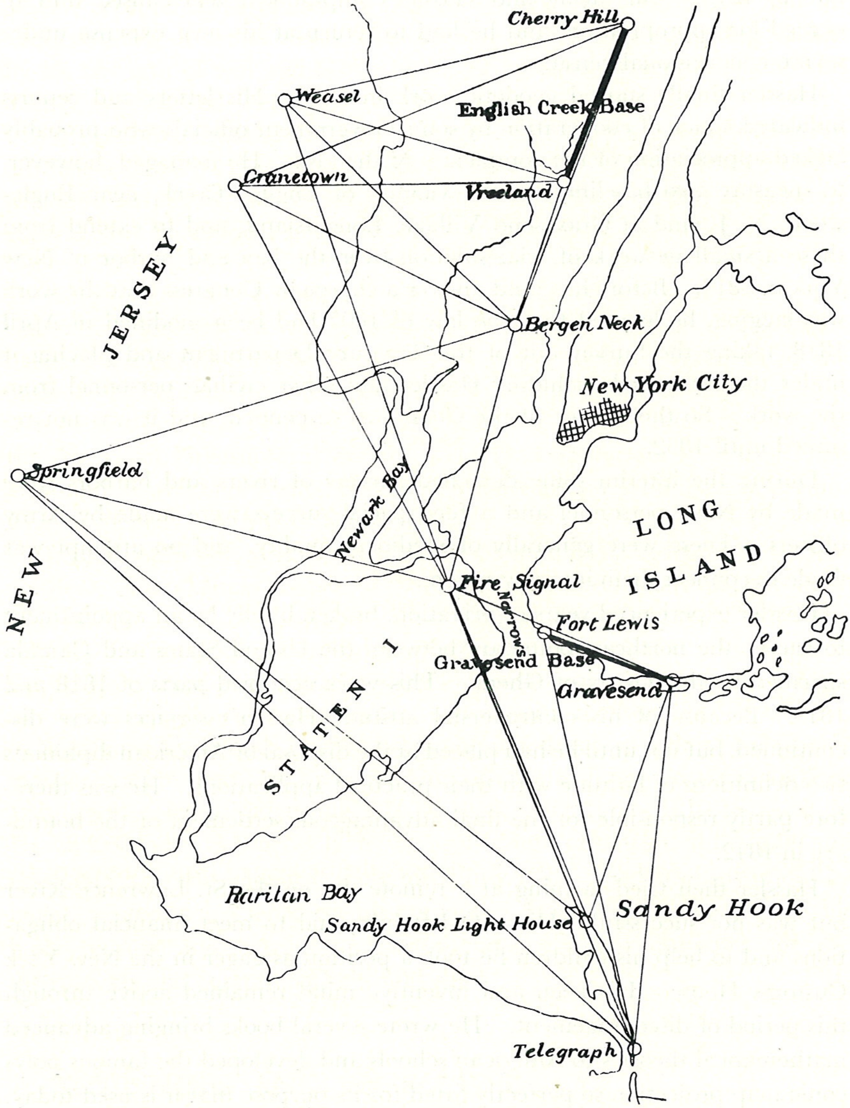
Hassler finally started geodetic work in 1816. His letters and reports indicated a lack of cooperation by some Government officials who probably lacked appreciation of the complexity of the task. He managed, however, to measure two baselines, in the vicinity of English Creek, near Englewood, N. J., and at Gravesend Village, Long Island, and to extend from these a small network of triangulation over the bay and harbor of New York in 1817. Before he could answer a charge by Congress that the work was lagging, he learned that the law of 1807 had been modified in April 1818, taking the Survey out of the Treasury Department and placing it under the Navy and excluding Hassler and other civilian personnel from the work. So the Survey of the Coast was suspended, and it was not resumed until 1832.

During the interim some detached surveys of rivers and harbors were made by Navy personnel and a few special surveys were made by Army officers. These were generally of mediocre quality, and no attempt was made to connect them into any system.

Hassler experienced years of privation, broken briefly by an appointment to survey the northeast boundary between the United States and Canada specified by the Treaty of Ghent. This work occupied parts of 1818 and 1819. Because of his controversial attitude Hassler's services were discontinued, but not until he had placed at the disposal of American diplomats two definitions of latitude with their practical applications. He was therefore partly responsible for the final advantageous settlement of the boundary in 1842.

Hassler then tried farming at a remote site on the St. Lawrence River but was not successful. His wife left him, and to meet financial obligations and to help his children he took a position as gager in the New York Customs House. His keen and inventive mind remained active through this period of discouragement. He wrote several books bringing advanced mathematical theories to American schools and developed the famous polyconic map projection so perfectly fitted for its purpose that it is used today.

In November 1830, because of his training and background and his interest in standards of measure, Hassler was appointed Superintendent of the new Office of Weights and Measures. Although 60 years old, he attacked the work with vigor, bringing the same sound philosophy to this new scientific work that he had tried to devote to the Survey of the Coast.



Hassler's First Field Work, 1816–1817

His work was now more favorably received, and he was able to take important steps toward uniformity of measures used in commerce and industry. He later incorporated the work with that of the Survey, where it remained until the National Bureau of Standards was created at the beginning of the present century.

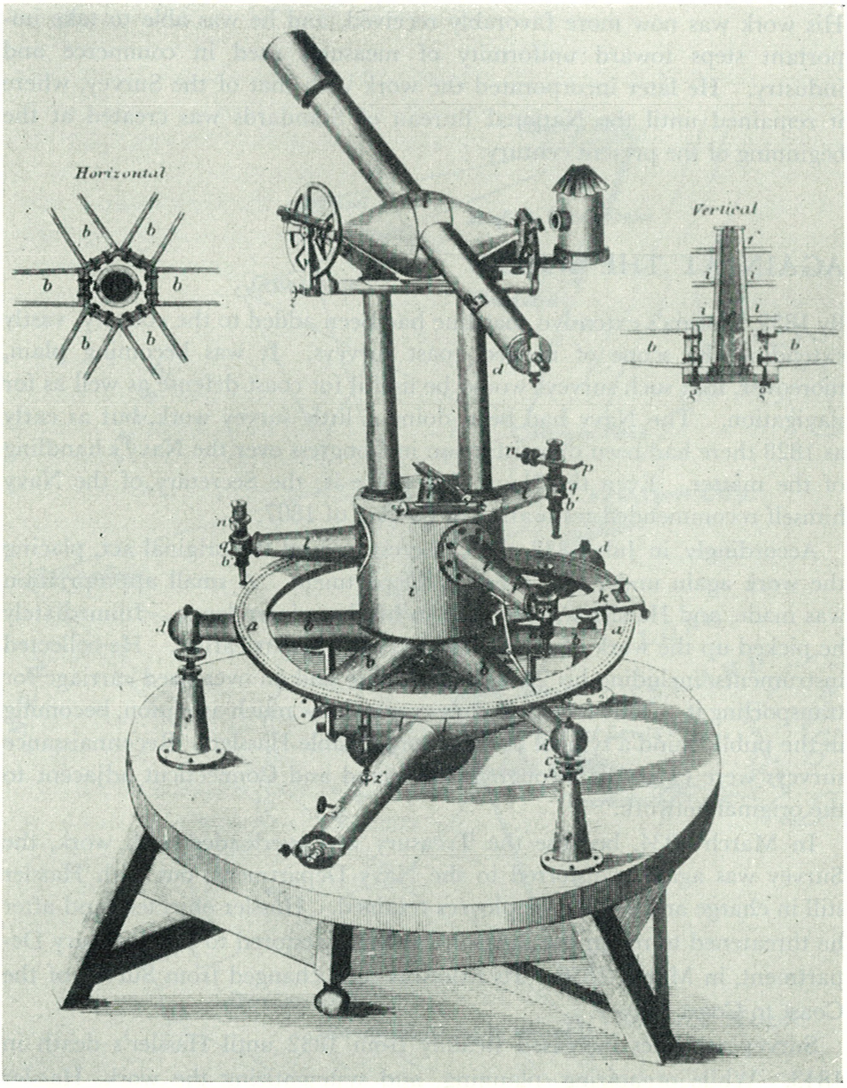
AGAIN AT THE WHEEL

By 1832, Florida's extensive coastline had been added to the country, vastly extending the scope of needed coast surveys. It was becoming plain, moreover, that such surveys would be useful for coast defense as well as for navigation. The Navy had been doing a little survey work, but as early as 1828 there had been dissatisfaction in Congress over the Navy's handling of the matter. Even the Navy didn't like it; the Secretary of the Navy himself recommended restoration of the Act of 1807.

Accordingly, in July 1832, the Congress revived the original act, placing the work again under the Treasury Department. A small appropriation was made, and Hassler was restored to his Superintendency. Immediately he picked up the work where he had left off 14 years earlier. He collected instruments, including his 24-inch theodolite and an over-sized carriage for transporting it. This eccentric conveyance drew much attention, becoming in the public mind a symbol of the unpredictable Hassler. Reconnaissance surveys were extended through Long Island and Connecticut adjacent to the original network.

In March 1834, because the Treasury was overloaded with work, the Survey was again transferred to the Navy Department, but with Hassler still in charge and civilian employees retained. Hassler objected, and after he threatened to resign the Bureau was again restored to the Treasury Department, in March 1836. Its title was then changed from Survey of the Coast to Coast Survey.

Survey activities increased steadily from 1832 until Hassler's death in 1843. While organizing, planning, and systematizing the work, Hassler trained numerous new assistants. After sufficient instruction, he could delegate responsibility and materially expand the scope and extent of the work. Navy officers and Army topographic engineers were detailed for duty with the Survey. In addition to performing excellent work, they received training that helped many of them later to become outstanding officers. Among the early military personnel were Army Capt. W. H. Swift, a trusted friend of Hassler's, and Lt. T. R. Gedney of the Navy. James Ferguson, experienced on the northeast boundary, came in 1833 as the first officially appointed civilian. Edmund Blunt, son of the publisher of the



Hassler's 24-inch Theodolite

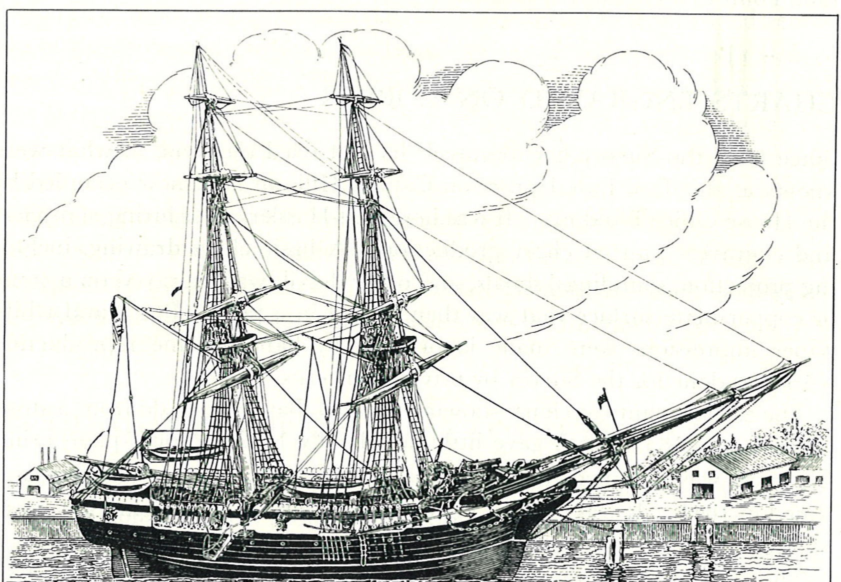
Blunt *Coast Pilot,* was appointed. Later others were engaged and trained. Hassler prepared his parties not only for astronomic and geodetic observation but also for hydrographic work, including the study of tides and currents, and later for magnetic observations at astronomical observation sites. He prepared in advance for the compilation and production of maps and charts, importing chart paper, copper plates, and even several trained engravers.

NEW CHANNELS, NEW DANGERS

Triangulation was pushed forward on Long Island and in Connecticut, and in 1834 the first maps were produced by the Bureau. They were on the scale 1:100,000 and showed the network of control points where precise latitude and longitude had been determined but gave no soundings or other hydrographic detail. Topographic surveys kept pace with triangulation, and shoreline detail was accurately delineated.

Hydrographic surveys began in late 1834 and early 1835, using the schooner *Jersey* under the command of Lieutenant Gedney and the schooner *Experiment* (shown on back cover) under Lt. George Blake. Work progressed along the south shore of Long Island, in New York harbor, and in Great South Bay. Important early results included the finding in Long Island Sound of many submerged ledges, dangerous to navigation at low tide, and a previously unknown channel leading to New York harbor from the southeast with more than 25 feet of water at high tide. Gedney Channel is now one of the main entrances to New York harbor.

The brig *Washington,* built in 1837 as a revenue cutter, was used by the Coast Survey during summers until it was permanently transferred to the Survey in 1840. This ship was slow and clumsy, but she was sturdy and functioned well. She also achieved public notice in 1839 by taking into



The Brig Washington, *an Early Survey Ship*

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custody the Cuban ship *Amistad* and her company of African mutineers. This action occurred under Gedney's command in Long Island Sound.

Methods and equipment were elementary. Nevertheless under Hassler's exacting demands they produced remarkably good results. Huge theodolites, hard to transport, were used in triangulation. Astronomical observations employed clumsy and difficult techniques. Topographic work was effected by plane table, without stadia devices or photographic aid. And hydrographic surveys employed soundings taken with a lead line from a sailing vessel. Where the shore was not visible, location of the vessel was determined by astronomic means or by inaccurate dead reckoning. The basic principles were much like those of today. The great difference was in the detailed methods employed and in the speed of performance.

Progress was quickened, despite limited facilities, as the new assistants caught Hassler's spirit. Before Hassler's death in 1843, triangulation had been extended east to Rhode Island and south to the head of Chesapeake Bay. The network of 1,200 geodetic stations covered an area of 9,000 square miles. Topographic surveys kept pace. Sixteen hundred miles of shoreline had been detailed and had been plotted on a number of topographic sheets. Hydrographic surveys, started near New York, had been extended to include all of New York Bay, Long Island Sound, and Delaware Bay and River. Offshore hydrography was almost completed from Montauk Point to the mouth of Delaware Bay.

CHARTS ENGRAVED ON COPPER

Since 1832 the Survey had occupied its first fixed quarters, in what were known as the Two Law Houses on Capitol Hill, on land now occupied by the House Office Building. It was here that Hassler, after hiring compilers and engravers, started chart production. A basic chart drawing, including projection, soundings, shoals, and other detail, was engraved on a stone or copper-plate surface that was then placed in a press. Black and white paper impressions were made laboriously by hand. Some reproduction work was done for the Survey by private concerns.

The earliest nautical chart, showing Newark Bay, was made from a stone engraving in 1839, but it gave little detail. By 1842 a copper-plate printing press was obtained, and a chart of New York Bay and Harbor was issued in 1844. It was the first to be printed with the finer definition possible from a copper-plate engraving.

The earliest charts showed excellent basic accuracy, reflecting Hassler's painstaking efforts, but lacked much of the detail of the modern chart.

In the face of difficulties, the Survey made continuous progress. Nevertheless, recurring protests came from the Congress. Unacquainted with the technical demands of the work, the legislators demanded impatiently to know when the job would be finished. The Congress felt that accuracy was being overstressed and that the results did not justify the expenditures. Again transfer to the Navy Department was proposed, but unsuccessfully. In his last years Hassler spent much of his time answering questions from the Congress. Finally, in 1842, he had to face an unfriendly congressional investigation during which he testified with such brilliance that the committee members were often amazed. He managed to meet the criticism and to win the committee's endorsement of his principles.

A detailed organizational and operational plan for the Survey was called for by act of Congress early in 1843, and a board was appointed to draw up such a plan. The board, which included Hassler, his two principal assistants, and several Army and Navy officers, approved a plan previously drawn up by Hassler that was in many respects a refinement of his original proposal of 1807. It defined the requirements for triangulation, topographic, and astronomic work, provided for the first time for a new activity—magnetic surveys—and specified the extension of hydrographic surveys out to the 120-fathom depth. The existing practice of using Army and Navy officers was recognized and an organization of field parties and office work was outlined.

In brief, various assistants, responsible to the Superintendent, were to be in charge of office work and field parties. The board recommended retention of the Survey in the Treasury Department and the continued employment of civilian personnel. The Congress approved the plan in April 1843. This action provided a basis for the Survey which lasted, with some modification, until the enabling act of 1947 established a new but not greatly altered restatement of functions. The 1843 clarification did much to solidify the Bureau and to further its effective functioning.

An act of 1844 specified that Navy and Army officers would be used only by request of the Coast Survey. No Army officers have been used since the Civil War and no Navy officers since the Spanish-American War.

PROUD INDEPENDENCE, AND LOYALTY

Hassler has often been pictured as arrogant, but this characterization seems unfair. Though he was proud and at times intolerant, these traits should be considered against a background of seeming official obtuseness, which Hassler simply could not understand. A Congressional committee once called at his office to inspect his work and, as *Harper's Monthly* related the incident in 1872, he sent the Congressmen packing on the ground that they would be totally unable to comprehend what he was doing.

Hassler once asked President Jackson for a raise, to $6,000 a year. Jackson protested that it was as much as the Government paid Levi Woodbury, Secretary of the Treasury and Hassler's superior. As *Harper's* tells it:

> "Mr. Voodbury!" screamed Hassler, rising from his chair and vibrating his long finger toward his own heart. "Pl-e-e-n-ty Mr. Voodburys, pl-e-en-ty Mr. Everybodys, for Secretary of de Treasury; v-o-ne, v-o-ne Mr. Hassler for de head of de Coast Survey!" and erecting himself in a haughty attitude, he looked down upon Jackson in supreme scorn at his daring comparison.

The increase was granted.

The Superintendent was loyal to his ideals, and loyal to his colleagues as long as they kept faith with him. He worked tirelessly in field and office and was certainly one of the most devoted of American public servants. He worked night after night, past midnight, at a table lit by candles, checking computations and verifying sheets of soundings—doing work for which his meager appropriations did not provide office help—and seeing personally to the maintenance of his own impeccable standards of performance. This he continued even after the close work on charts had lost him the sight of one eye.

Freed from interrogation after adjournment of the Congress in 1843, Hassler spent the fall in the field making geodetic surveys in New Jersey and Delaware. In Delaware he was caught in a severe wind and hailstorm that swept away the tents protecting his instruments. In his attempt to save the instruments, he fell on a pointed rock, suffering an injury in his left side and undergoing several hours of exposure which left him with a severe cold. He returned to Philadelphia, extremely ill, but wrote reports until his death on November 20, 1843. He was buried in Laurel Hill Cemetery near Philadelphia.

He lived to see the value of his work at last being recognized. His life had been stormy and subject to many trials, but he achieved his aim of creating a work of lasting value for America. Hassler's sincerity and integrity won political and public acclaim in the end. Men with surveying experience, like Jefferson and Madison, appreciated his work and were of great moral and material support.

Bache Continues in the Hassler Tradition

III
Under Franklin's Great-Grandson

THE DEATH OF HASSLER was a sore loss to the Coast Survey and was keenly felt by intellectual groups and institutions as well. A new Superintendent of the Bureau would have to be a worthy successor. Again the American Philosophical Society was consulted, and again it proposed a superbly fitted man—Alexander Dallas Bache, great-grandson of Benjamin Franklin. The recommendation was generally approved, and Bache was appointed Superintendent of the Coast Survey in December 1843.

Bache was born in Philadelphia in 1806, a product of one of America's best families. After early schooling in Philadelphia, he entered West Point, from which he was graduated with high honors in 1825. He served 3 years as a lieutenant of Engineers before leaving the Army. Thereafter he held positions of professor of natural science and chemistry at the University of Pennsylvania, president of Girard College, and superintendent of schools in Philadelphia. He investigated educational institutions in Europe, became president of the American Philosophical Society, and established at Girard College the first magnetic observatory in the United States.

His wide scientific activities included investigations in meteorology, magnetism, and metal corrosion and water power for the Franklin Institute. His training thus fitted him well for his new position as head of the Survey. Moreover he possessed the required talents for organization and administration as well as personal charm. Where Hassler would have fought at being asked when he would finish the survey of the coast, Bache would smilingly ask, "When will you gentlemen stop annexing new territory?"

Bache won the highest honors the country had to bestow in science and technology. He helped form the National Academy of Sciences, the highest organization of its kind in America, and was its first president. He was a regent of the Smithsonian Institution, and president of the American Association for the Advancement of Science. He also became the organizer and head, during the Civil War, of the United States Sanitary Commission, forerunner of the American Red Cross.

