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National Ocean Survey-The Government's First Technical Agency

by Rear Admiral Allen L. Powell
Director, National Ocean Survey

Presented at Joint Plenary Session
1976 Convention
The American Congress on Surveying and Mapping
and The American Society of Photogrammetry
Washington, D.C.
February 22-28, 1976

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National Ocean Survey

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THE GOVERNMENT'S FIRST TECHNICAL AGENCY

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Rear Admiral Allen L. Powell
Director, National Ocean Survey
National Oceanic and Atmospheric Administration
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BIOGRAPHICAL SKETCH

Allen L. Powell was born July 12, 1915, in Nacogdoches County, Texas. He graduated from the University of Texas with a degree in Petroleum Engineering in 1938, and joined the Coast and Geodetic Survey in 1942 as a civilian. In 1944, he was appointed to the Coast and Geodetic Survey Commissioned Officer Corps and shortly thereafter transferred to the Marine Corps, serving as a Regimental Survey Officer in World War II.

Following his return to the Survey in 1946, Powell spent the next 12 years in a wide variety of assignments including duty aboard eight survey vessels, and service with numerous photogrammetric and geodetic field parties. For the next 3 years, he was head of a special party making precise geodetic measurements at the Patrick Air Force Base Missile Test Center. For outstanding performance on this assignment, he received the Department of Commerce Silver Medal in 1961.

After a 2-year tour on the EXPLORER, Powell returned to Rockville headquarters and was assigned to the New Ships Staff. With the formation of ESSA in 1965, he was placed in charge of ship construction and played a key role in the design and construction of 10 of the Survey's 14 vessels. For this exceptional service, he received the Department of Commerce Gold Medal. In 1968, he was appointed Director of the Atlantic Marine Center in Norfolk, Virginia, and promoted to rear admiral. He returned to Rockville headquarters in 1971 as Associate Director of Fleet Operations, and was sworn in as Director of the National Ocean Survey on May 18, 1972.

ABSTRACT

This paper is a condensed history of the National Ocean Survey which was established by Congress in 1807 to survey United States coastal waters and prepare nautical charts for the purpose of improving the safety of coastal navigation and promoting waterborne commerce. It was conceived as a scientific and technical agency, planned under direction of the Nation's leading scientists, and organized by a scientist/engineer with exceptional farsighted principles and ingenuity. Major events, significant achievements, and individual accomplishments are traced over 169 years of public service in the fields of geodesy, hydrography, nautical charting, photogrammetry, oceanography, marine engineering, instrumentation, naval architecture, seismology, geomagnetism, gravity, aeronautical charting, and printing.

Ferdinand R. Hassler
First Superintendent
National Ocean Survey

INTRODUCTION

The National Ocean Survey (NOS), a part of the National Oceanic and Atmospheric Administration, is an engineering and scientific organization which acquires, processes, analyzes and disseminates solid earth and ocean data for: maintenance and improvement of commerce, understanding of earth dynamics, efficient utilization of marine resources, and protection of the environment.

Staffed by