During Bache's period there continued some feeling in the Congress that the work of the Survey was a naval responsibility, and occasional attempts were made to effect another transfer back to the Navy. In 1848 a bill to accomplish this was defeated in the House. In 1849 the same bill narrowly failed of passage in the Senate. The bill was rejected after a dramatic speech by the then Senator Jefferson Davis who had the support of the scientific societies, in the affairs of which Bache was a prominent figure.

The question of where to locate the Survey still had not been answered. Bache himself later felt that an impartial review was needed. He therefore encouraged an investigation sponsored by the American Association for the Advancement of Science that was conducted in 1858 by a committee of 20 leading scientists. The committee endorsed the Coast Survey, recommending adherence to its plan of organization and its retention in the Treasury Department, and praised the Survey for superior work.

CHARTS FOR A GROWING AMERICA

Bache's period saw great growth of the Coast Survey as territory was added to the country. The scope of activities was broadened and techniques were improved. Even the Civil War did not hinder this growth.

At the outset Bache recognized the necessity of subdividing the work. The country now included the entire Atlantic and Gulf coasts, with the exception of Texas. He divided this area into nine sections, in each of which all operations were to be carried on simultaneously. Besides improving efficiency, this arrangement afforded the additional speed demanded by the Congress.

Assistants of the highest calibre were required, for great responsibility had to be delegated. Bache, using his ability to win cooperation, assembled a strong staff that included civilian assistants as well as Army and Navy officers. In his relations with his assistants, Bache was quick to recognize ability and gave credit for accomplishment, thus maintaining high morale.

Without this enlarged and strengthened organization, the demands of the growing country could not have been met. Texas joined the Union in 1845, adding 3,359 miles of tidal coastline to the already existing 42,455 miles. After the war with Mexico, California came under United States control, and finally the remainder of the west coast was added by negotiation with the British. This brought the total coastline to 53,677 miles. Inland territory was also annexed, necessitating the demarcation of international boundaries and ultimately the extension of control surveys to facilitate division of land. More operating districts were formed, and the Survey engaged in operations on a scale large even by present standards.

Hydrographic surveys were urgently needed, and soundings were being taken along all coasts, including a reconnaissance in the Gulf of Mexico between New Orleans and Mobile, as early as 1845. Harbor areas were being surveyed with greater care. Many steamships had been added to the country's merchant fleet, and their deeper draft and greater speed necessitated more detailed charts. Asst. Henry L. Marindin, Lt. John Maffitt, and others were doing significant work in southern waters, while Lt. Charles H. Davis and Asst. William Mitchell were similarly employed in New England.

Surveys were extended farther seaward, with Lt. H. S. Stellwagen operating as far out as Georges Bank, off New England. The brig *Washington,* under Capt. George M. Bache, brother of the Superintendent, was sent in 1846 to make observations of the Gulf Stream.

BEFORE THE GOLD RUSH

West coast surveys became critically necessary. In 1848, even before the gold rush, Lt. Comdr. W. P. McArthur, had been making hydrographic surveys of California waters with the steamer *Ewing.* Discovery of gold in 1849 resulted in a frantic increase in ship traffic. George Davidson, an exceptional assistant whom Bache had been encouraging, was one of four civilians sent west in 1850. He started geodetic and topographic surveys immediately.

McArthur died in 1850, and Lt. James Alden was sent to continue the west coast hydrographic surveys. Other ships and personnel were added, and the work progressed at an accelerated rate. By 1857 work had begun on the northern boundary between the United States and Canada in the vicinity of the Strait of Juan de Fuca.

Tidal surveys, a technical necessity in the processing of hydrographic survey observations for chart compilation, had been carried out by visual observation until automatic recording gages were introduced early in Bache's administration. This development permitted widespread and systematic tide surveys, the subsequent analysis of tidal regimes, and the publication of tables of predicted tides. These were published first in Bureau reports in 1853 and have been printed since 1867 as separate booklets for general use. Such predictions are of critical importance in the navigation of bars and channels and have always been an important accessory to the charts.

Geodetic control and topographic surveys were being expanded throughout the entire coastal area. Triangulation networks were fringing the country. Field work on the Eastern Oblique Arc, extending from the Bay of Fundy to New Orleans, was progressing well. This ambitious triangulation arc was a far-sighted undertaking designed to strengthen the whole structure of American mapping work and to bring geodetic control over large areas to surveyors and engineers. The arc was later to figure importantly in calculations of the figure of the earth, resulting in the subsequent adoption of the Clarke Spheroid of Reference for geodetic surveys.

Geomagnetic surveys, provided for by the act of 1843, were extended and by 1855 maps showing isogonic lines were prepared. In 1860 a magnetic observatory was established at Key West, Fla., and in 1877 one at Madison, Wis. The former continued in operation for 6 years, the latter for 4. Magnetic observations of declination, dip, and intensity were made at all astronomic stations and correlated with data from American and foreign observatories. Systematic methods and improved instruments—including a magnetometer by Bache—were devised, and a theory was developed as to the location of magnetic poles. Asst. Joseph Saxton and Bache himself were prominent in the correlation of data and development of theories, and Assts. R. H. Fauntleroy, Julius Hilgard, Charles Schott, and William Mitchell participated in the field work. By 1856, 160 magnetic observation stations had been established.

The purchase of Alaska from Russia in 1867 added 33,904 miles of tidal coastline and another large job for the Coast Survey. This purchase had been anticipated, and by the time of actual negotiations Davidson was doing reconnaissance work in Alaskan waters with the cutter *Lincoln.* He was followed by Asst. William H. Dall and others, and the long job of surveying Alaska was under way.

THE COAST PILOTS

Charts are supplemented by *Coast Pilot* books which provide information not easily shown graphically. By 1867 work was nearing completion on the first of the *Coast Pilots,* dealing with the Gulf of Maine. Started in 1849 by Bache and compiled largely by Asst. J. S. Bradford, it was published in 1875. This volume was soon followed by a *Coast Pilot* treating the area from Boston to New York and later by others dealing with the remaining sections of the east and gulf coasts. In 1867 the Bureau bought the copyright and stereotype plates of the Blunt Company, and *Coast Pilots* for the United States and possessions became a primary function of the Coast Survey.

At the same time Davidson, who had published his *Coast Pilot Notes* in a series of artices in a San Francisco newspaper before 1858 and in the *Coast Survey Annual Report* for that year, was revising the preliminary edition of his famous *Coast Pilot of California, Oregon, and Washington Territory.* It was published by the Survey in 1869 as the *Pacific Coast Pilot* and in 1889 in more complete form. Early *Alaska Pilots,* prepared by Davidson and by Dall, were published by the Survey in 1869 and 1879.

LOSSES AT SEA AND A MUTINY

Early in September 1846 the brig *Washington,* under the command of George M. Bache, brother of the Superintendent, was returning north from observations of the Gulf Stream off the southeast coast when she was caught in an extremely violent hurricane north of Cape Hatteras. Great waves broke over the ship, and Captain Bache perished with 10 members of the crew. The ship would have been lost but for superior seamanship. The crippled vessel drifted for more than a week after the storm but was finally towed to port by the U. S. frigate *Constitution.* The loss of Bache and the men was sorely felt by the Survey, which had a monument erected in their honor in the Congressional Cemetery in Washington. For the survivors, commemorative medals were struck by the Treasury Department.

The *Jefferson,* commanded by Lt. Comdr. F. K. Murray, was lost off the coast of Patagonia in 1851 without loss of life while enroute to assignment in California. She was broken in a gale.

An unfortunate result of the 1849 gold rush in California was the *Ewing* mutiny. McArthur, in command of the U. S. S. *Ewing,* was making detailed surveys at San Francisco to accommodate the great increase in ship traffic. He had difficulty holding crews against the lure of the gold fields, and desertions were common. On September 13, 1849, the five-man crew of the *Ewing's* gig threw the boat's officer overboard and absconded with the craft. The officer, Midshipman William Gibson, was rescued in critical condition, and the men were caught heading for the gold fields.

As the men were naval seamen and subject to Navy discipline, they were tried by court martial and convicted of "Mutiny, Desertion, and running away with a boat, the property of the United States." One was convicted also of "Attempt to Kill." He and another were hanged from the yard arm, and the rest were sentenced to prison for the remainder of their enlistments.

This affair, though small, has historical interest because it is the only mutiny in the long history of often arduous and difficult sea voyages made by the Survey.

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SCIENCE AIDS THE SURVEY

Bache inspired almost countless technical improvements that met the growing demands of the work and attracted the attention of the world.

As surveys extended throughout the coastal areas, ships were added. Among them were the *Nautilus,* the *Wave,* the *Phoenix,* and the *Forward.* At first they were sailing vessels, but on the insistence of Bache steamships were introduced. The first of these was the *Bibb,* obtained on trial in 1847 and tested by Lieutenant Davis near Nantucket. As early as 1849 the Survey employed an iron vessel, the *Jefferson,* but metal ships were not used extensively until the 1870's.

Louis Agassiz, the Swiss-born naturalist and professor of zoology at Harvard University, made studies of the Florida coral reefs as a consultant for the Survey.

Oceanographic observations were made, and among them were the taking of bottom samples by means of a small cup devised by Lieutenant Stellwagen. Wire instead of hemp sounding line was introduced by Lt. Mathew Fontaine Maury, who, though not assigned to the Survey, worked with it closely. His contribution permitted deeper and more accurate soundings. Asst. Joseph Saxton devised a self-registering deep-sea thermometer, and the Superintendent's brother, George Bache, invented a self-closing deep-water sampler.

Studies of tides and currents, started by Hassler, were carried forward under Bache. Surface current observations were usually made by tracking the direction and speed of the drift of marked bottles. Maury contributed much collateral information in his capacity of collaborator through his important *Wind and Current Chart of the North Atlantic* and *Physical Geography of the Oceans.* Tide studies were aided by Assistant Saxton, who developed an automatically recording tide gage. This instrument, installed at critical sites, made possible the publication of tide prediction tables.

Geodetic work saw notable advancements. Bache personally was active in geodesy, as were Assts. George Davidson, C. O. Boutelle, R. H. Fauntleroy, and William Mitchell. The Horrebow-Talcott method of determining latitude with the zenith telescope achieved new heights of accuracy.

The electric telegraph, invented 1846, was used in the determination of longitude in July and August 1847, when the difference between Washington, Philadelphia, and Jersey City was found by time signals flashed under the direction of Asst. Sears C. Walker. These achievements drew the plaudits of all Europe.

A chronometric longitude difference from European stations was made in 1852–53 by Asst. B. A. Gould. Base line measurements for triangulation were improved by Assts. F. H. Gerdes and Julius Hilgard. Using apparatus he had devised, Bache himself measured a 7-mile base line on Bodie Island, N. C., in 10 days with a total uncertainty of only 1 inch—an accuracy almost unbelievable at that time.

The public value of the work lay, of course, in the charts and other publications by which the Survey presented its results. Bache not only promoted effective work in cartography but also encouraged the publication of scientific papers by his assistants. Important early papers presented studies on the Hudson River submarine canyon and the Gulf Stream by Asst. Adolph Lindenkohl, one of the most precise cartographic artists ever employed by the Survey. The first transverse polyconic projection of the United States was devised by Lindenkohl.

Great effort was expended on methods of chart production. More detail was added, copperplate engraving methods were improved, and more engravers were imported from Europe. Buoy locations were shown on charts, and, as suggested by George M. Bache, they were colored by hand and identified by a numbering system as early as 1847. Asst. George Mathiot vastly improved reproduction with an electrotype process for the mechanical preparation of plate copies of the original copperplate engravings, thereby eliminating the wearing out of the originals and the necessity of re-engraving after the printing of relatively few charts. The method facilitated chart correction on the electrotypes.

Lt. E. B. Hunt was responsible for many improvements in reproduction processes. Speed was so increased that data sent to Washington from California in 1850 appeared as finished charts within 20 days after arrival. The number of charts issued annually rose by 1860 to about 10,000 copies with help from contract printers. The number rose sharply to 66,000 in the Civil War year 1863.

Color printing was introduced first in 1862 with two colors for maps in critical war zones and later was extended to more and more charts and maps and with additional colors.

BACHE'S LIEUTENANTS

The Bache period developed many men of outstanding calibre, some of whom deserve special notice for their individual accomplishments. George Davidson was certainly one of these. His unusual ability was first discovered by Bache when he was superintendent of Philadelphia Schools. With encouragement from Bache, Davidson joined the Survey in 1845. Until 1850 he did astronomic and geodetic work in the east under Bache's direction and in the company of such brilliant engineers as Asst. Robert H. Fauntleroy. In 1850 he was sent to the west coast. There, with the exception of the Civil War period and a few foreign assignments, he spent most of his 50 years with the Survey.

Like Bache, Davidson gathered and trained a corps of helpers, who performed excellent work. Like Hassler, he was tireless, spending night and day with his work. While Lieutenant Alden performed hydrographic work, Davidson headed the necessary geodetic and topographic surveys. He made astronomical observations, establishing his own observatory, measured base lines, and extended triangulation and topographic surveys along the west coast. He made numerous observations of tides and currents and wrote recommendations for the establishment of lighthouses and buoys.

The work gave him the excellent knowledge of the coast on which he drew for his famous notes, later published by the Survey. The book contained more than 2,000 manuscript pages with 400 illustrations. It was considered one of the best *Coast Pilots* of all time.

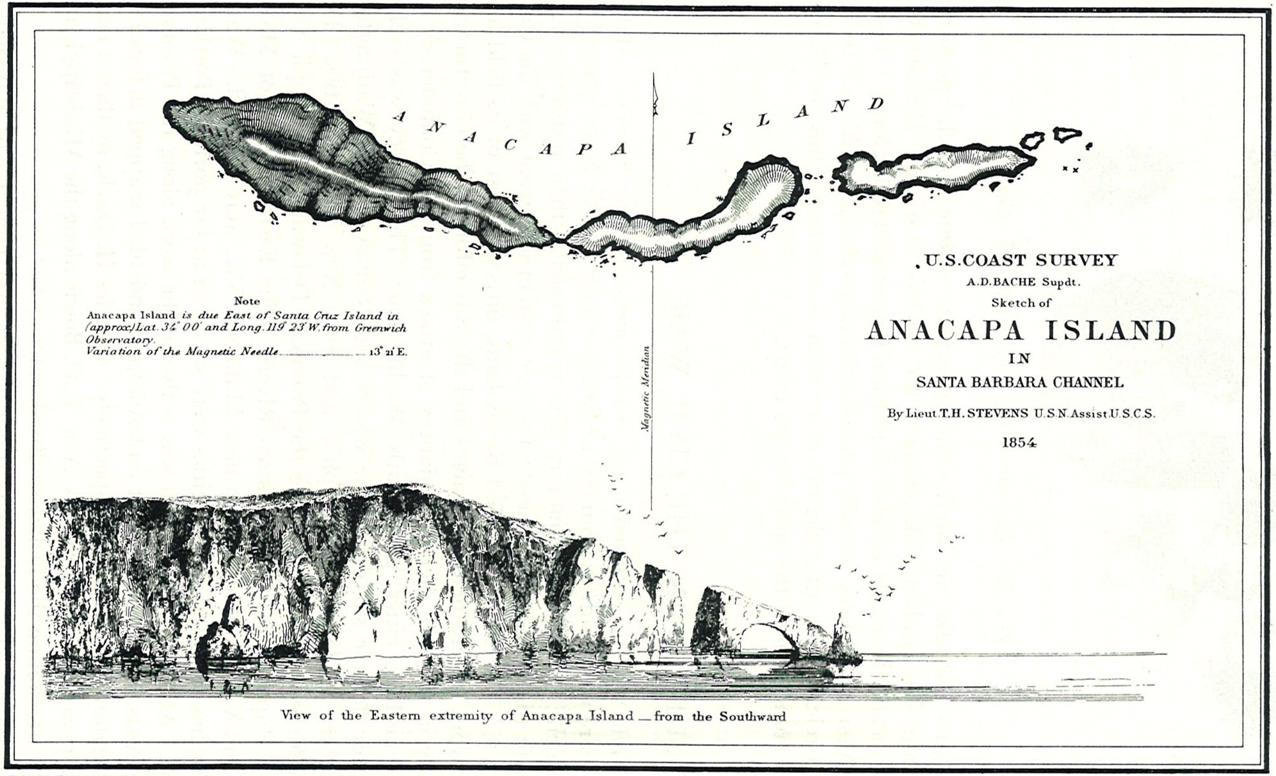
Davidson engaged in many civic and local activities, practicing as a consulting engineer, teaching at the University of California, organizing the California Academy of Sciences, and leading in other cultural and scientific activities. He induced the eccentric millionnaire James Lick to endow one of the great astronomic observatories of the world, built on Mt. Hamilton.

Lt. Mathew F. Maury, who worked so closely with the Survey that he was naturally associated with it even though not on actual assignment, became the most famous oceanographer of the Navy and the founder of the Naval Depot of Charts. In his professional capacity he led the world in the study of ocean winds and currents and other aspects of physical oceanography.

A southerner, Lieutenant Maury served during the Civil War as a Confederate admiral. He was one of several men of the Survey who followed the Confederate cause. Lt. John Maffitt commanded Confederate blockade runners. Lt. Ambrose P. Hill became a general in the Confederate Army and is commemorated in name by the Army reservation near Fredericksburg, Va.

Lt. Charles H. Davis, who tested the first steam survey vessel, the *Bibb*, so distinguished himself in his work for the Survey and later in the Navy that he eventually became a rear admiral and director of the Naval Observatory. Maj. Isaac Stevens, known for his work in improving reproduction processes, eventually became governor of Washington Territory.

James McNeill Whistler contributed little of cartographic importance to the Survey but during his brief period under Bache he made a start toward a brilliant career as an artist. Having failed after 3 years at West Point, he was placed in the Survey through his father's influence. He was an indifferent draftsman at charts and was not to be bound by office hours. There is a story that he brought an extra hat to his office. When a superior came looking for him, one hat was on its peg. Whistler, it is said, was wearing the other hat in a nearby tavern.



Drᵍ by W. B. McMurtrie

Engᵈ by J.A.Whistler J.Young & C.A.Knight

Headland Engraved by James McNeill Whistler

Doodles Engraved on Chart by Whistler

Whistler *did* take an interest in copperplate etching, but he preferred caricature and landscape sketching to the work of charting. He executed several headlands and a number of fanciful figures alongside charts. Those decorations the Survey proudly prizes as the first Whistler etchings. Bache had to release him after slightly more than 3 months. Thus the Survey helped launch one of the great careers in art.

THE SURVEY IN THE CIVIL WAR

The Civil War necessitated many readjustments for the Survey. At the start there were with the Survey 12 Army officers and 11 Navy officers on assignment. Most of the military officers returned to their respective services with the Union, and others, who were southerners, went with the Confederacy. The Survey, staffed by civilians, directed most of its field and office work toward field campaigns and the war effort of the Government.

Early in the war there was danger of attack from the Confederacy on many northern cities, particularly Washington. The Survey was called upon for defense surveys of the waters and country around Washington, Baltimore, St. Louis, Philadelphia, and some New England cities. Detailed surveys were made along the Potomac, Delaware, Mississippi, Tennessee, Rappahannock, and James Rivers. The Eastern Shore of Maryland and Virginia and an area near Manassas, Va., were mapped. Water approaches to New England cities were surveyed as far north as Portland, Maine. Asst. H. L. Marindin was active in the work along the Potomac, while Assts. Charles A. Schott and Adolph Lindenkol mapped defenses of Washington and Baltimore respectively. Charles H. Davis, by then a commander, worked near St. Louis, Asst. T. C. Bowie along the Mississippi, and C. P. Patterson on the Delaware Breakwater.

In 1863, as Lee's armies moved north, Superintendent Bache and George Davidson were prominent in the design of Philadelphia's defenses. Asst.

Charles A. Schott determined the effective range of artillery near Washington and New York, and Assts. W. Mosman and S. Lyman ascertained geodetic data for many military posts.

Survey units were active in many of the field campaigns of the war. Admiral DuPont's assault on forts guarding Port Royal, S. C., was aided by sounding and buoy-laying activities performed under fire by Asst. C. O. Boutelle on the *Vixen.* Farragut's penetration of the lower Mississippi River was facilitated by the work of Asst. F. H. Gerdes with the vessel *Sachem.* The steamer *Bibb* was used in the examination of Charleston Bar in preparation for an attack in that area, and Survey ships and men were used extensively in the Union blockade of the southeast coast. Grant's running of the batteries at Vicksburg depended on maps and location of batteries by Survey men. Sherman had several Survey employees with him on his march to the sea. The attack on Fort Fisher near Wilmington, N. C., was aided by Asst. J. S. Bradford, who went in under fire and set out the course for the ship *Louisiana,* which was purposely blown up in front of the fort.

Charts were extremely important in the war. In 1862 Asst. Julius Hilgard was placed in charge of the Washington office, still located in the Two Law Houses on Capitol Hill. The unprecedented demands for maps and charts strained the resources of the Survey to the utmost, but by the careful organizational leadership of Bache and Hilgard the requirements were met. Fewer than 10,000 charts had been issued annually before the Civil War. But 44,000 were produced in 1862 and 66,000 in 1863.

With the end of hostilities, the Survey readjusted to peacetime activities. Its production had been increased during the war and its products were now more appreciated. It never reverted to the rate of prewar production. Its civilian ranks were increased to compensate for the loss of Army officers.

In the meantime, Alexander Dallas Bache was failing. In 1867 he passed away in Newport, R. I., and his body was returned for burial with honors in Washington. Bache was not only one of the great leaders of the Coast Survey but also one of the outstanding scientists of his age. His influence was destined to shape the future of the Survey.

The Bureau Sets Markers
from Coast to Coast

IV
Surveying a Continent

THE HALF CENTURY following the Civil War was an era of great expansion for the Bureau. The Congress broadened its functions to include geodetic surveys in 1871 and 7 years later formally changed the name to Coast and Geodetic Survey. The agency set about determining not only the exact latitude and longitude of thousands of selected points across the continent but also elevations above sea level.

Arcs of triangulation were in time completed from the Bay of Fundy to New Orleans and across the continent at the 39th parallel. A line of leveling was also completed across the country.

As delicate measurements are affected by the earth's gravity as well as its magnetism, the Survey extended its studies into both these fields. It was led forward from Bache's death to World War I by a succession of Superintendents who were chosen generally for their professional competence.

Benjamin Peirce, Bache's successor, had worked with the Coast Survey since 1852 as a consultant on latitude problems. He was thoroughly familiar with the work when selected as Superintendent on the recommendation of learned societies. He had been professor of mathematics, astronomy, and natural history at Harvard University since 1843 and had been consulting astronomer to the *American Nautical Almanac* and the *American Ephemeris.*

Peirce carried forward the work started by Hassler and Bache, but with added objectives. He resumed survey work on primary triangulation, which had been halted during the Civil War, and emphasized surveys in southeast Alaska. He pushed ahead with the Eastern Oblique Arc of Triangulation and fostered the planning of the great Transcontinental Arc, which was to be a network of triangulation connecting the coasts along the 39th parallel. In 1871 he got congressional authorization for this program, thus launching one of the greatest surveying undertakings of the time.

While holding his Survey office Peirce retained his position as professor at Harvard. The double burden was too much for him and in 1874, at the age of 65, he resigned and returned to Harvard.

LEADERS FROM THE RANKS

Carlile P. Patterson was the first Superintendent to be selected from the active working ranks. A former Navy captain, he had for years been hydrographic inspector for the Survey, with outstanding success. He assigned vessels and personnel efficiently in meeting the increased demand for hydrographic surveys. He also pursued the policies of Hassler and Bache during his 7 years as Superintendent, before his death in 1881.

Hydrographic work was pushed in many places and investigations of the Gulf Stream were resumed. Work continued on the Eastern Oblique Arc of Triangulation and was begun on the vast undertaking of the Transcontinental Arc. He initiated work on a precise level survey to provide vertical control to correspond with the position control provided by triangulation, thus advancing projects in mapping and engineering. Gravity observations were started when a Bessel pendulum was imported from Europe in 1875.

An act of Congress passed in 1879 provided for membership of a Survey representative on the Mississippi River Commission, a provision still in existence. Patterson served on an international committee that decided the vital question of building the Panama Canal as a high level lock canal instead of at sea level.

It was Patterson who advocated the change of name to Coast and Geodetic Survey. At about that time Congress considered the addition of nationwide topographic surveys as a function of the Survey but rejected the proposal. Such mapping work later became a function of the Geological Survey.

The second Superintendent chosen from the ranks was Julius E. Hilgard. He had built a brilliant career and his appointment in 1881 had the approval of the scientific groups. He joined the Survey in 1845, as Davidson did, at the encouragement of Bache. In 1862, in recognition of his work, Hilgard was given charge of the Washington office. He brought honor to the Survey through his work on the International Metric Commission, on the International Bureau of Weights and Measures, and as one of the founders of the Philosophical Society of Washington. In 1882 he initiated a systematic program of Alaska surveys.

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Hilgard's administration was beset with troubles. Funds to increase the scope of the work found little support. Hilgard was ill and lacked his former keen perception. But he convinced Navy partisans in 1882 that the Survey should continue as a separate agency.

A few members of his staff were accused of exploiting their positions for personal ends. A Congressional investigation in 1884–85 found evidence of drinking during office hours and diversion of funds.

Upon urging by the National Academy of Sciences and other scientific organizations, the Committee recommended no action to change the organic status of the Bureau. Hilgard, in illness, tendered his resignation in 1885.

Frank M. Thorn, an official from the Bureau of Internal Revenue and a member of the committee that had investigated Hilgard, was appointed Superintendent specifically to correct conditions that had caused Hilgard's troubles. Thorn systematized the accounting methods. He became a strong supporter of the organization, and, feeling that he had accomplished his purpose, resigned in 1889 at the end of the first Cleveland administration.

A GOLD RUSH AND A WAR

The next superintendent, Thomas C. Mendenhall, had a scientific background and a keen mind. He followed the principles of Hassler and Bache, carrying on the work commendably in spite of the economies in funds. Work was advanced on boundary surveys, especially on the Alaska-Canada boundary. Mendenhall himself served on the boundary commission. The Mendenhall Glacier, flowing down from the international boundary near Juneau, Alaska, perpetuates his name.

Mendenhall started the remonumentation of the Mexican boundary and provided help in the recovery of part of the old Mason-Dixon line. He was particularly interested in astronomic and gravity observations, which received special emphasis until his retirement in 1894. He initiated the publication of tidal current information in 1890 as informational notes in tide tables referring to the times of current slack and strength.

William W. Duffield, in his seventies when appointed in 1894 to head the Survey, was a professional civil engineer with an excellent Civil War record as a general in the Union Army. During his tenure many of the Survey's experienced employees were dismissed. Incredibly, George Davidson, the great Survey scientist on the west coast, was dismissed without explanation. He became a professor at the University of California. Old age incapacitated Duffield, and he retired in 1897.

Henry S. Pritchett also held office for 3 years. A brilliant and vigorous man, he restored confidence among Survey employees and regained the support of Congress and the public. During the Klondike gold rush, Pritchett gained financial support for accelerated surveys in Alaska. Large increases in funds were obtained also for magnetic observations. He started a systematic magnetic survey of the country and established the Division of Terrestrial Magnetism in 1899.

The Spanish-American War of 1898 was fought during Pritchett's incumbency. All Navy officers were withdrawn, never to return. After the war Pritchett resisted transfer of the Survey to Navy control. The loss of naval officers required a reorganization of the hydrographic work. Pritchett hired experienced seamen and established the ranks of deck officer, junior officer, and senior officer, with appropriate uniforms, for assistants and aides who worked aboard the Survey's ships. After 3 years he retired in 1900 to become president of Massachusetts Institute of Technology.

Otto H. Tittmann was one of the last of the old line. He entered the Survey in 1867, well grounded in the traditions of Hassler and Bache. He had seen the vast panorama of changing conditions, knew all phases of the work, and had served as Assistant Superintendent. Until the end of his term in 1915, he prepared for a dramatic new era of change and technical advances.

Tittmann's 15-year term was the longest since those of Hassler and Bache. During this period many long-range projects were completed and others were begun. Surveys of new territories, including the Philippines, were started, and work was carried forward in Alaska. The great Transcontinental Arc of Triangulation was finished, and a standard geodetic datum for all North America was established. Many boundary matters were settled, a new concept of tidal phenomena was developed, and the Harris-Fischer tide-predicting machine was completed.

The wire drag, one of the outstanding modern developments of hydrographic surveying, evolved during this time, greatly enhanced the safety of navigation. New innovations in chart reproduction work stepped up chart production in both volume and quality.

Tittmann also saw the Bureau transferred in 1903 from the Treasury Department to the new Department of Commerce and Labor, and to Commerce in 1913 when the separate Department of Commerce was created.

SCIENTISTS AND AN EXPLORER

Asst. Charles A. Schott accomplished the computation and analysis of geodetic data as chief of the Computing Division. His work, published in two volumes near the end of the century, was acclaimed throughout the world. In consequence of Schott's computations, the Survey in 1880 adopted the Clarke Spheroid as a geodetic base.

Schott correlated and evaluated triangulation, astronomic, and topographic data. He also collected magnetic data, made studies on the variation of magnetic declination, and provided the basis for improved isogonic charts. For his work, President McKinley presented Schott the Wilde Gold Medal from the French Academy.

John Hayford and William Bowie contributed to the theory of isostasy, concluding that the crust of the earth is in equilibrium at a depth of perhaps 60 kilometers and that excesses or deficiencies of volume under equal areas are nevertheless in balance because of compensating differences in density. In 1909 Hayford derived the new and more perfect theoretical figure representing the earth called the International Spheroid of Reference. This concept was adopted in 1924 at the meeting of the International Association of Geodesy and is now used by many countries as the basis of geodetic surveys. The United States did not adopt the International Spheroid because of the excessive cost and work involved in such a change.

Hayford, using the notes of the mathematician W. H. Burger, also developed a strength-of-figure formula for evaluating the theoretical geometric limits on the extension of triangulation surveys from measured base lines. Adjusting the various triangulation networks, Hayford in 1901 established a standard datum for the country to provide a unified survey reference system for mapping and engineering work.

William Bowie carried forward the constructive work of Hayford, doing much to strengthen and verify the important isostasy principle. He was one of the strongest advocates in modern times of coordinated mapping programs. He obtained international cooperation for joining the control survey networks of the United States to those of Canada and Mexico, setting up the North American Datum in 1913. This was essentially the same as the United States Standard Datum.

Robert E. Peary, a former Survey employee, reached the North Pole in 1909. He accomplished this feat in part as an observer for the Survey under instruction to make tidal observations in the Arctic Ocean. Peary made numerous astronomical observations at the Pole and turned them over to the Survey upon his return. His claims were widely questioned and his observations therefore received critical scrutiny by the mathematicians Hugh Mitchell and C. R. Duval of the Survey. Their analysis gave proof of Peary's accuracy and afforded the presently accepted authenticity of Peary's discovery. Peary was awarded the Navy rank of rear admiral.

C. D. Sigsbee invented so many hydrographic and oceanographic instruments and techniques that he is now remembered as one of the Survey's outstanding technical leaders. For his brilliant services in the Survey and in the Navy, Sigsbee became a rear admiral. He was the commanding officer of the *Maine* when she was lost at Havana.

A HALF CENTURY OF SURVEYS

At sea and on land, surveys were greatly extended in the 50 years that followed the Civil War. The United States acquired many new coasts to be charted.

Hydrographic surveys of coastal waters continued without interruption except for a few months during the Spanish-American War. Tide observations were made at many places, and current observations were started. Eventually charts in more or less detail were available for most areas, but many were still sketchy. Larger, faster merchant vessels were built, necessitating better charts. Harbors already charted were being changed by natural forces and improvements.

The continuing need for surveys—even an accelerated program—became increasingly evident. Superintendent Patterson did much to meet the growing hydrographic needs by increasing personnel and ships, particularly from the personnel and vessels of the Navy. As an old Navy man he got excellent cooperation. Navy officers were, for the most part, glad to get Survey duty as they found life in the Navy less active after the Civil War.

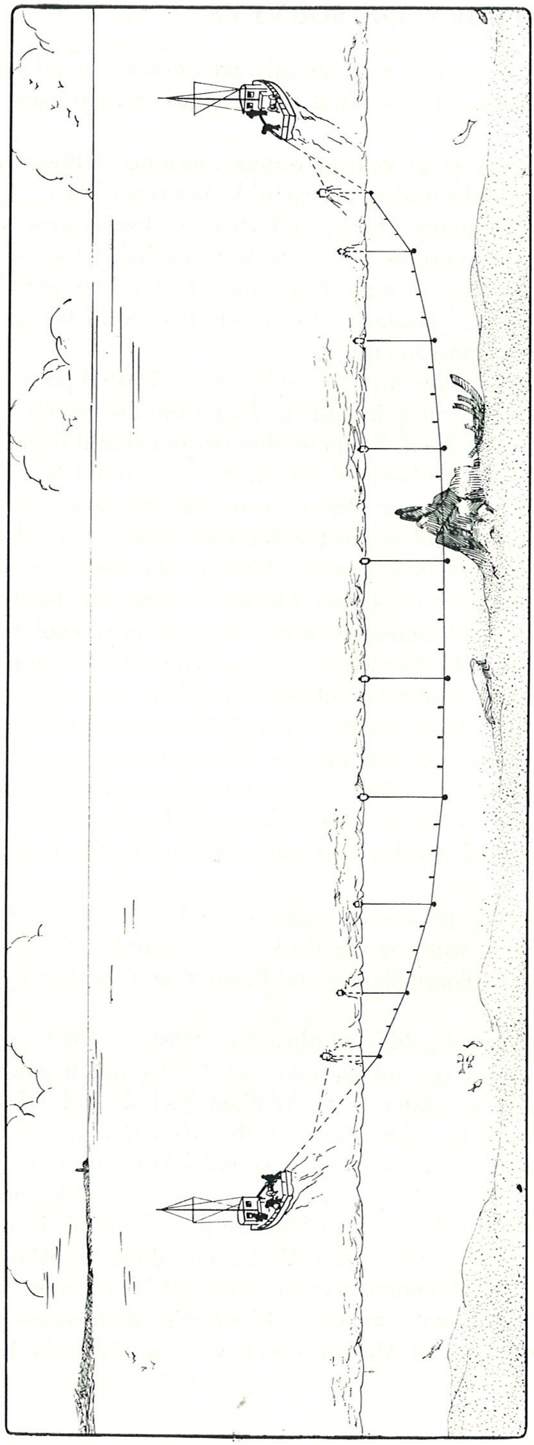
Alaskan work progressed slowly. George Davidson reconnoitered in southeastern Alaska with the cutter *Lincoln* in 1867 and 1868 and wrote a *Coast Pilot* in 1869. William Dall conducted extensive exploration surveys between 1871 and 1874, after which he returned to Washington and wrote a more comprehensive *Coast Pilot* published in 1879.

Asst. Marcus Baker was associated with Dall and continued reconnaissance surveys until 1880, reaching the Aleutians and following the coast nearly as far north as Point Barrow. Joining the Geological Survey in 1880 and later the National Geographic Society, Baker wrote his famous *Geographic Dictionary of Alaska,* first published by the Geological Survey in 1891.

These exploratory operations complemented the only previous chart information, including work by the Russian cartographer Sarichev, who had worked under the explorers Bering and Barinof, and sketches by the mariner Tebenkof.

With the discovery of gold in southeastern Alaska in 1882, more funds became available and a systematic survey of Alaska was begun. The ships *Hassler* and *Patterson* under Assts. William Nichols and John Pratt were sent immediately, to be joined later by the *McArthur* under Asst. Robert Faris. These survey parties carried on combined operations with each party performing its own geodetic, topographic, hydrographic, and magnetic operations. This was the most productive plan for work in remote areas.

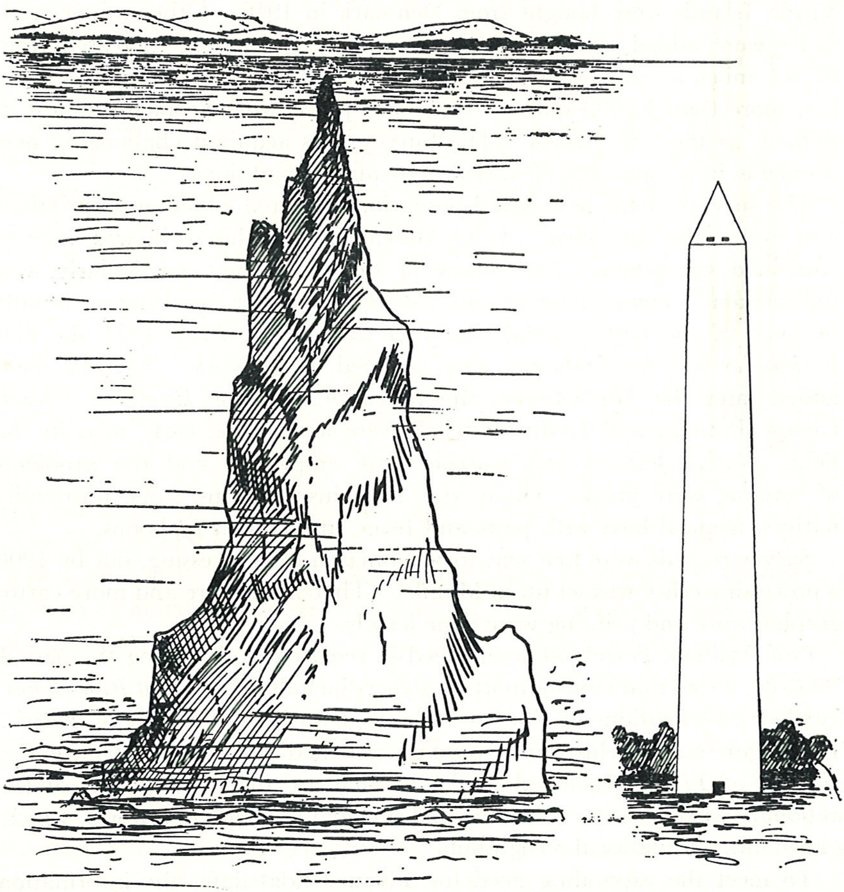
Work progressed in southeastern Alaska, out along the Alaska Peninsula into the Aleutians, and along the coast toward Point Barrow. Storms, fog, and short working seasons posed difficulties and made progress slow. However, a number of charts of Alaskan waters were published in the 1880's and early 1890's.



Wire Dragging for Hidden Obstructions

The Klondike gold rush in 1898 gave even greater impetus to Alaskan surveys. As in the 1849 rush in California, there was a dramatic increase in shipping, and more and more charts were needed. There were many hidden rocks and other dangers, and insurance rates were high. The Congress authorized further expansion, and more detailed surveys were made in harbors and traveled lanes like the inland passage through southeastern Alaska were sounded thoroughly. Faris and Pratt made a survey of the Yukon Delta in 1899. Adjacent areas were surveyed by Assts. George Putnam, H. G. Ogden, and others. The first *Pathfinder,* under Assistant J. J. Gilbert, was used in the surveys of Norton Sound and Fox Islands in the Aleutians in 1900 and 1901.

Pinnacle rocks abounded in the waters, constituting serious dangers. Following earlier crude sweeping operations with towed sections of pipe, wire drag surveys were made in harbor areas and important passages in



Sketch of Washington Monument Rock

the early 1920's. This safety measure eventually was applied widely throughout the navigable waters of Alaska. The number of treacherous rocks discovered in this way was appalling. One named the Washington Monument Rock reached within 17 feet of the surface in general depths of 650 feet. The charting of such dangers eventually increased the safety of navigation, decreased marine insurance rates, and provided better commerce for Alaska.

NEW TERRITORIES, NEW TASKS

The Spanish-American War brought the Philippines, Guam, and Puerto Rico under U. S. control in 1898; and in the same year Hawaii was added by negotiation. The Panama Canal Zone was acquired in 1903 and the Virgin Islands were bought from Denmark in 1916. Other minor territories were added, and the tidal coastline to be charted increased from 87,581 miles to more than 100,000 statute miles. The Philippines alone had more than 14,000 miles of coast and posed work problems almost as difficult as those in Alaska. The Survey thus acquired challenging new problems in a vast area of varied geographic conditions.

The surveys of the new island possessions required added appropriations and more ships and men. As in Alaska, most of this work was done as combined operations. The survey of the Philippines, particularly, was undertaken in comprehensive and systematic manner, resulting eventually in some of the best colonial charts in the world. After 1901 the first *Pathfinder* and the *Fathomer* were assigned to the work. To these were added later the *Marinduque,* the *Research,* and the *Romblon.* Assts. George Putnam and Henry Mitchell were among the early men in the field. Native seamen and workers were employed, and the problems of training were great. There were local insurrections, some unfriendly natives, tropical heat with pests and fever, and violent typhoons.

Survey records were first sent to Washington for processing, but by 1906 a processing office was set up in Manila. Thereafter more and more cartographic work and printing were done locally.

Prof. William Ferrel, while engaged in research work during the period 1868–86, wrote numerous important papers including his *Tidal Researches.* Further investigations of tides were carried on by Dr. Rollin A. Harris. The major results of his studies were documented in the exhaustive treatise *Manual of Tides.* Included in the manual are the development of his stationary-wave theory of the tide and his tidal maps for the world, which gained him international recognition.

To meet the expanding need for advance tidal data, the information previously published in annual reports was discontinued and separate tables of tide predictions were published in 1867 for the Atlantic and Pacific coasts of the United States. For the year 1896 the tables were extended to include the entire maritime world.

For a number of years information on tidal currents was included in the annual tide tables. By 1923 the information had so expanded that it was issued as separate publications known as *Current Tables,* one for the Atlantic coast and one for the Pacific coast.

ARCS CROSS THE CONTINENT

Land crews were as busy on geodetic projects during this period as the offshore parties were on hydrography.

Long arcs of primary triangulation were extended throughout the country. The Eastern Oblique Arc from the Bay of Fundy to New Orleans, started by Hassler in 1816, was completed in 1889. Triangulation begun at various places on the west coast by Davidson was connected, and in 1890 a West Coast Arc was completed from Mexico to Canada.

After receiving its broader assignment in 1871, the Survey began triangulation along the 39th parallel to connect the east and west coasts. This was the start of a survey control system destined eventually to link all parts of the country and even the continent. By 1895 field work was completed on this 2,500-mile arc, the longest in the world at the time. This work, with the Eastern Oblique Arc, furnished the basis for highly important geodetic investigations.

Many field parties worked on parts of the arc, carrying out an impressive piece of teamwork as well as a survey project of unprecedented magnitude. During this work Mount Shasta, in California, was climbed in 1878 by Asst. B. A. Colonna, working under the direction of George Davidson. Colonna and his party reached this remote and difficult peak, made their geodetic observations, and returned within 9 days—a remarkable accomplishment in the wilderness of the time.

Between 1878 and 1893, George Davidson surveyed the California-Nevada boundary line. In the years to come similar surveys of State boundaries were carried out in many places. From the Texas Arc, which had been joined to the Eastern Oblique Arc, two great networks were extended, one northerly along the 98th meridian to the Transcontinental Arc, and the other westerly to meet the West Coast Arc. All were completed by 1900.

A local accomplishment of interest was a special triangulation survey of the New York City area between 1903 and 1908, authorized by Congress in cooperation with city officials. This was the first of many such projects for individual cities and States.

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The surveying and marking of new international boundaries continued. The survey of the northern boundary separating the United States and Canada, which had been started in a small way in 1857, was brought eastward to the Great Lakes with the Survey participating in the work.

The survey of the Alaska-Canada boundary, although provided for at the time of the purchase of Alaska in 1867, was largely delayed until the 1890's. Superintendent Mendenhall was a member of the international committee for laying down the boundary, and his men took part in the surveys. The line started at the historical 54–40 parallel, following Portland Canal to the mountains, thence along the crests to the 141st meridian, and along that line to the Arctic Ocean.

The Survey laid down water portions of this boundary and helped on some land portions, including some topographic mapping. Asst. Fremont Morse was active in this work. The Canadians, assisted by Sub-Asst. J. A. Flemer of the Survey, did much topographic work, introducing a primitive form of photogrammetry as early as 1894, using oblique photographs. The work was finished by 1913.

Between 1891 and 1895 the Survey assisted in the remonumenting of the boundary with Mexico, particularly the portion through New Mexico and Arizona, provided for earlier by the Gadsden Purchase. The Survey was represented on the international commission by A. T. Mosman, the Bureau's chief representative, and William Bowie, who was active in computing the position of the boundary.

Some desultory leveling had been done around the country from the beginning. Systematic, precise, or first-order, leveling was begun about 1875 and accelerated in 1878. By 1907 a line of levels had been completed across the continent and other lines parallel to the coasts and crossing the interior of the country from north to south had been accomplished. By 1915 over 33,000 miles of first-order levels had been run and more than 13,000 bench marks established.

OBSERVATORIES AND EXPEDITIONS

Latitude and longitude observations were made in various parts of the country, particularly by Davidson, who devised his famous combination meridian telescope and theodolite. In 1899 the Survey cooperated with the International Geodetic Association in a worldwide investigation of latitude variations by establishing latitude observatories that still exist at Gaithersburg, Md., and Ukiah, Calif.

After the chronometric longitude connection with Europe in mid-century, better observations were made in 1866–67 and again in the 1870's, using the Atlantic cable. Early in this century a trans-Pacific longitude connection was made by cable with Japan. In the interest of more general scientific work, the Survey participated in a number of famous astronomic expeditions including the Labrador Eclipse Expedition in 1860, the Spanish Solar Expedition in 1870, the African Moon Eclipse Expedition in 1889, and the Transit of Venus Expeditions in 1874 and 1882.

Gravimetric observations were begun by the Survey in 1875, when a Bessel reversible pendulum was imported. Since then, largely through the early work of Charles S. Peirce, who was also a famous philosopher, the systematic gravity survey of the country has continued. Data so gathered figured in the works of Putnam, Hayford, Bowie, and Lambert, and in all geodetic work since. International gravimetric connections were made in the 1870's and 1880's with Europe and Japan. In 1882 the Survey participated in a special expedition on gravimetric studies to New Zealand, Australia, and India. Among those active in the work were Assts. George Putnam and Edwin Smith.

Magnetic surveys provided for in the Reorganization Act of 1843, and carried out at sites of astronomic observations, were amplified by a series of short-term magnetic observatories. One survey of two years' duration, was started in 1867 in Washington, D. C.

The Bureau collaborated with the Army Signal Corps in two expeditions comprising United States' cooperation with many other nations in the International Polar Year of 1882–83. Funds were contributed for an expedition to Point Barrow, Alaska. Extensive technical assistance was rendered both to this expedition and to the expedition headed by Capt. Adolphus W. Greely, U. S. Army, which set out in 1881 for Fort Conger, Lady Franklin Bay, in the Canadian Arctic.

The first high-class magnetic observatory was operated at Los Angeles for 7 years beginning in 1882. In 1890 a 5-year series was begun at San Antonio, Texas. In 1899 a large expansion and the beginning of a systematic magnetic survey became possible through the efforts of Superintendent Pritchett and L. A. Bauer, a physicist who appreciated the need for accurate magnetic data for navigators and engineers. The Division of Terrestrial Magnetism was established with Bauer as chief.

By 1900 magnetic surveys were greatly accelerated, and during the next few years five magnetic observatories were established at Cheltenham, Md.; Sitka, Alaska; Honolulu, T. H.; Vieques, Puerto Rico; and Baldwin, Kans., the latter relocated in 1912 at Tucson, Ariz. These observatories were the sites later for seismographs for the investigation of vibrational disturbances affecting the magnetic instruments. These investigations led eventually to seismological work by the Survey.

In the late 1860's the exploration of the Gulf Stream, which had been interrupted by the Civil War, was resumed. Assistants Henry Mitchell and F. Pourtales, with the steamer *Bibb,* began working in the Florida Strait, while Lt. J. E. Pillsbury with the *Blake* and Lt. Comdr. C. M. Chester and Lt. W. B. Freemont with the *Drift* worked farther north.

Some years later, between 1885 and 1889, the most comprehensive work in the Gulf Stream was accomplished by Pillsbury from the survey vessel *Blake.* His extensive observations of currents and temperatures while anchored in the deep water of the swift stream are among the classical data in physical oceanography.

Investigations in tides and tidal hydraulics were carried forward with notable accomplishments. Asst. Henry Mitchell directed his attention to the study of the tidal regime as related to hydrographic features with particular reference to the forces and factors at work in forming shore lines and channels.

NEW SHIPS AND NEW DEVICES

As the late 19th century increased the pressure on the Survey, ingenuity was as valuable as money. Technicians of the Bureau developed many new instruments and methods for measuring the sea and the earth.

More steamers were obtained for the Survey fleet, and power was added to those originally rigged as sailing vessels. A notable and long-serving ship was the schooner *Matchless,* a sturdy vessel built in 1859. Although there had been a few iron vessels in use beginning with the *Jefferson* in 1849, it was not until the 1870's that iron ships became common. One early iron vessel was the *Bache* built in 1871–1872 and the second Survey vessel to bear the name. Others followed and were widely used, especially in Alaska.

These sturdier and better-powered ships added much to the efficiency of operations, although they required troublesome adjustments to their compasses, and their construction interfered seriously with the practice of making general magnetic observations at sea.

Many new devices added to the efficiency of the work. Among these was a sounding machine, adapted by Lt. C. D. Sigsbee in the 1870's from Sir William Thomson's machine developed slightly earlier in England. This instrument automatically registered the length of wire reeled off under the weight of the lead going to the bottom. Another useful device was a wire cleaning attachment that eliminated the necessity of frequent washing of sounding wire in lime water.

Sigsbee devised a clam-bucket type bottom sampler, which made the recovery of the specimens more certain than previously. He also developed a multiple container that took simultaneous water samples and temperatures, automatically registering the results. Current measurements were made by tracking the motion of buoys holding weighted cans submerged at various depths. This method was improved when Lt. Pillsbury's current meter became available. It registered velocity by the rotation of a cylinder and direction by a self-locking fin.

Most significant of all was the introduction of the wire drag early in the 20th century. This method, which replaced earlier crude pipe-sweeps, was developed principally by Asst. Nicholas H. Heck and tested in New England waters by Asst. Robert L. Faris. It employed a weighted wire, supported at a set depth by buoys and towed between two launches. An area could be completely swept, revealing all hidden rocks that might have been missed in sounding. The development of the wire drag was accelerated when the cruiser *Brooklyn* struck an uncharted pinnacle near New Bedford, Mass., in 1904. The value of wire drag and up-to-date charts was demonstrated dramatically in 1912 when the battleship *Texas* was damaged, while using obsolete charts, on a pinnacle in Penobscot Bay. The rock had been discovered several years earlier by wire drag and was shown on the charts of the Survey.

To support hydrographic surveys, tide observations were made continuously, and permanent tide stations were operated at key points along the coasts. Asst. William Ferrel built a tide-predicting machine in 1882 which could be set for the constants representing 19 harmonic components of the tide, thence producing the curve of future tidal motions. It remained for Rollin A. Harris, a tidal mathematician, to work out more precise tidal theories and, in 1910, to construct with E. G. Fischer a better tide predictor, which used 37 components.

Better triangulation instruments and methods were devised. Smaller theodolites were built, among them a 12-inch instrument constructed under the supervision of Chief Mechanician E. G. Fischer which afforded ease in transportation and faster operation. Better wooden towers were constructed for elevating sight-lines above obstructions. Heliotropes, reflecting sunlight, were adapted for pin-pointing distant shots. Acetylene lamps in 1902 and electric lights in 1916 were used for night observations, obviating daytime disturbances. Signalman Jasper Bilby developed rapid methods of triangulation reconnaissance.

Base-line measurements were improved by an extremely precise set of duplex bars developed by Asst. William Eimbeck in 1897. Although a steel tape had been introduced by Asst. R. S. Woodward in 1891, the variability of the metal with temperature changes rendered it less accurate than bars. The Invar (invariable) tape, first used by Fischer in 1906, overcame this trouble, giving consistently accurate readings even in daytime. It was easy to handle and greatly expedited base measurements. Leveling work was much expedited by the development in 1899 of a direct-reading level rod and in 1903 of Fischer's precise level. These instruments greatly increased speed and accuracy.

FROM COPPER AND ALUMINUM

Charts, except those of the Philippines, have generally been printed in the Washington office of the Survey. Until 1871, the original Law Houses on Capitol Hill first occupied by the Survey in 1832 held the Washington office and printing plant. In 1871 the Survey moved to the Richards Building on the site of the present New House Office Building. In 1891 the Ben Butler house at New Jersey Avenue and B Streets was added. There the office remained until long after World War I.

Until 1905 charts were printed from engraved copper plates based on compilations of field data. Details were added to the charts from time to time in response to the needs of navigators. More place names appeared on charts, and the Survey has been represented on the Board on Geographic Names continuously since its formation in 1891.

The electrotype, developed during the Bache period, was still used in the reproduction process. Color printing and power presses had been adopted, thus increasing production, but little else had changed in reproduction processes. Many of the copperplate engravers were artists, and many of their plates were magnificent examples of esthetic expression.

In 1905 photolithography was introduced into the work. Lithographic stones containing photo impressions were used in special flatbed presses. Many impressions resulted from one inking; moreover the use of multicolors was facilitated. Production and accuracy were both increased. It was now possible to use dry paper and eliminate much of the former distortion.

A much greater improvement, however, came in 1916 when George Hoover, chief of reproduction, introduced the aluminum printing plate. This possessed the advantages of the lithographic stone, with flexibility that permitted its use on a rotary press. From the 75,000 copies printed in 1900, production increased to 330,000 in 1916.

Charts for the Air and the Continental Shelf

V

Water, Land, and Sky

THE FIRST AIRPLANE PILOTS used roadmaps. As late as 1927, on his historic flight to Paris, Charles A. Lindbergh relied on various kinds of maps embellished with navigational lines.

The demands of modern air traffic have changed all that. Aeronautical charts are issued in the millions. Indeed, from the time of World War I the entire complex of American life changed, and with it the character of the Bureau. Pioneering shifted from geographic to scientific frontiers. There were rapid changes in transportation and communication, in economic and scientific specialization, in the United States' role in the world, and in governmental activities.

In 1915 President Wilson appointed as Superintendent E. Lester Jones, a veterinary surgeon with a record in public administration. He had been Deputy Commissioner of the Bureau of Fisheries for 2 years. Jones possessed a keen, orderly mind and was an expert in organizational and financial matters. Probably no man since Hassler and Bache had so much to do with the course and nature of the Survey.

At the outset Superintendent Jones saw need for reorganization. Teamwork still prevailed but conditions now failed to attract and keep high calibre men. The work required frequent moves by the field men, sometimes to remote and unpleasant places, and new incentives were necessary. Technical complexities of the work demanded a corps of highly qualified field engineers who could be moved about freely and thus become familiar with and integrate all phases of the work, commanding ships and field camps, and working as a large team.

A precedent for commissioned status had already been set by assignment of Navy and Army officers to the Survey. Through Jones' efforts this status was obtained during World War I, with an immediate beneficial effect on morale.

On May 22, 1917, Congress empowered the President to transfer vessels, equipment, and personnel of the Survey to the War or Navy Departments in emergency, subject to return to the Commerce Department after the emergency. In 1920 Congress changed the title Superintendent to Director.

Jones is recognized as the father of the present commissioned service. With the help of others, he set high standards, including civil engineering training and good scholarship, for officers of the Bureau. Not being an engineer himself, Jones placed the technical aspects of the work in the hands of qualified experts and freed himself to work on the reorganization and strengthening of the Survey.

He saw the Bureau begin to flower under the new system. Competent civil engineers were added, and the work progressed in scope and area. Echo sounding, one of the outstanding improvements of all time in the field, was developed. Radio-acoustic ranging was introduced into hydrographic surveying. Photogrammetry was beginning to develop, and seismology was added to the Bureau's functions. Work progressed in all phases of Survey activities in the United States, Alaska, the Philippines, and other possessions.

An executive proposal to transfer the Bureau to the Navy in the early 1920's was dropped in consideration of the Survey's record as a separate agency. Subsequent relations with the Navy were cooperative and amicable. Other proposals affecting the Bureau were a plan in 1921 to create a bureau of surveys and maps built around the Survey and a plan in 1928 to transfer the Division of Geodesy to the Geological Survey which was defeated after protest from scientific organizations.

On leave from his position as Director, Jones won military honors as an Army colonel during the war. He participated later in the organization of the American Legion and its pioneer post in Washington, D. C. When he died in 1929, the Bureau was an aggressive and progressive organization equipped to function in the modern electronic era.

DIRECTOR MADE A REAR ADMIRAL

The first of the newly commissioned career officers to become Director was Raymond S. Patton, appointed in April 1929. During his term the rank of the office was elevated to rear admiral (upper half). Patton was active in scientific organizations, being instrumental in starting the American Shore and Beach Preservation Association and the U. S. Beach Erosion Board.

The Bureau was displaced from its ancient offices in 1929 to make way for the construction of the New House Office Building. For 2 years a business building near Union Station Plaza housed the Survey. It moved to the present quarters in the new Commerce Department Building in January 1932.

The advance in technical methods continued. Echo sounding and radio-acoustic ranging were brought to full development, hydrographic surveys were extended, and geodetic work was expanded upon the new 1927 North American Datum. Photogrammetry was developing and aeronautical charting was started.

The reorganization of Government agencies in the late 1930's had little affect on the Survey, although the closely associated Bureau of Lighthouses was moved from the Department of Commerce to the Coast Guard. An executive proposal in 1938 to create a coast and interior survey, as an independent agency by merger of a number of agencies in the mapping field with the Survey as a nucleus, was dropped in view of the disparate functions of the several agencies.

Patton died in office in 1937.

Rear Admiral Leo Otis Colbert succeeded Patton in 1938 for a term that was to last 12 years. A career officer of wide experience, he had participated in most phases of Bureau activity. He had worked in the United States, Alaska, and the Philippines. He had commanded various Survey ships and participated in troop movements in World War I. Between 1928 and 1930 he had directed Survey operations in the Philippines, and for 5 years before his appointment as Director he had been chief of the Division of Charts.

His strong talents in administration saw the Survey successfully through its many important functions during World War II.

Technical developments of the war afforded many fields for exploitation in higher surveying, and these were utilized to the utmost during Colbert's tenure. Sonic systems were improved. Electronic navigational and detection devices that came into use included shoran and the system known as EPI (electronic position indicator), which was developed in the Bureau. These constituted epoch-marking improvements.

Two modern surveying ships, the *Explorer* and the *Pathfinder*, were built and named for earlier vessels. Surveys proceeded in Alaska on a large scale, including the start of work on the Arctic coast in 1945. Philippine Island work was terminated in an advanced state of completion at the establishment of the Republic of the Philippines.

Colbert served on the Mississippi River Commission, as had many of his predecessors, and was active in many scientific organizations. In 1947 he successfully urged the enactment by Congress of a new enabling act which concisely restated the Bureau functions and removed numerous areas of uncertainty. Colbert retired in 1950.

Admiral Colbert's successor, Rear Admiral Robert F. A. Studds, had also served through the commissioned ranks, seeing service in many phases of Bureau operations. He received a departmental Exceptional Service Medal for his handling of the ship *Fathomer* during a severe typhoon in the Philippines in 1936. He had been in charge of personnel in the Chart Division during World War II, and had been chief of that division for a few months before his appointment as Director. Under his charge, work was pushed forward in Alaska, and the first phase of the survey of its Arctic coast was completed in 1953. The Korean War required much special chart production, and the furnishing of detailed tide, current, geodetic, and geographic information.

Admiral Studds was absent because of illness for extended periods during his last 2 years in office, and in 1955 he retired for disability after major surgery.

AT THE HELM TODAY

With a background of 32 years of commissioned service, Rear Admiral H. Arnold Karo succeeded to the directorship of the Bureau by Presidential appointment in August 1955. Born in Lyons, Nebr., on December 24, 1903, he was graduated from the University of Nebraska in June 1923 with a degree in civil engineering. His career had included 22 years at sea in surveying the waters of Alaska, the Philippines, and the Virgin Islands and the waters along the Atlantic, Pacific, and Gulf coasts of the continental United States.

Karo advanced through the ranks from ensign. As a senior officer he had under his command the largest ships of the Survey fleet. In 1941, while commanding the ship *Lydonia,* Karo received a commendation from the Governor of the Leeward Islands for the excellent cooperation and goodwill maintained during his tour of duty in the West Indies. In 1950, while serving as commanding officer of the ship *Explorer,* his last sea command, Karo was commended by the Secretary of Commerce for aiding in the rescue of a severely injured Eskimo in a remote area of Alaska.

After transfer to duty with the Army Air Forces in World War II, Karo's assignments included 2 years as commanding officer of the Air Force Aeronautical Chart Plant in St. Louis. It had just been established and was not yet in full operation. The plant he organized became recognized as one of the most important map reproduction plants in the world.

During the summer of 1951 Karo represented the Survey at the British Commonwealth Survey Officers' Conference in London. He completed the

1954–55 course of study at the Industrial College of the Armed Forces and prepared as his term paper a study on world mapping that was distributed to interested organizations and agencies.

His assignment for the 4 years immediately preceding appointment as Director was as chief of the Division of Charts in the Washington office. Coinciding in part with the Korean conflict, annual production of charts increased to more than 40,000,000 copies during that period. He was responsible for the production and distribution of all nautical and aeronautical charts issued by the Bureau for use of the Merchant Marine, civil aviation, and the Armed Forces, for the compilation of a number of related publications, and for the operation of the Bureau's reproduction plant.

During his directorship, new emphasis has been placed on scientific and technical progress and on improvements in administration and management. Admiral Karo has been active in many professional organizations. He is president of the Society of American Military Engineers and is the Survey's member on the Mississippi River Commission.

BETTER SURVEYS

In the modern period new surveys have progressed in Alaska, the Philippines, and elsewhere, while repeat or revision surveys have been carried out on changeable parts of the coast. New surveys of major ports and other areas subject to heavy traffic had to be made to accommodate ships of ever-deepening draft, and to meet the requirements of higher speeds, new methods of navigation, and new standards of safety. Hydrographic surveys, expedited by new methods and devices, were extended toward the edges of the continental shelves and to other remote areas.

A comprehensive survey of the entire Philippine Archipelago approached completion in the years leading up to World War II and the Japanese occupation. This vast project was organized and carried out largely as a separate activity. A local bureau had administrative offices, a computing division, and chart compilation and printing facilities. The local government provided a large part of the cost, but the United States contributed one major ship and the services of necessary field engineers, mathematicians, and cartographers.

The director was assigned from among the senior officers of the Survey and received additional pay from the Insular Government. The tropical duty afforded by this kind of work became a recognized feature of the professional careers of a whole generation of Survey field men. The unusual problems presented by a tropical and unaccustomed environment gave scope for originality and resourcefulness. Such assignments served as tryout periods in positions of advanced responsibility preliminary to important promotions later at home.

After the war the new Republic of the Philippines undertook to maintain its own bureau, with consulting services of Survey officers until 1950. Operations began on a substantial foundation of excellent surveys and charts built by the Survey over more than 40 years. The new agency, designated the Philippine Coast and Geodetic Survey, was closely patterned after the United States organization.

In Alaska surveys extended into the Aleutian Islands, the Bering Sea, and other untouched areas. The wreck of the U. S. S. *Tahoma* in Alaskan waters in 1915 resulted in greater interest and new funds for surveys. More and more the efforts of the Survey were devoted to meeting the challenge of the American arctic territory, full of natural riches and awaiting the beginnings of commerce that in those days had to be by sea. As later in the Philippines, service in Alaska was a routine element in the training and development of Survey engineers. Weather and unfriendly terrain were good teachers.

The strategic importance of Alaska became evident during World War II, and surveys became even more important. They were carried toward the extremity of the Aleutian chain and to the Bering Straits area and throughout the entire Arctic coast west of the Canadian border. Wire drag surveys continued in critical areas. Unusual climatic and environmental conditions on the northern coast of Alaska required the development of new methods of transportation and survey operations, including caterpillar-tractor trains, helicopters, field work in subzero weather, and launch sounding operations among drifting icefloes.

The ships working in Alaskan waters took systematic deep-sea soundings on lines across the Gulf of Alaska and the northern Pacific Ocean en route to and from their seasonal working grounds. Many seamounts were discovered in this way and important additions made to the general bathymetry of the Pacific.

Hydrographic surveys of some inland lakes were undertaken, including Lake Tahoe on the California-Nevada border during the 1920's and later Lake Okeechobee, Lake Pend d'Oreille, and Lake Franklin D. Roosevelt.

Coast Pilots continued to be published in 10 volumes covering different areas. Field investigations were made and complete revisions of the volumes were issued at intervals of about 7 years. Yearly supplements were published. These volumes contained a great variety of information about port facilities, regulations, and general descriptive matter not shown on charts.

Tide observations were made in connection with hydrographic surveys and provided engineering and general information. Numerous control tide stations were installed, and temporary ones were operated in many places.

Foreign tidal data were gathered from all over the world, eventually permitting the publication of complete tables of predicted tides for some 190 widely separated places.

Current observations were made in conjunction with other work. Tables providing tidal current predictions were produced. To satisfy growing needs for full current information in the handling of large ships in restricted places and for engineering use, intensive current surveys were made with new instruments and methods in a number of harbors and bay areas. From these surveys charts were compiled to show the water circulation at hourly intervals.

GREAT ARCS CROSS THE LAND

The importance of geodetic surveys grew rapidly after World War I. Intensive coverage in many areas became necessary because of rapid industrial development and such wide-scale operations as the Tennessee Valley project. Capt. William Bowie, one of the great geodesists of his time and chief of the Division of Geodesy until his retirement in 1936, was a strong advocate of comprehensive mapping based on geodetic foundations. Much of the vigorous advance, both in geodetic techniques and in the great scope of the work accomplished, grew from his inspiration.

In the 1920's, second-order triangulation surveys were extended through remote areas to reach the north and east coasts of Luzon Island in the Philippines.

In the depression of the 1930's greatly increased funds were directed to geodetic work as a means of relieving unemployment through useful work. Large relief and recovery projects were set up by the Government. Many unskilled people who were employed required training by engineers of the Bureau. The work of the Survey expanded, and great advances were made toward fuller mapping control of the country.

During and after World War II, work in geodetic surveys was accelerated in Alaska while normal work went on in the United States. Necessary astronomic and gravimetric observations continued to be made, but the greatest effort was concentrated on first-order triangulation and leveling.

Triangulation and traverse throughout the country and in Alaska by the time of World War II amounted to nearly 100,000 miles of first-order arcs, with more than 100,000 accurately located points. During World War II, the arc connecting the triangulation of the United States with that of Alaska was completed. After the war other arcs were pushed north to Point Barrow and west to the end of the Aleutians. These, with connections made by the Inter-American Geodetic Survey with Bureau assistance, provided continuous triangulation almost from end to end of the Americas, nearly 10,000 miles.

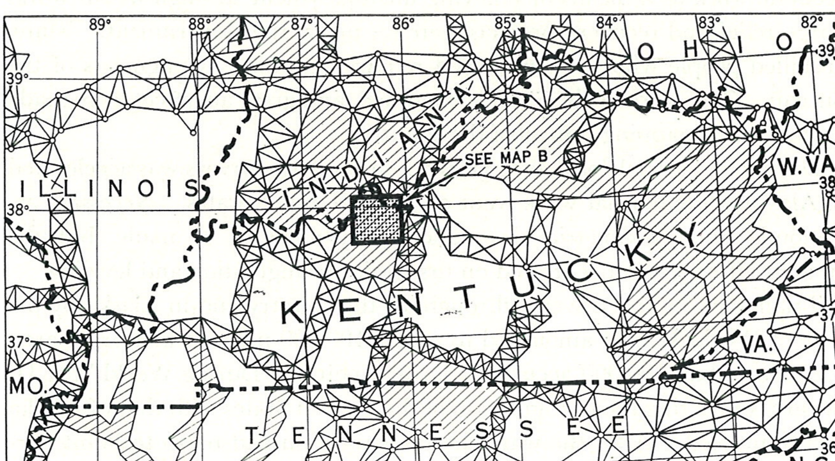
First-order triangulation was pushed further into the interior of northern Alaska, along the coasts of the Bering Sea and the Arctic Ocean, and a basic net was extended through the western Aleutians and to St. Lawrence Island in the Bering Sea. The last was accomplished by trilateration, through direct distance measurements by electronic means. Even the remote St. Matthew Island was connected by exceptionally long lines measured by the electronic position indicator system.

In the United States, area triangulation was started to fill in the spaces between the original arcs and to bring the control points to all localities. In 1956 there were more than 160,000 precisely determined points.

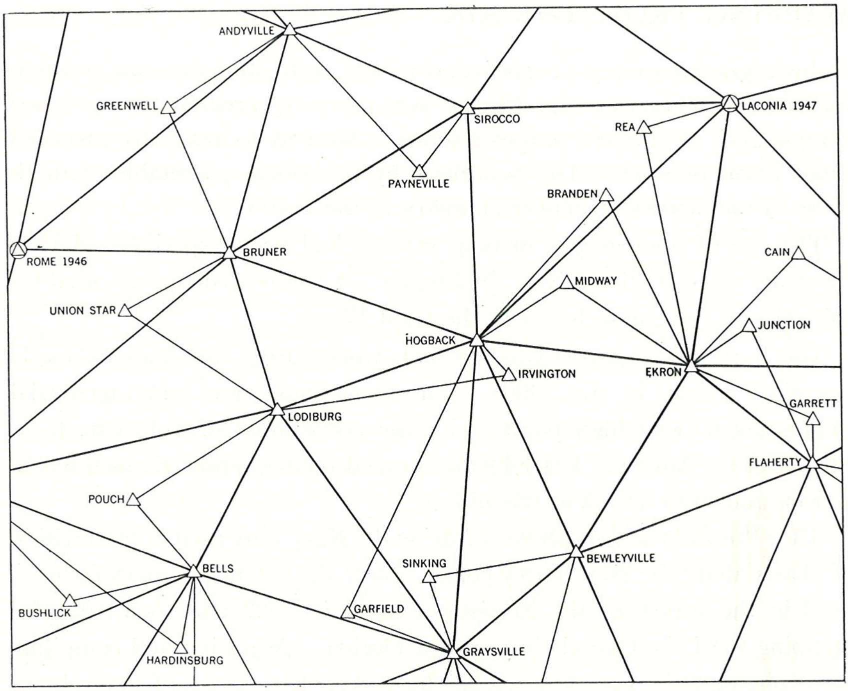
Several special projects were executed. A base line of unusual accuracy, having a probable error of only one part in 11 million, was measured by Lt. Comdr. C. L. Garner in 1922–23 near Pasadena. From this, triangulation was extended to a line between San Antonio Peak and Mt. Wilson, used by Prof. Albert A. Michelson of the University of Chicago in his famous determination of the speed of light.

A special survey was made of the panhandle boundary of Texas. By Supreme Court order the accurate measurement of the arc-of-circle boundary between Delaware and Pennsylvania was accomplished. The latter survey, of an extremely technical nature, reaffirmed an accurate survey made by the Bureau as early as 1892.

The first-order level net was expanded with unprecedented rapidity. By 1929, 45,000 miles of these lines had been run. By 1940, 112,000 miles were finished and had been complemented by 166,000 miles of second-order



Portion of Triangulation Net of the United States



Area Triangulation to Fill Gaps

lines and connected with a large network in Canada. The work accomplished in postwar years paralleled that of triangulation and other lines, until in 1956 there were nearly 425,000 miles of lines, considerably more than half of which were of first-order standard of accuracy.

Leveling work has been performed extensively for special purposes, such as the studies of land subsidence in California, of tectonic problems associated with reservoir loading at Lake Meade, and for the investigation of sea-level problems in many places.

Modern program objectives for the extension of geodetic surveys call for the placing of primary horizontal control points at average distances of about 7½ miles, with a point in each 50 square miles of area—a standard now reached for only about one-quarter of the country. Vertical control points of basic accuracy are intended to be established at distances of 1 mile or less along lines not more than 6 to 8 miles apart on the average. As part of an international study of the shape of the earth, it is intended to complete a chain of astronomic observations about 18 miles apart along the entire 35th parallel in this country. The gravity control network is to be expanded to provide a station about every 100 miles, and the present 900,000-square-mile area with spacing of 10 miles or less will be extended over the entire country.

MAPPING FROM THE AIR

As hydrographic surveys progressed, detailing of the shoreline and positioning of fixed objects and landmarks were necessary preliminaries to chart compilation. For these purposes topographic surveys normally preceded other forms of work. This was done by traditional planetable methods prior to the advent of photogrammetry in the 1920's.

The use of photographs in map making had been experimented with for many years, particularly by the French. A captive balloon was used for this purpose by Union forces in the Civil War.

The Survey first participated in such work during the Alaska-Canada boundary survey in the 1890's. The Canadians were using terrestrial photos taken from high points, with the cooperation of Sub-Asst. J. A. Flemer of the Survey. Later Flemer studied photogrammetric methods in Europe and wrote a book on the subject.

After World War I air photos made by the Navy were used in the revision of charts along the New Jersey coast. Navy single-lens photographs were used in the survey of the Mississippi Delta in 1922 and soon after for mapping the Lake Okeechobee area of Florida. Adjusting and compiling these photographs was slow work. Moreover, the supply of new photographs was uncertain and scheduling the work was difficult. So planetable methods persisted widely, and photogrammetric mapping in the Survey was irregular for many years.

In 1928, with the advent of multiple-lens cameras and a more reliable supply of photographs from the Army Air Corps, continuous and systematic photogrammetric mapping began. The Ten Thousand Islands areas and other inaccessible portions of the Florida coast were mapped. By 1937 a nine-lens camera, designed by Lt. Comdr. O. S. Reading of the Survey, and auxiliary instruments were constructed, and photogrammetric mapping along the coasts of the United States and Alaska took on large-scale proportions. Aircraft were assigned to the work by the Coast Guard and other flying agencies.

The Division of Photogrammetry, created in 1945, rapidly became a major element of the Bureau, with responsibility for the topographic mapping required in the production and maintenance of nautical and aeronautical charts. Modern aerial mapping cameras and stereoscopic plotting instruments were installed and a corps of photogrammetrists developed to carry out the exacting task of producing large scale planimetric and topographic maps of the coastline and airports.

THE CENTER OF MAGNETIC STUDIES

Until 1925 the geophysical work of the Bureau, except in geodesy and gravity, consisted largely of magnetic investigations carried out by the Division of Terrestrial Magnetism. Formerly there had been a little work with seismographs at some of the magnetic observatories, primarily to investigate the magnitude of seismic disturbances that had impaired magnetic records from time to time. In part because of this, seismological investigations were assigned to the Bureau as a normal function in 1925. Magnetism and seismology, though small in relation to the major surveying functions of the Bureau, assumed a variety of important aspects. The Division became in turn Terrestrial Magnetism and Seismology, Geomagnetism and Seismology, and finally Geophysics.

The observatory at Vieques, P. R., was discontinued in 1924, to be reestablished in 1926 at San Juan. In 1948 a new observatory was opened at College, Alaska, near Fairbanks. In 1949, with the financial help of the Office of Naval Research, an observatory was built at Point Barrow, Alaska, and completed with the College station an array capable of monitoring the magnetically significant north auroral zone.

The old Cheltenham observatory, built at the beginning of the century, largely under the direction of the late John Fleming and long considered the central station of the United States system, was closed in 1956. Its functions, including an internationally important practice of comparing and calibrating the magnetic instruments of many countries, were transferred to a new observatory at Fredericksburg, Va., after a period of simultaneous operation to correlate the transfer of the basic standards. The new Fredericksburg station was provided with facilities for the development of magnetic instruments and for the performance of magnetic research observations. A Fanselau-Braunbeck coil installation for the manipulation of local magnetic fields is considered the best in the world.

The College (Alaska) observatory is the culmination of work that began in 1932–33 on the occasion of the Second Polar Year. Nicholas Heck, a member of the international commission for that undertaking, planned an expedition to College, cooperatively with the Carnegie Institution of Washington, the United States Weather Bureau, and the Alaska Agricultural College and School of Mines, now the University of Alaska. The Survey carried out magnetic work for the first time at that site.

In 1956 and 1957 extensive preparation was made for magnetic observation work at many temporary stations in Alaska, the western Pacific area, and Antarctica as part of the International Geophysical Year program.

Magnetic surveys for the delineation of the magnetic field continued on a slackening scale, because of the increasing sufficiency of station distribution. However, a program of repeat observations at key stations was maintained to obtain secular-change data. The development of airborne magnetometers in the late 1940's gave access to the flying levels used in air navigation and to very remote areas. In 1950 and 1951, with Air Force flight facilities, a complete aeromagnetic survey of the North American Arctic region was made, facilitating use of magnetic compasses in that hitherto unknown region. Subsequently, the Survey cooperated with the Air Force in surveying magnetic fields in Florida and California.

Magnetic charts and other magnetic data publications pertaining to the United States and territorial areas have been produced at intervals. Beginning in 1950, isomagnetic charts of the world were compiled by the Bureau for publication by the Navy Hydrographic Office under an agreement of 1947 centralizing all United States magnetic chart compilation in the Survey. This centralization was implemented by the organic act of 1947, which designated the Bureau as the United States central repository of world magnetic data. This function has since been discharged through extensive exchange activities with all accessible countries.

A MAJOR ASSIGNMENT: EARTHQUAKES

Seismological work was assigned to the Bureau by the Congress in 1925. This function has been carried out in part by using the magnetic observatories as sites for seismographs. The Survey has assumed responsibility also for general coordination of seismological work throughout the country, in many cases assisting private operators or institutions with the loan of apparatus, technical advice and assistance, and reimbursement for cooperative services.

Sources of seismological information were gradually extended widely over the world by data-exchange arrangements with foreign institutions, much of it by radio to permit prompt location of earthquake epicenters. Now more than 40,000 earthquake messages from all sources are analyzed annually, and epicenter determinations for about 1,200 earthquakes are reported by postcard notices each year.

Beginning in 1932, a specialized investigation of the magnitude and characteristics of strong earth motions, characteristic of the central areas of destructive earthquakes, has been carried out with special instruments giving quantitative records of ground motions. The work was developed to include field investigations of earthquake-damage effects and special instrumental investigations of the vibrational characteristics of numerous types of structures. Recording instruments are maintained at 69 stations in California and adjacent States and at 7 locally operated stations in Central and South American countries.

Geodetic work in the vicinity of active California faults has been performed periodically since the late 1920's to develop information about the ground movements that precede or accompany earthquakes.

Following the destructive seismic sea wave of 1946, the Bureau organized and operated a warning system involving the cooperation of seismograph stations at several Bureau observatories, surveillance reports of tide observers, special sea wave warning devices, and an integrated communications network centering on the Honolulu observatory. This system warned the coastal communities of Hawaii of seismic sea waves originating from submarine earthquakes.

In collateral seismological activities, the Bureau has investigated vibrations due to construction activities, traffic, machinery, and meterological disturbances. The magnitude and effects of ground disturbances due to explosions have been widely investigated, particularly on behalf of the defense agencies. Tectonic problems associated with the crustal deformation from reservoir loading have been investigated. Consulting services have been rendered to government agencies, commercial and industrial organizations, and foreign governments on all aspects of earthquake problems.

CHARTS BY THE MILLION

The expanding area of charted seaways and the growing requirements of commerce have occasioned a vast increase in the work of compiling and publishing charts. Before World War I the Bureau's catalog listed 658 nautical charts, and 128,000 individual copies were published annually. The war required a great increase in printing, raising the number of copies to 237,000 by 1918. The World War II peak year of 1945 required 21,200,000 copies of all kinds, and new presses had to be installed and operated on three shifts. Special charts were printed on behalf of the Hydrographic Office, the Air Force, and other agencies. In 1956 the catalog listed 806 different nautical and 1,533 aeronautical charts, and the publication volume was about 750,000 nautical and 43,000,000 aeronautical chart copies.

Contributing to this tremendous increase in the volume of chart production was the issuance of many new harbor and Alaska charts, of a basically new series of general charts designed for coastal navigation, and of the Intracoastal Waterways series of charts.

The big growth in charting, however, resulted from aviation. When the need for aeronautical charts developed in the mid-twenties, the Survey with a century of experience in chart-making was called upon to produce them.

The first aeronautical chart, published in 1927, was in strip form and covered the route from Kansas City, Mo., to Moline, Ill. This early chart portrayed prominent topographic features for contact flying and the newly installed airport lighted beacons for night flights. This strip chart concept was extended to other lighted air routes between the major air terminals until about 1930, when it became evident that area-type charts were needed to provide complete coverage. A series of 87 sectional charts was then developed to cover the entire United States. These became the basic charts for contact flying.

There began an evolution of the character of the charts as electronic aids to navigation, and controlled airspace came into being. Faster and larger aircraft flying at greater altitudes required new types of charts to keep pace with the rapidly growing aviation industry.

All-weather instrument flying required a special series of radio facility charts for enroute navigation as well as a separate series portraying instrument approach and landing procedures. Nine separate series of charts at various scales and for varying uses are published in 1957.

As a large part of the topographic information on aeronautical charts was taken from existing maps and the aeronautical information was furnished by other Government agencies, the field work in connection with the charting program was limited in scope. However, flight-checking was extensively performed at 5-year intervals.

Geodetic, triangulation, and photogrammetric parties precisely located navigational aids, obstructions to air navigation, and prominent landmarks as part of their regular programs. Three or four airport parties were continuously in the field making airport surveys showing runway layouts and obstructions in the approach and departure areas.

SOLAR EXPEDITIONS AND TRIPS TO COURT

Other new services included the gathering of basic data of many kinds, map information, data on geographic names, special research, drafting, technical services, and public information. After World War II such collateral activities were handled by the Geographic Branch, which in 1956 became the nucleus of the Technical Services Division.

Administrative divisions for personnel, budget and finance, and purchasing and office administration were formed. The rank of Assistant Director was elevated to rear admiral (lower half), and the Office of Assistant Director for Administration was created.

As in previous periods of the Survey, expeditions of many kinds and to many parts of the world were joined by Bureau specialists. These included several solar eclipse expeditions to various parts of the world. In 1947 a Bureau magnetic observer accompanied a U. S. Navy Antarctic expedition. In 1946 another accompanied a joint United States-Canadian expedition to arctic North America and Greenland.

An important feature of the years of the modern period, particularly during and after World War II was the large volume of cooperative work done for the Defense and other Federal agencies. Not only were the operating facilities used in many cases on major projects, but there were a wide variety of consulting and advisory services, justified by the special skills and facilities of the Survey. Of special importance was the work of Comdr. Carl Aslakson in electronic distance measurements and of Dr. Dean Carder in seismic detection techniques.

Bureau specialists became outstanding authorities in their fields and often trial experts, consultants, and advisors on seaward boundary problems, matters of riparian rights, geodetic surveys, geophysics, and many cartographic matters. Bureau records had long been accepted in courts as incontestible documents.

Radio and Sound Measure
Depth and Distance

VI

New Tools for the Electronic Age

THE SURVEY CAN BOAST a unique nine-lens camera, one of the few in existence. It was still in use in 1957, 21 years after it was developed by Lt. Comdr. O. S. Reading. Once it had to be rebuilt after a crash that destroyed the plane in which it was transported.

The big aerial camera, one of many instruments devised or improved by Survey specialists, covered 124 square miles in a single picture, on a scale of about 3 inches to the mile, at a flying height of 14,000 feet. The equipment was particularly valuable to the Bureau as much coastal area is swampy, rugged, and inaccessible. It reduced the amount of ground control necessary for mapping.

Other innovations of the modern period were sonic sounding of depths and various electronic instruments to determine a ship's position.

Among the improved tools were larger and better-equipped vessels, replacing over-age, inefficient, and unsuitable ships and converted yachts. The *Surveyor,* built just before World War I and long considered the finest survey vessel afloat, was discarded in 1955 after a historic career of which most was spent in Alaska waters. The *Oceanographer,* renamed from the yacht *Corsair II,* was given to the Bureau in 1930 by J. P. Morgan. She carried out various missions, culminating in World War II activities in Alaska and the western Pacific, after which she was decommissioned as unsuitable for further work. Converted naval vessels were used after each of the world wars.

The beginnings of the present modern fleet were the *Explorer* and the *Pathfinder,* built in the early 1940's. These, with the *Hydrographer,* built in 1931, and the *Pioneer,* a converted naval vessel, constituted the 1956 fleet of the major ships. All bore names of former Survey ships. Numerous intermediate-size ships and tenders comprised the remaining hydrographic fleet.

A new vessel to be named *Experiment* was authorized for construction in 1957, the first of two newly authorized ships. These were to be the first built to carry flying auxiliaries—in the case of the *Experiment,* a helicopter.

The second major ship loss in Survey history occurred in 1920 when the *Isis,* a converted yacht, foundered on the wreck of a sunken dredge near St. Augustine, Fla., while making a survey.

After World War II attention turned to the sea as a producer of natural resources. As population grew and resources diminished this reservoir became increasingly important. Oil was being extracted from the continental shelf beneath the Pacific Ocean and the Gulf of Mexico, and other minerals were available. Disputes arose between the Federal Government and several States over the ownership of minerals under the coastal waters, and Survey personnel participated as experts on technical matters in Supreme Court hearings on the question.

In 1953 the Outer Continental Shelf Lands Act (Public Law 212) was passed by the Congress, setting up machinery for the development of resources on the continental shelf outside the historical boundaries of the States. Determination of these historical boundaries posed an interesting problem which the Bureau was asked to help solve, and hydrographic surveys grew increasingly important on the outer fringe of the continental shelf.

SOUNDING THE DEPTHS

The introduction in 1923 of braided-wire-center cotton cord, widely used as a non-stretching tiller rope, provided the advantage of a hand leadline that held its length substantially without stretching. To permit deeper sounding than was formerly possible with a moving ship, elaborate arrangements known as trolley rigs had been devised, about 1916, to carry the lead a whole ship length forward of the sounding machine and give it more time to settle to the bottom without stopping the ship.

A notable technical advance was the development of the sounding tube by G. T. Rude and E. C. Fischer in 1922. This device gave an indication of depth through pressure effects without the necessity of a vertical measurement. Depths as great as 600 feet could be sounded with sufficient accuracy for charting purposes. A great advantage was sounding without stopping the ship, merely by allowing the tube to trail astern until it had reached bottom.

Great ingenuity was exercised in developing methods of fixing the points on sounding lines far offshore and beyond sight of control points. Celestial sights were used with refinement far exceeding ordinary ship navigation practices. Dead reckoning was carried out with scrupulous attention to currents, leeway, close calibration of ships' logs, and elaborate methods of adjusting lines from point to point.

Arrays of survey buoys were laid out in the shallow continental shelf waters of the Atlantic and gulf coasts. These were located by sextant observations and became the basis of hydrographic surveys over vast areas beyond sight of shore signals. Sometimes these buoys were laid out as triangulation networks, the distance between them being measured by a taut-wire system. Metered lengths of piano wire were stretched along the lines. Azimuths or bearings of the lines were determined by inclined sextant angles to the sun.

The wire drag method was widely used for certainty in the hydrographic surveys of rocky areas like those of the New England coast and Alaska and for the discovery of coral-head formations in the waters of Florida and of the Philippines and other tropical areas. After World War II, the method helped in the finding and charting of hundreds of dangerous hulks of torpedoed ships in the shallow waters of the eastern coast.

The great modern development in hydrographic surveying is the outgrowth of the submarine acoustic research performed by Survey officers and others during World War I. Submarine acoustic signals became the means of virtually instantaneous sounding in practically all sea depths, as well as of distance measurement techniques permitting position fixing at great distances without any requirement of visibility. The first of these great methods still prevails; the second gave way after World War II to radio signaling methods of even greater scope and utility.

In the early 1920's a Boston firm developed the fathometer, an echo sounder permitting a reading of the depth by an observer who had to match a moving light with a spot on a circular fathom scale. It measured the depth by use of the time-distance factor of a sound signal which traveled from an oscillator to the bottom and back. It was extensively tested by the Survey, largely on the east coast ship *Lydonia,* and adopted in preference to a Navy device for echo-sounding that was tested in the Pacific on the ship *Pioneer.*

Survey cooperation in the development work may be credited for a large measure of the eventual success and general use of sonic sounding methods. Dr. H. G. Dorsey, an engineer with a private firm, developed an improvement utilizing a flashing red light that obviated the difficult and uncertain readings of the original fathometer. Dr. Dorsey later joined the Survey and contributed to a long process of improvement and innovation.

By the late 1920's fathometer soundings became routine procedure, permitting sounding at will while the vessel proceeded without interruption on the sounding course with particular advantages in deep water.

In the years just before World War II, recording fathometers brought about the second great development in sounding methods. They afforded a permanent record and the means for critical scrutiny and appraisal of the sounding record. Instruments in this field are now so sensitive that they reveal "scattering layers" of minute marine life and schools of fish in the water, and even layers of gravel or rock below the silt bottom of the sea. Such instruments are sufficiently portable to be used in launches and other small boats.

FINDING A SHIP'S POSITION

Sound signaling through the sea water is possible over great distances under favorable circumstances. The time of travel of submarine signals from place to place indicates the distance. This principle provided the basis of the hydrographic surveying system developed by the Bureau about the time sonic sounding came into being.

Sound waves generated by the explosion of small TNT bombs were sent to shore-based hydrophone stations, which relayed the signals immediately back to the ship by radio, where the plotting of the ship position occurred as the soundings were made. This method, tried on the *Guide* as early as 1924, gradually became an accepted system, although it was beset by difficulties and limitations of many kinds during the years up to World War II.

Dr. Dorsey participated actively in the development of radio acoustic ranging, including the study of many problems of sea water physics and of the complex factors affecting the propagation of submarine and sound waves. Among the significant steps was the development in 1932 of an automatic sono-radio buoy, which became much more successful than the original shore-based hydrophone stations. These buoys were forerunners of many types of sentinel- and detector-buoys employed by the Navy in World War II. Sono-radio buoys, anchored solidly and located accurately with relation to known shore points, automatically performed the same function as shore stations. They not only operated better but also extended the effective range of the radio-acoustic ranging system farther seaward.

The wide use of sonic signaling methods for both sounding and position finding required intensive observation and analysis of the physical properties of the sea water, including temperature and salinity. Pressure due to depth was also a factor in the determination of velocities. Collateral observations of these factors enhanced sonic signaling in meeting the general problems of physical oceanography.

Radio acoustic ranging was not entirely accurate because of the impossibility of obtaining comprehensive data on the composition of the sea water. It nevertheless reached areas at great distances from any visible points. The accessible areas at sea were therefore vastly extended, relieving the hydrographic ships of the difficult and unsatisfactory dead reckoning and celestial navigation methods previously used.

An element in the extension of radio acoustic ranging to its greatest distances was the discovery and interpretation of the so-called sofar layer in the early 1930's by Comdr. O. W. Swainson and Dr. Carl Dyk, working in the Pacific aboard the ship *Pioneer.* Following suggestions of A. L. Shalowitz, a Survey cartographic engineer, they showed that certain depth layers exist where combined factors of temperature and pressure cause a velocity inversion, and hence a channeling effect that conserves energy and sends the sound signals almost undiminished over great distances. This is the basic phenomenon now employed in the well-known sofar signaling system developed by the Navy for distress calls.

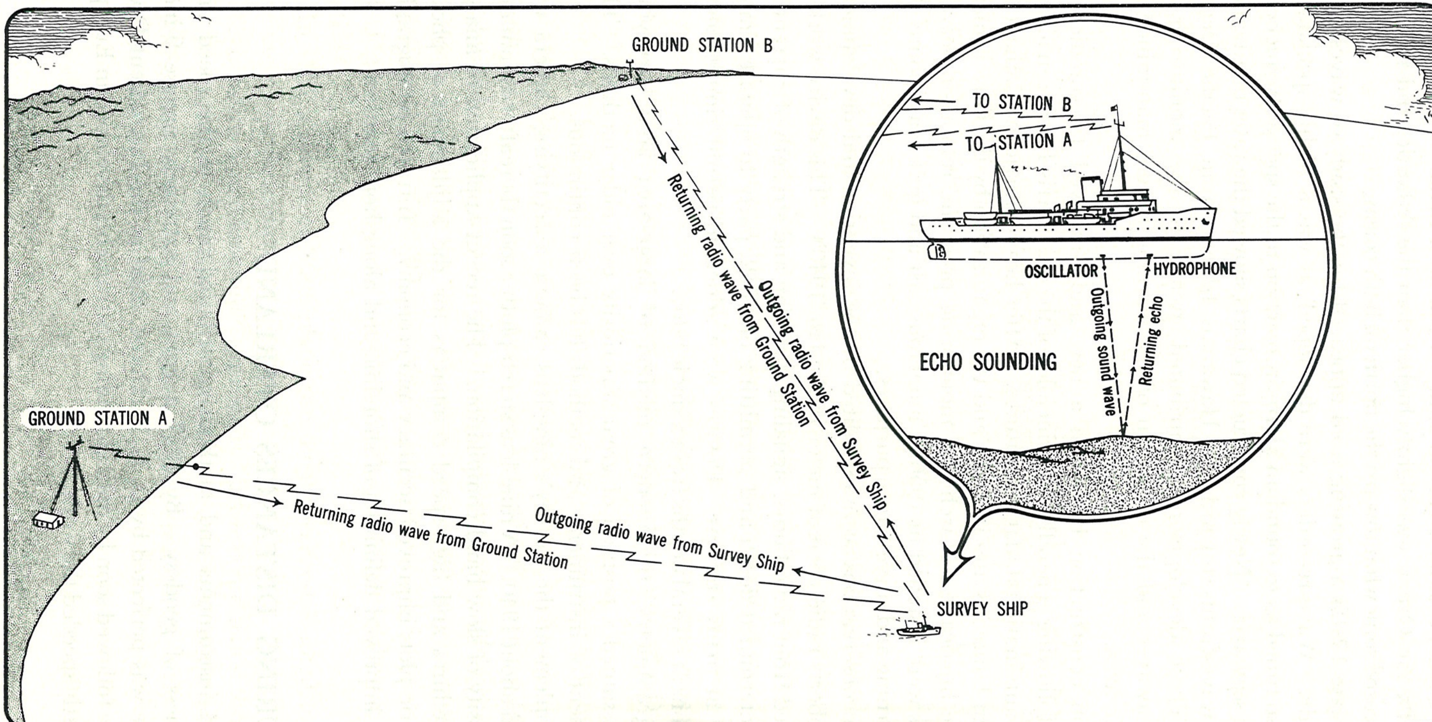
LORAN AND EPI

Radio technical developments of World War II made possible the use of radio velocities and radio wave-lengths for the measurement of distances. The first practical application on the surveying ships was radar, a detection device initially used by military ships and planes. It quickly became an invaluable aid to ships in the dangerous waters of western Alaska or in combat areas where navigational aids and signals were lacking, though survey accuracy with it was impossible.

A specialized form of radar called shoran, using responder stations equipped to return radar signals to their source and first used to pinpoint air bombing attacks in Europe, became available immediately after the war for hydrographic survey control. This equipment ended the dependence of the Survey upon radio acoustic ranging, and dramatically improved offshore survey accuracy.

Shoran was a pulsing system using very high frequency signals limited nearly to line-of-sight distances. Other systems existed, such as loran, which had lower frequencies and greater distance range but far less precision. The Survey radio laboratory, originally established by Dorsey in 1931, developed the special system termed EPI (electronic position indicator), which provided excellent accuracy, with effective distance ranges of several hundred miles. Comdr. C. A. Burmister, Thomas Hickley, and others participated in this valuable development. Shoran and EPI in 1957 controlled all hydrographic surveys except those in immediate shore areas where visible signals serve the purpose.

A portable automatic tide gage, developed by Rude and Fischer in 1923, greatly expedited tidal work in hydrographic surveys. Using accumulated



Echo Sounding and Electronic Position Indication tidal and geodetic data, a special study of sea level made in 1927 showed that the Pacific Ocean was slightly higher than the Atlantic, and that sea level increased somewhat toward the north on both coasts.

In the late 1940's a growing need appeared for the study of waves on a broad scale. Wave-recorders were developed, as was a highly specialized detector so tuned as to sound an alarm in reaction to the special frequencies of seismic seawaves. Newly constructed charts showed the rates of advance of such wave-fronts toward the Hawaiian Islands from Pacific Ocean points. These developments contributed greatly to the monitoring of seismic seawaves and the operation of the warning system maintained in the Pacific area.

In 1956 construction began on a new and improved tide-predicting machine following generally the principles of the old Harris-Fischer machine but with automatic tabulation features. After heavy hurricane damage in the eastern United States in 1955, and the organization by the Government of a large hurricane research and monitoring program, remote-indicating tide gages were installed in 1956 at numerous east and gulf coast points for better warning and surveillance purposes.

Current observations were expedited by the invention and development of the Roberts radio current meter in the late 1940's. This device worked unattended from radio buoys, signaling direction and strength of current at any predetermined depth and permitting one field party to operate simultaneously at many stations. Devices were added to permit simultaneous observations at several depths from a single buoy.

Photogrammetry, the modern method of large-area land surveying, rapidly assumed a position of great superiority over older methods. The development of instruments and methods has been continuous.

To supplement the Survey's nine-lens camera, a rectifying camera was developed about 1940. A nine-lens stereo-plotter soon thereafter eliminated the necessity of slow hand compilation. The recent application of analytical procedures and high-speed computers for the adjustment of photogrammetric plots improved accuracy and economy. Infrared photography provided improved definition of shoreline and alongshore features.

MEASURING DISTANCES OVERLAND

Improved instruments and methods contributed much to the speed and effectiveness of geodesy. By 1927 a light and extremely precise 9-inch theodolite was perfected by D. L. Parkhurst, chief of the Instrument Division, to be followed soon by optical-reading instruments developed in Europe which vastly speeded the work.

About the same time Signalman Jasper Bilby completed development of a portable steel tower for triangulation observations, with separate stands for observer and instrument, which could be erected in one-fourth of the time required for a wooden tower. Motor vehicles were used widely in field transportation.

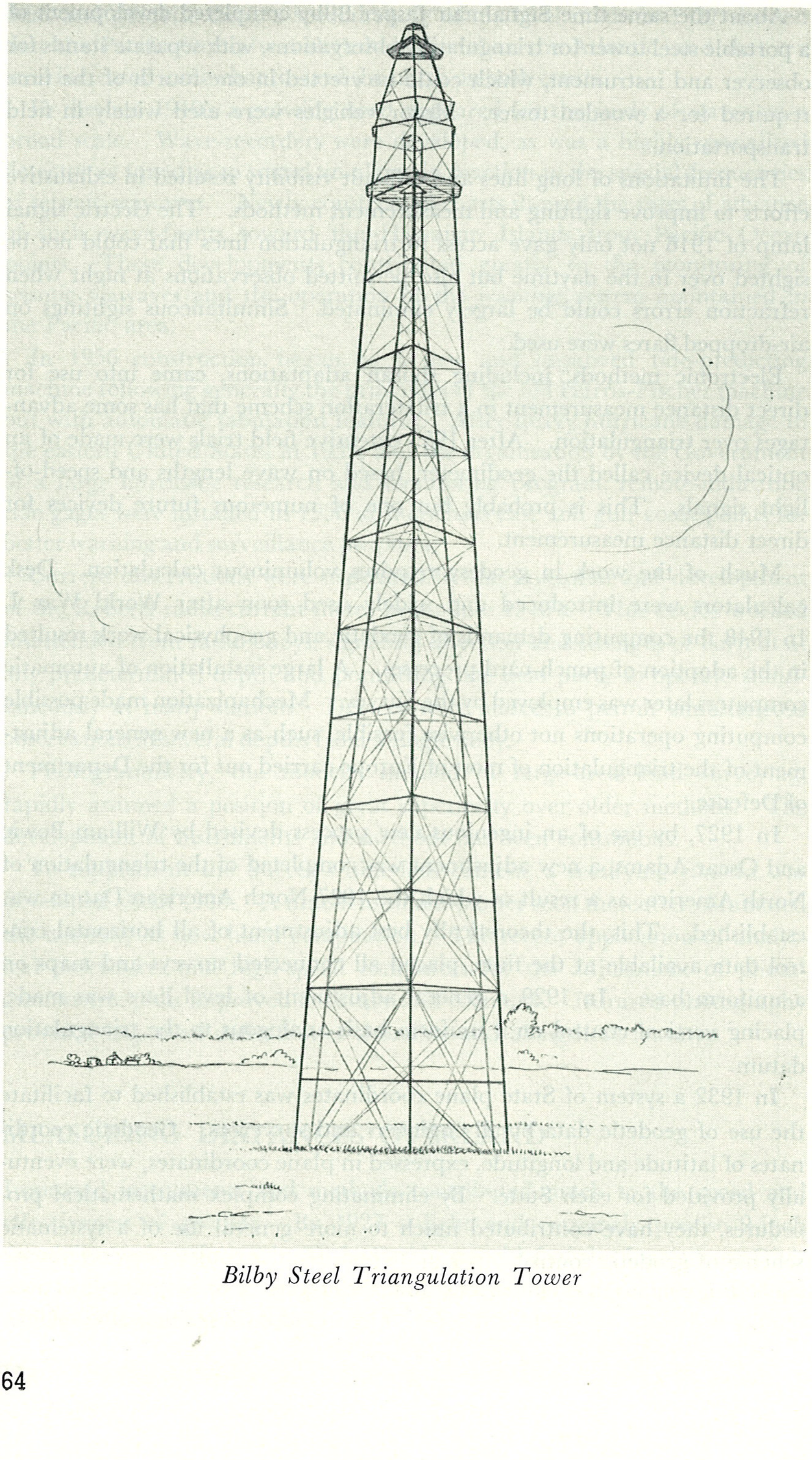
The limitations of long lines and difficult visibility resulted in exhaustive efforts to improve sighting and measurement methods. The electric signal lamp of 1916 not only gave access to triangulation lines that could not be sighted over in the daytime but also permitted observations at night when refraction errors could be largely eliminated. Simultaneous sightings on air-dropped flares were used.

Electronic methods, including shoran adaptations, came into use for direct distance measurement in a trilateration scheme that has some advantages over triangulation. After 1953 extensive field trials were made of an optical device called the geodimeter, based on wave lengths and speed-of-light signals. This is probably but one of numerous future devices for direct distance measurement.

Much of the work in geodesy requires voluminous calculation. Desk calculators were introduced and widely used soon after World War I. In 1948 the computing demands of geodetic and geophysical work resulted in the adoption of punch-card processes. A large installation of automatic computers later was employed by the Survey. Mechanization made possible computing operations not otherwise feasible, such as a new general adjustment of the triangulation of most of Europe carried out for the Department of Defense.

In 1927, by use of an ingenious new process devised by William Bowie and Oscar Adams, a new adjustment was completed of the triangulation of North America, as a result of which the 1927 North American Datum was established. This, the theoretically best adjustment of all horizontal control data available at the time, placed all connected surveys and maps on a uniform base. In 1929 a general adjustment of level lines was made, placing vertical control on a uniform basis analogous to the triangulation datum.

In 1932 a system of State plane coordinates was established to facilitate the use of geodetic data by all engineers and surveyors. Geodetic coordinates of latitude and longitude, expressed in plane coordinates, were eventually provided for each State. By eliminating complex mathematical procedures, they have contributed much to more general use of a systematic scheme of geodetic control.



Bilby Steel Triangulation Tower

BETTER INSTRUMENTS, GREATER USE

The outstanding feature of Bureau work in geomagnetism and seismology in the modern period has been the expanding collateral usefulness of the results. Geophysics enters into many aspects of military and general technology.

There were important improvements in geomagnetic instruments and in methods of publishing results shortly after World War II. On the basis of magnetic submarine detection instruments, an induction magnetometer was developed by the Navy for airborne use at the instance of the Survey. This instrument for the first time provided means of measuring magnetic fields entirely free of disturbance by shock and accelerations. In 1957 still newer magnetometers employing nuclear resonance effects were under study for possible use in the observatories. Portable magnetographs developed in Europe about 1950, producing records approaching those of the observatories, were prepared for use in the field during the International Geophysical Year.

Improved methods of compiling isomagnetic charts, developed in 1949, systematized and speeded magnetic cartography. In 1950 the Bureau first published reproductions of magnetograms as well as numerical scalings. This scientifically useful practice was followed by other countries.

In seismology the improvements in instruments were many. Standard instruments of earlier days sustained modifications such as the McComb-Romberg viscous coupling to compensate for instrument-tilt. The Neumann-LaBarre vibration meter was developed. Frank Wenner, of the National Bureau of Standards, developed a torsion seismometer for the Survey. Among the many other improvements was a low-cost seismometer of high quality developed by Bureau employees.

The advent of engineering-seismology investigations required the development by H. E. McComb and others of accelerographs providing quantitative records of ground motions, to which were later added Carder displacement-meter components. A torsion-pendulum analog machine was developed for the analysis of structural deflections, but was later supplanted by electric-analog methods.

The development of visible recording methods and telemetering through long cables or radio links, carried out in the late 1940's and early 1950's, greatly contributed to the ease of seismological fieldwork and particularly to the continuous monitoring of the seismic sea-wave warning system, which required visible recorders and alarm calls.

The content and format of nautical charts underwent continued improvement. Accuracy was increased by the use of nondistorting materials and by improved methods of review and evaluation of data. The fine-line detail and artistry of former years gave way to bold, simple drawing, which was better adapted to high-speed marine traffic. Chart detail was highlighted and its legibility was improved by new symbols and multi-color printing. Use of depth curves was extended for offshore waters as an aid for mariners using echo sounders.

The development of electronic navigational aids required the charting of hyperbolic loran position lines on general and sailing charts. Radar required the development of new methods of representing coastal topography as an aid to the interpretation of radar screen images.

Aeronautical charts, although begun a century later than the nautical charts, nevertheless underwent a long process of refinement and development to reach their present form. Instrument flying called for the charting of a complex variety of radio navigational aids. More than 160,000 miles of airways, 300 control towers, and 1,000 radio route aids had to be shown. Sometimes the charts required special projections and as many as nine colors to permit identification of all the details.

Moreover, special uses and situations required diversification of aeronautical chart types, resulting in the present nine series of charts—planning, aircraft position, jet navigation, route, world aeronautical, sectional, local, radio facility, and instrument approach procedure. Some of these were needed so promptly, and their correctness was so important, that improved reproduction methods were devised to permit publication simultaneously with major changes of detail.

The assembly of the best and most comprehensive detail for aeronautical charts had the incidental effect of producing some of the finest general maps ever known. They were distributed for many uses, often in limited editions lacking strictly navigational detail.

Reproduction processes, grown more complex with these changes, were speeded and made more efficient by new methods and better presses. Copperplate methods gave way gradually to the faster and better methods of photolithography and glass negative engraving. Flat bed presses were superseded by high-speed presses, including multi-color presses. Plastic sheets came into general use. Graining equipment facilitated the preparation and re-use of aluminum plates. By 1933, a 50-inch precision camera, then the largest in the world, had been completed by O. S. Reading, permitting accurate copying of large chart drawings on only two negatives.

Projection ruling machines and coordinate plotters quickly provided accurate projections for all kinds of chart work.

Men and Ships Join the Armed Forces

VII
The Survey in Two World Wars

TARGET CHARTS OF HIROSHIMA and Nagasaki, on which atom bombs were dropped, and of the Ploesti oil fields in Romania were compiled and published by the Coast and Geodetic Survey during World War II. In 1944 the Bureau produced 2,000,000 copies of target charts.

The Survey was the principal source of aeronautical charts of the world during that war. Under the heavy demand it multiplied its staff and its output. At the same time many of its officers and ships were serving on active duty with the armed forces.

The War of 1812 delayed Hassler in his return from Europe, where he had gone for instruments. Survey experts helped plan the defense of key northern cities in the Civil War. The Mexican and Spanish-American Wars added to the coastlines they must survey. World Wars I and II involved the Bureau fully.

The First World War stimulated advances in nautical and navigational practices, and the Bureau thus entered a period of changes that had not halted after 40 years which included another World War.

Operational contributions to the campaigns of World War I, particularly those of naval character, were by no means minor. Legislation empowering the President to transfer vessels and officer personnel of the Bureau to the War and Navy Departments resulted, by September 1917, in numerous assignments.

Some officers were ordered to duty as navigators on troop transports. Others were sent to the Army, mostly in field artillery units where their geodetic and survey skill came into good use in fire-control problems. Director Jones achieved distinction during Army service in both France and Italy.

Five vessels, the *Surveyor, Isis, Bache, Patterson,* and *Explorer,* with their officer complements, were assigned to the Navy, where they participated primarily in troop and cargo convoy duty, seeing little combat. The *Surveyor,* however, was later cited and decorated for disabling, by use of depth charges, the notorious German submarine U–39, which had sunk the *Lusitania.* This action occurred during an attack on a ship convoy and resulted in the internment of the U–39 in Spain.

At New London, Conn., Lt. Comdr. Nicholas H. Heck and others conducted extensive experiments on the travel of sound through water in efforts to develop a system of detecting and locating enemy submarines. Their work was used with some success during the war and became the basis of the postwar development of echo-sounding and radio-acoustic ranging. It was, moreover, the forerunner of vast developments in sonic and sound-ranging techniques for naval purposes.

Wire-drag work was done in the vicinity of Long Island for submarine-testing areas, and instructions in this operation were given Navy officers relative to mine-sweeping methods. Among many other special services was the laying-out of artillery ranges at the proving ground at Aberdeen, Md.

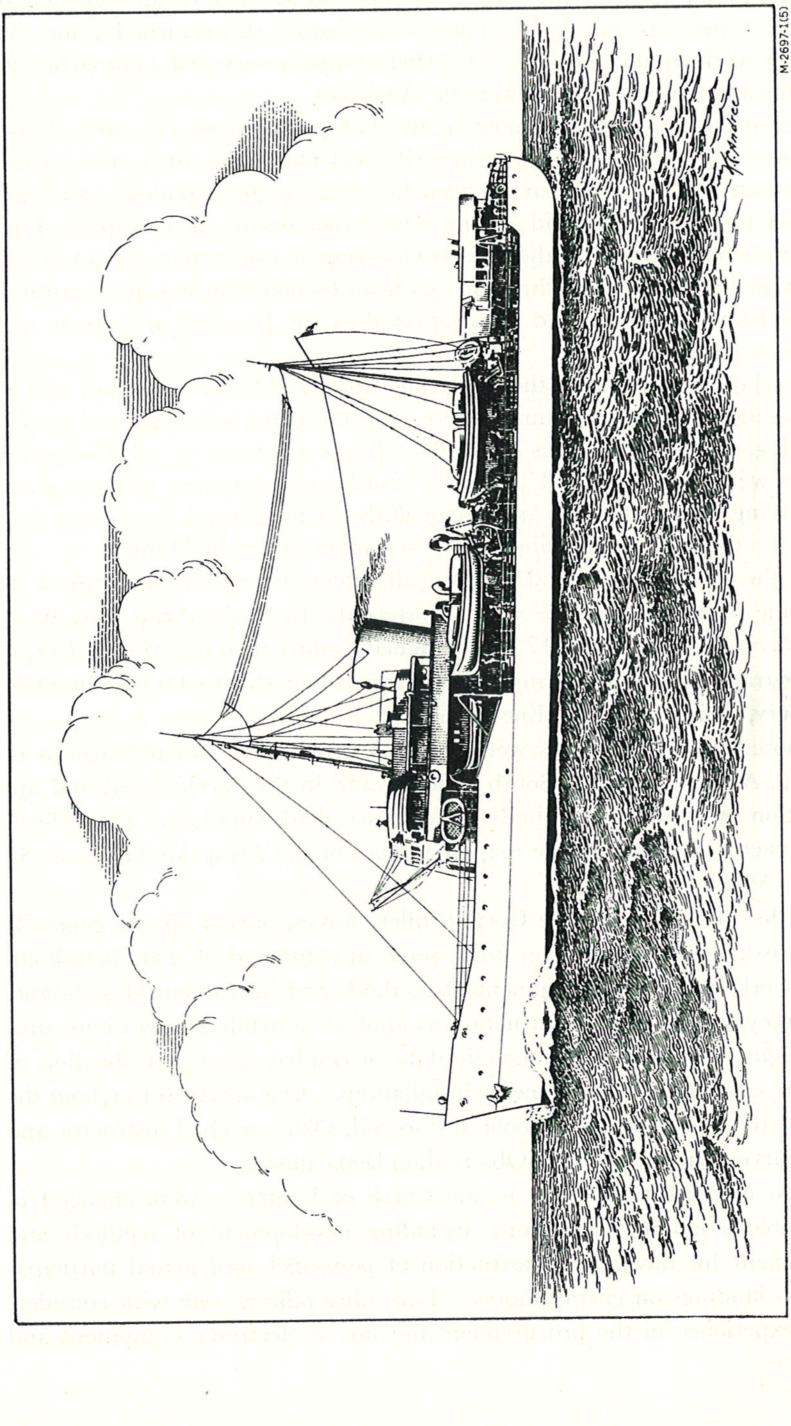
The use of charts naturally grew rapidly. In 1917 and 1918, more than 250,000 nautical charts were supplied to the Navy and 14,000 to the Merchant Marine. Charles H. Deetz, a cartographer, and Oscar Adams, a mathematician, both of the Survey, compiled the *Manual of Lambert's Conformal Projections with Two Standard Parallels,* upon which many war maps including an official map of France were based. Special training charts and maps were made for instruction of officers and troops in all branches of the armed forces.

COMBAT SURVEYS IN WORLD WAR II

World War II placed unprecedented demands and unique problems on the Survey. Not only were major survey projects carried out, but the specialized technology of the Survey provided countless services in instrumentation, graphical techniques, geodetic and geophysical applications, and expert consultation.

Six of the Bureau's nine major ships were ordered to duty with the Navy: The *Guide, Discoverer,* and *Pioneer* were former Navy mine sweepers; the *Oceanographer* was the former Morgan yacht *Corsair II;* the *Hydrographer* had been built by the Bureau in 1931 and the *Pathfinder* in 1942. They all participated in survey work in combat areas, sometimes under fire.

The *Pathfinder* was active in the Pacific, surveying channels, anchorages, and beachheads, often surreptitiously at night. She sustained a kamikaze



The Modern Survey Ship Pathfinder

hit at Okinawa, losing a crew member and narrowly escaping destruction. She discovered the Pathfinder Reef 300 miles northeast of Guam. Although several times "Tokyo Rose" reported her sunk, she returned after the war to work in the Survey. The *Hydrographer* surveyed approaches to landing areas at Kiska and Attu in the Aleutians.

The original *Pathfinder,* used in the Philippines from the turn of the century and renamed *Research* in 1940, was finally beached and scuttled at Bataan in 1942 after having been hit twice in the Japanese campaign against the Philippines and having served temporarily as a hospital ship. The *Fathomer,* owned by the Insular Government and also a veteran of the Philippine work, was lost through American bombing during the recapture of the Islands after she had been captured by the Japanese and put to use as a transport.

The Japanese took over the Philippine Coast and Geodetic Survey offices on Engineer Island in Manila harbor, and the plant was destroyed in the retaking of the Philippines in 1944. However, copies of all Philippine charts were on file in the United States although important geodetic data pertaining to the Islands and particularly to northern Luzon were lost with the destruction of Philippine Government offices in Manila.

Of the 171 commissioned officers (all subject to military assignment in wartime or emergency) 94 were transferred--48 to the Army and 46 to the Navy. Of the latter, 17 were assigned to duty with the Marine Corps. Those transferred to the Army served principally in the Air Forces, the Field Artillery, and the Corps of Engineers.

Those in the Air Forces were engaged in mapping isolated regions of Africa, Asia, Alaska, and South America and in the development and application of electronic methods for distance determinations. One officer was placed in charge of the mapping depot of the Army Air Forces at St. Louis, Mo.

In the Army and Marine Corps artillery forces, Survey officers generally were assigned to observation units, some in command of their battalions. The work included development of methods and instruction of personnel in surveying and map construction as applied to artillery operations, procurement of control and magnetic data in combat areas, and location of battery emplacements and enemy installations. One served throughout the war at the Field Artillery School at Fort Sill, Okla., as chief instructor and staff survey consultant of the Observation Department.

Most of those transferred to the Corps of Engineers were engaged in amphibious landing operations, including development of methods and equipment for navigation, instruction of personnel, and actual participation in landings on enemy shores. Two other officers, one with considerable experience in the procurement and use of electronic equipment and the other with special knowledge of ocean tides and currents, were detailed without formal transfer to duty with the Corps of Engineers.

The majority of those transferred to the Navy served on the transferred Survey ships and other naval survey ships, some as commanding officers, others as executive officers or survey officers. Their duties included surveys in enemy areas under combat conditions, preparation of preliminary charts or copies of field survey sheets for immediate use, establishment of aids and removal of dangers to navigation, piloting, salvage operations, and the layout of anchorages. Bureau officers helped form mobile hydrographic units that facilitated fleet advances in the Pacific.

At the start of the war, 18 Survey employees held reserve commissions in the military services. Later 1,020 men were drafted or requested military furlough in order to enlist. Twenty women left to join the women's service units. Many of these employees rendered important specialized services, and eleven died of wounds received in military action.

One magnetic specialist was transferred to the Navy, where he served in the development of magnetic devices and in the design and use of airborne electronic equipment for submarine detection.

DEATH IN THE PHILIPPINES

No Survey officers were killed while on military assignment. There were casualties, however, among those on duty in the Philippines at the outbreak of the war. Comdr. George D. Cowie, in charge of the Bureau's office in Manila, was killed December 24, 1941, during the bombing of that city by the Japanese. Lt. Joseph W. Stirni, who was first imprisoned in the Santo Tomas Internment Camp, was killed in the bombing of the vessel in which he was being transferred from the Philippines to Japan as a prisoner of war. Lt. (jg) Joseph A. Sosbee was killed in an airplane crash in Alaska on July 18, 1943, while engaged in photo-topographic surveys.

Comdr. Charles Shaw, Comdr. Carl A. Egner, and Lt. George E. Morris were held prisoners by the Japanese in Manila. Lieutenant Morris was later transferred as a war prisoner to Japan. These officers were returned to the United States upon liberation by American forces. Commander Shaw died shortly thereafter. Clarence A. Maynard, a civilian cartographer and mathematician, was taken prisoner at Manila and was released after the war.

The Bureau rendered extensive technical services during the war. Ships not transferred to the Navy undertook special operations, and many had to be armed in their own defense because of their employment in combat areas.

A major contribution to the war effort was the survey of the Alaska Peninsula and the Aleutian Islands. Operations in these regions had been conducted as part of the prewar program of gradual extension westward of suitable surveys and charts. With the occupation of islands in the Aleutians by the Japanese, these waters became of great strategic importance and surveys were carried on to the maximum possible extent. The ships *Explorer, Surveyor, Derickson, E. Lester Jones,* and *Patton* were engaged in this work.

To insure effective cooperation with the Navy, a Survey liaison officer was assigned to duty on the staff of the Commander, Alaska Sector. The ships operated under general orders from the Washington headquarters of the Survey but were under the immediate direction of the liaison officer, who was authorized to issue orders for projects desired by the naval authorities and to arrange for the prompt dissemination of the results of surveys.

Surveys were made upon request of the Army and Navy at a number of other places in Alaska, including the vicinity of Sitka and the approaches to Army bases in Cold Bay and Cook Inlet. A shore-based unit carried on surveys needed by the Navy near Point Barrow. Areas were wire-dragged for deep submergence tests of submarines.

Hydrographic surveys of special anchorages were made for naval use, as well as hydrographic and topographic surveys of military and naval bases at various places along the coasts, surveys of approaches to shipyards, topographic surveys in Puerto Rico, and surveys of speed-trial courses in connection with ship construction. Data obtained from hydrographic surveys were used for laying submarine nets on all coasts.

From November 1940 to March 1941, comprehensive surveys were made at the request of the Navy Department at the sites of proposed naval bases in the British West Indies. Detailed hydrographic, wire-drag, and topographic surveys were completed at Port of Spain, Trinidad, by the ship *Oceanographer;* at Antigua by the *Lydonia;* at Mayaguana by the *Hydrographer;* and in the Portland Bight area of Jamaica by the *Hydrographer* and *Gilbert.*

SUNKEN SHIPS AND AIRPORT HAZARDS

Work was done in many places for cable laying, equipment testing, ship launching, fleet anchorages, and troop landings. Wire-dragging was conducted for the location of sunken ships. Topographic surveys were made in many places, 16,000 square miles of shore areas being photographed with the nine-lens camera. As the number of airports in the United States grew, field parties mapped their approaches and obstruction plans showing critical elevations were produced.

Geodetic field surveys and astronomic observations were extended to critical areas in the Aleutians and the Caribbean. Triangulation was extended through Canada, following the Alcan Highway, to connect the work of the United States and Alaska.

Numerous other projects included the accurate location of battery emplacements, fire control centers, airplane spotting towers, and similar installations in a large number of defense areas along our coasts; establishment of airplane speed trial courses; determination of distances for testing and calibrating various types of distance finders; location of loran stations and radar installations; establishment of control points for bombing ranges; installation of control systems for ballistic measurements and rocket experiments; and alignment surveys at a naval ship model basin.

Gazetteers were made for the Philippines, Hawaii, Alaska, and the Pacific coast. *Coast Pilots* for these and other areas increased from the 1940 level of 11,000 copies to some 70,000. Comprehensive tide and current data covering the entire world were prepared for the Navy, particularly for amphibious operations.

An especially important project was the preparation of 68 reports of tide and current conditions for various areas throughout the world. It involved the collection and correlation of detailed information from material in the files of the Bureau, from captured enemy documents, and from various libraries. Translations were made from Japanese, German, French, Russian, Dutch, and other foreign nautical and scientific publications. The distribution of tide and current predictions rose to 72,000 volumes annually, three times the former level.

Bureau magnetic observatories carried out special tests and assisted in the development of instruments involved in magnetic mine warfare, ship degaussing, and other military activities. Magnetic field data were collected from all over the world for military use. Seismological studies and field tests were made for the solution of machinery vibration problems at Navy Yards and war plants. The strategic effects of earthquakes in enemy lands were evaluated with the help of Survey earthquake reports and consulting services.

The war required enormous quantities of charts and special maps. The Survey provided a large portion of this requirement. With the Hydrographic Office, the large demands of the combat fleets had to be met. Between the Bureau and the then Aeronautical Chart Service, the Air Forces had to be supplied. The Army and other services required special charts and maps, many supplied by the Survey.

In 1940, 800,000 copies were published; in 1945 the number had risen to 13,500,000 copies—a tenfold increase in nautical charts and 25 times as many aeronautical charts. The chart copies published in 1939 would have stacked 335 feet high; those of 1945 some 5,990 feet, or 10 times the height of the Washington Monument. (These quantities were greatly exceeded later during the Korean conflict of 1950–53.) Many of the world aeronautical charts series, known as WAC's and covering the entire world, were published.

Many special aeronautical charts were required, including target charts. In this series, comprising 2,479 separate charts, were the Ploesti oil fields and the atom-bombed cities of Hiroshima and Nagasaki.

The wartime charts in many cases required special treatment, such as unusual projections, star curves, gnomonic compass roses, hypsometric coloring, fluorescent sheets for aeronautical charts, pictorial representation, and simulated views as land detail might appear on radarscopes.

This and the heavy workload placed an unprecedented strain on the Chart Division. The press room worked around the clock, and multi-color presses, copying cameras, and engraving machines were added. Chart Division employees were increased 700 percent, and special training programs were introduced.

Bureau cartographers constructed numerous different projections to meet needs for varying kinds of chart bases. Among them were five Lambert projections with different standard parallels, five gnomonic projections with different centers, an oblique mercator projection, and an azimuthal equidistant projection.

VIII

Science Knows No Boundaries

MORE THAN A CENTURY ago, an official of the Coast Survey sent hundreds of chronometers back and forth between Boston and London by sailing ship and steamer. He needed a precise comparison of his observatory clock with Greenwich time in order to calculate the exact longitude of points in the United States.

The Survey has always profited from the findings of its friends abroad and has shared its observations with them, for science itself takes no account of man-made boundaries. A recognized part of the work of a technical agency such as the Survey is cooperation with official and private organizations of our own and friendly countries.

As it celebrated its sesquicentennial early in 1957, the Survey was preparing to take part, with other United States agencies and those of more than 50 foreign countries, in the International Geophysical Year. Its assignment was to conduct a special field program in geophysical subjects, including geomagnetism, seismology, geodesy, and sea-level studies. For the seismological observations, the Survey provided instruments to be used at stations in Greenland, Antarctica, and the Pacific islands.

The Survey was represented by Capt. Elliott Roberts on the United States National Committee for the International Geophysical Year. It has also provided members for other committees of the National Research Council, including one formed to study Paricutin Volcano in Mexico. In the mid-1940's, the Survey made magnetic and seismological observations in the area.

In 1926 the Survey participated in an international longitude determination under the auspices of the International Geodetic Association, occupying stations at Honolulu and Manila, in cooperation with many other nations. Astronomic sights coupled with the then new radio time signals and radio recording methods were utilized. These were intended to furnish, among other things, epochal data on the intercontinental distances for later comparison. Preparations were under way early in 1957 for new international longitude determinations, based on more highly refined astronomic methods, during the International Geophysical Year program.

The Bureau cooperated with the Army in 1946 in organizing the Inter-American Geodetic Survey by providing advisory services of Survey engineers. The organization was created to promote the mapping of Latin America, carrying out its work largely through agreements with many of the American republics. In the years since, a succession of Survey officers have served with the Army unit, training technical employees and helping in the organization of field projects.

After 1948, assistance was given the Inter-American Geodetic Survey in starting a magnetic survey of large parts of Latin America and in helping to establish magnetic observatories at Bogota, Colombia, and Belem, Brazil. In 1950 the Bureau cooperated with the Republic of the Philippines in setting up a standard magnetic observatory at Muntinlupa in Rizal Province.

The Bureau assigned observers and equipment to cooperate in the observation of tidal regimes at many points on the Latin American coasts. Beginning in 1941 this work was done as part of an international cooperation program and after 1946 in conjunction with the Inter-American Geodetic Survey. In 1946 tide stations were established at several western Pacific island sites in cooperaiton with the Corps of Engineers.

The Survey has taken part since 1941 in a series of foreign aid programs administered by the International Cooperation Administration and its predecessors. A training school in surveying, cartographic, and geophysical subjects has been maintained in the Bureau since World War II. Here more than 300 students from many foreign lands, including most countries of Latin America, have received instruction from Bureau specialists. Their courses, in periods averaging 12 months, include in most cases field party tours and training periods.

Missions of Survey experts have also been sent to South America, Africa, and other parts of the world to carry out project undertakings and training programs in Bureau subjects.

INTERNATIONAL ORGANIZATIONS

Some of the organizations in which the Bureau has interest are of the type to establish international working agreements and standards at government level. Among them have been the International Civil Aviation Organization, the International Hydrographic Bureau, and the Pan American Institute of Geography and History. Others—such as the International Society of Photogrammetry, the International Union of Goedesy and Geophysics and its member associations, and the International Astronomical Union—function primarily as professional organizations for international collaboration and exchange of information.

The International Civil Aviation Organization, a specialized United Nations body established in 1945, functions at diplomatic level to coordinate operating and technical practices and standards. It maintains permanent headquarters and holds continuous sessions at Montreal. A Survey officer, Paul A. Smith, who was first sent to advise on matters pertaining to aeronautical charts and air navigation, eventually became the United States representative. Retaining his Survey commission with rank elevated to rear admiral, he filled the State Department post of minister until he retired in 1952.

The International Hydrographic Bureau, founded in the early 1920's at Monte Carlo with the aid of the Prince of Monaco, a zealous oceanographer, coordinates hydrographic surveying and nautical charting practices. It maintains a permanent secretariat and holds triennial conferences to which the United States sends official delegates authorized to represent the Survey and the Hydrographic Office.

The Pan American Institute of Geography and History, a specialized body under the Organization of American States, was organized in 1928 with the support of William Bowie. The headquarters and secretariat are in a historic edifice in Mexico, D. F., where a large hall has been named Salon Bowie. The Institute embodies three commissions, of which one on cartography has technical committees to which member nations appoint representatives. The Survey has provided many United States representatives on these committees and has sent delegates to the biennial consultations of the Commission on Cartography at various places.

These representatives have helped to establish technical standards, to coordinate surveying and mapping work, and to cultivate friendship among American hemisphere cartographers. The results attained have been a strong factor in the successful operation of the Inter-American Geodetic Survey.

The International Society of Photogrammetry, founded in 1910, has been a vigorous force in its field. The Survey has participated regularly and from 1950 to 1952 provided the Society's president, O. S. Reading.

The International Union of Geodesy and Geophysics, organized in 1919, is primarily a unifying organization for a group of associations concerned with geodesy, geomagnetism and aeronomy, seismology, physical oceanography, and other sciences. Triennial reunions in selected capitals afforded opportunity for professional interchange, organizational activities, and the presentation of scientific papers. Captain Bowie and Dr. Lambert were presidents of the union.

The International Association of Geodesy, outgrowth of an organization established in 1864, has long had collateral interest for the Survey. Tittmann, Hayford, and Bowie, as well as many more recent geodesists, were active in its affairs. Bowie and Lambert were presidents. As a result of a program developed by this association, the observatories for the study of variations of latitude have been operated by the Survey at Gaithersburg, Md., and Ukiah, Calif., since 1899. A subordinate organization, the International Gravity Commission, established in 1953, has a Survey member. The International Seismological Association, organized in 1904, was presided over by Nicholas Heck from 1936 to 1945. Survey magneticians have been prominent in the International Association of Geomagnetism and Aeronomy, concerned with terrestrial magnetism and electricity since its origination in 1919. The Survey has had representatives on two commissions of the International Astronomical Union since its creation in 1922. These commissions are concerned with variations of latitude and time.

OTHER FEDERAL AGENCIES

From time to time the Bureau has made special surveys, particularly in geodetic work, for other agencies of government. The enabling act of 1947, which defined the functions of the Survey, clarified some points that had been ambiguous. The Bureau now can enter officially into cooperative agreements with States or their political subdivision and with private organizations and be reimbursed for its services. The policy of the Bureau is to make its facilities and skills available to private organizations under reimbursement when competent private services are not available.

Historically, moreover, the Survey has always contributed to the effectiveness of other agencies of the Federal Government and of private scientific organizations. From the beginning its staff has been active in interagency boards and committees and in professional societies and foundations. Such collateral activities have increased with the complexity of our national life. Some of the groups with which the Survey has been associated are cited in the paragraphs that follow.

The Air Coordinating Committee, an interdepartmental body established during World War II, deals with technical and operating problems of aviation. Standardization of aeronautical charts is the concern of a subcommittee on which the Bureau has always been represented, generally in the chairmanship. An arctic subcommittee including Survey representatives was responsible in the late 1940's for starting North American Arctic meteorological and geophysical investigations of high strategic value.

The Research and Development Board, created by the National Security Act of 1947 after a year of preliminary existence as the Joint Research and Development Board, coordinated and promoted technical development activities of the defense agencies. Among the technical fields were several in cartography and geophysics, served by technical panels upon which the Survey had representatives. One of the undertakings carried out with the advice of these Bureau members was an important aeromagnetic survey of the North American polar regions. The Board was superseded in 1953 by a Department of Defense secretariat.

The Federal Board of Surveys and Maps was formed in 1919 and discontinued in 1942 by Executive orders. Its beginning was largely the result of the efforts of William Bowie, who sought to coordinate and promote progress in mapping the country. Twenty-three bureaus and twenty-one professional organizations including the Survey were represented.

The Mississippi River Commission, formed in 1879 with Superintendent Patterson as an original member, has had representation ever since. Admiral Colbert served on the Commission for many years, and Admiral Karo was appointed to it in 1956.

A Map and Chart Symbols Committee, created during World War II to standardize practices, has a subcommittee on nautical charts which has functioned under the chairmanship of a Survey representative.

The Board on Geographic Names, created in 1891 by Executive order, has established naming procedures and approved the names of geographic features. It has always had a Bureau representative.

The Survey Director has served at times as member of an Advisory Committee on Technical Methods of the National Security Council. The Department of Commerce Science Committee and numerous other temporary or routine bodies for special purposes have been maintained at various times with the help of Bureau members.

AMERICAN PROFESSIONAL SOCIETIES

The American Geophysical Union was organized in 1919, largely through the efforts of William Bowie and J. A. Flemer, as a committee of the National Research Council and the body through which the United States adheres to the International Union of Geodesy and Geophysics. It is organized in technical sections and its membership consists of more than 5,000 individuals. Survey employees have participated actively and continuously. Heck and Bowie were early presidents, and the Union annually honors outstanding geophysicists by the award of the Bowie Medal, held to be the highest honor in American geophysics.

The Institute of Navigation, started in 1945, brings together organizations and individuals concerned. Many Survey members have taken part. Rear Adm. Robert Knox, Assistant Director of the Bureau, was president in 1955.

The American Congress on Surveying and Mapping, organized in 1941 with strong support from the Bureau, has had many of its offices filled by Survey members. Among its presidents have been Rear Adm. Studds and Capt. Frank Borden.

The American Society of Photogrammetry was organized in 1934 by a group including Captain Reading, who became its president in 1937.

The Society of American Military Engineers is concerned, among other engineering matters, with military surveys and maps. William Bowie was an early president, and many personnel of the Survey have since been members.

The American Society of Civil Engineers has long included numerous members from the Bureau, and many have served on committees.

The Seismological Society of America is a leading organization in its field, and an important factor in maintaining relations with seismologists and in planning field-work operations. Nicholas Heck was president from 1936 to 1938.

The Survey has always had close working relationships with the Carnegie Institution of Washington and particularly with its Department of Terrestrial Magnetism. The department was founded in 1904 by L. A. Bauer, chief of the Survey's Division of Terrestrial Magnetism, with the help of Andrew Carnegie. Dr. Bauer and John A. Fleming, also of the Survey, became officials of the institution. The Survey and Carnegie have exchanged instruments for geomagnetic work and have jointly developed and built others. Carnegie scientists have been free to work in Survey observatories. Field programs have been jointly planned and executed. Working relations have always existed with the Carnegie observatories at Huancayo, Peru, and Watheroo, Australia, and formerly existed with the institution's non-magnetic survey ship *Carnegie*. The institution participated with the Survey in organizing the work of the Second Polar Year at College, Alaska.

As it grew with expanding areal frontiers in its early days, the Coast and Geodetic Survey is advancing today with the broadening of scientific and technical horizons. For a century and a half, quiet and dedicated men have devoted themselves to the tasks charged to the Bureau. This brief history tells how they met and handled their tasks in the past and something of how they are doing their work today.

Directors* of The Survey

Ferdinand R. Hassler	1807–18, 1832–43
Alexander D. Bache	1843–67
Benjamin Peirce	1867–74
Carlile P. Patterson	1874–81
Julius E. Hilgard	1881–85
Frank M. Thorn	1885–89
Thomas C. Mendenhall	1889–94
William W. Duffield	1894–97
Henry S. Pritchett	1897–1900
Otto H. Tittmann	1900–15
E. Lester Jones	1915–29
Raymond S. Patton	1929–37
Leo O. Colbert	1938–50
Robert F. A. Studds	1950–55
H. Arnold Karo	1955–

*Until 1920, Superintendent.

A Glossary of Special Terms

Accelerograph—An instrument for recording ground accelerations during an earthquake.

Arc—A portion of a mathematically defined curve.

Azimuth—The horizontal direction of an object usually reckoned clockwise from north or south.

Base line—A precisely measured line between two points for control of triangulation.

Bathymetry—The study and delineation of ocean depths.

Cadastral—Pertaining to land areas and boundaries.

Chart—A specialized map for navigators, particularly on water or in the air.

Datum—A basis of reckoning, as sea level.

Epicenter—A point directly above the center of disturbance of an earthquake.

Geodetic—Pertaining to surveying which takes in consideration the size and shape of the earth.

Geomagnetic—Pertaining to earth magnetism.

Geophysical—Pertaining to the physical properties of the earth and its atmosphere.

Gravimetric—Pertaining to the measurement of gravity.

Hydrographic—Pertaining to the survey of the water areas of the earth.

Hypsometric—Pertaining to the measurement of land heights.

Isogonic—Having the property of indicating places of equal magnetic declination (variation of the compass).

Isomagnetic—Having the property of indicating places of equal magnetic character.

Isostasy—The principle of equilibrium of vertical forces in the earth's crust.

Leveling—Determination of height differences, usually by use of level bubbles.

Loran—Long range navigation method, using radio wave pulses.

Magnetician—A specialist in earth magnetism.

Magnetogram—A graphic record of magnetic fluctuations.

Photogrammetry—Surveying and mapping by use of photographs.

Plane table—A drawing board mounted on a tripod, for field mapping; generally used with sighting and measuring devices.

Polyconic—Pertaining to a map projection or grid widely used in surveying.

Shoran—Short range navigation method using radio wave pulses.

Spheroid of reference—An assumed geometric shape of the earth used as a basis for geodetic calculations.

Tectonic—Pertaining to the structure of the earth's crust.

Theodolite—An extremely precise instrument for measuring horizontal and vertical angles.

Topography—The configuration of a surface, including relief, streams, roads, etc.

Traverse—A line or series of connected lines surveyed across an area.

Triangulation—A surveying system involving the location of points on the earth's surface through a connected series of triangles determined by angle measurement and trigonometry.

Trilateration—A surveying system involving the location of points on the earth's surface through the direct measurement of the sides of triangles.

Source Material

In the interest of brevity, documentation has not been attempted for this history. Much of the material was taken from original records of the Coast and Geodetic Survey, in the Survey's offices in Washington and in the National Archives. Supplementary data were obtained from records of other agencies and organizations associated with the background of the Bureau, a partial list of which is given below. First-hand information was gained also from Survey personnel and others, many of them now retired, who are personally familiar with developments of the last half century.

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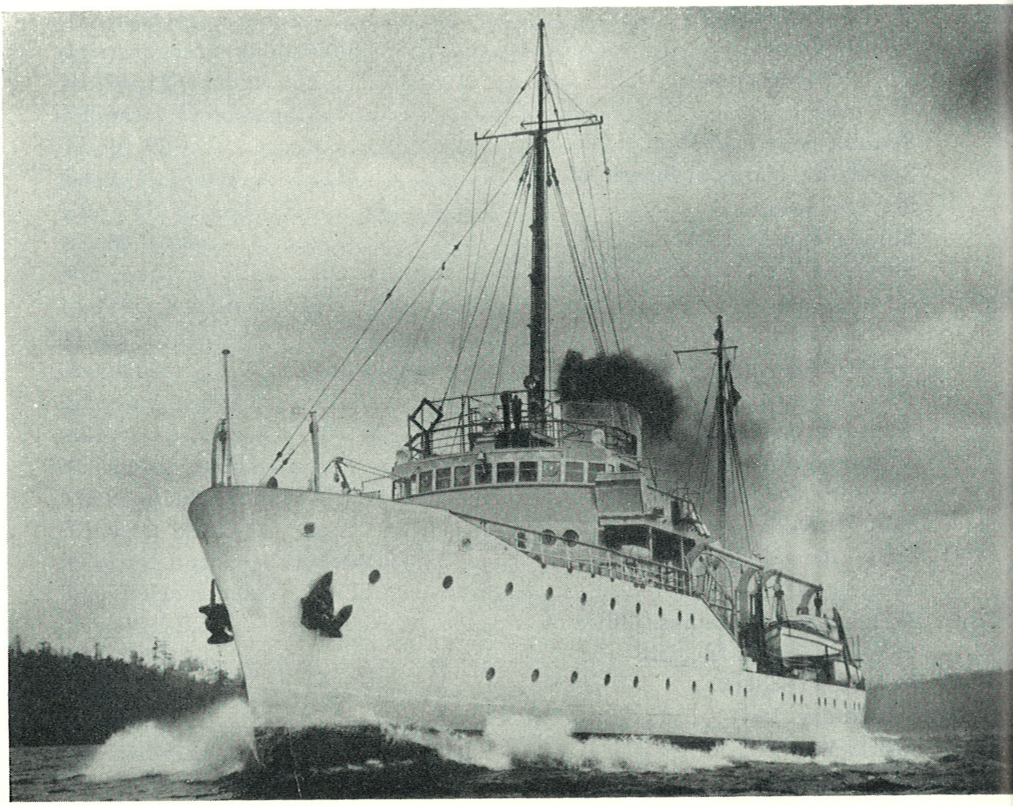
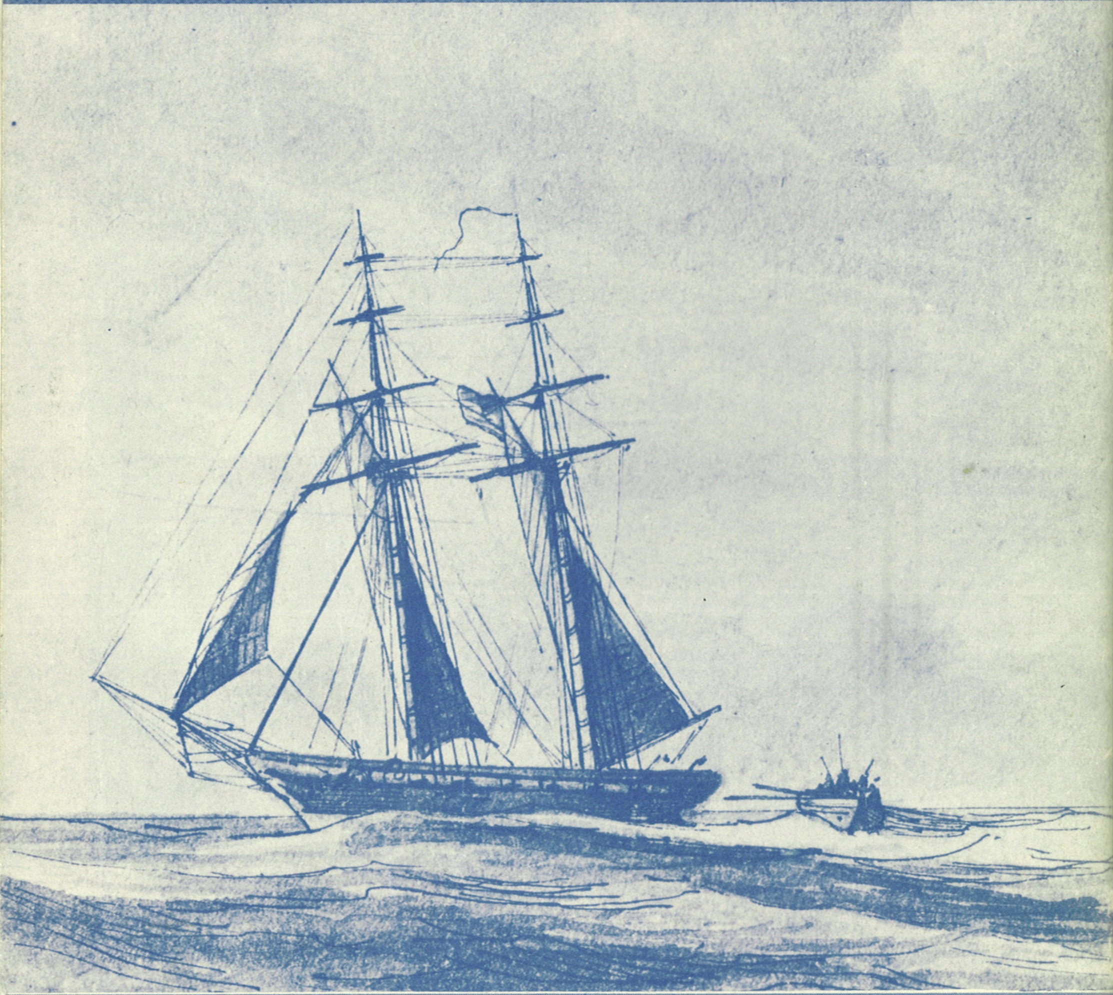


Survey Ship Explorer



UNITED STATES COAST AND GEODETIC SURVEY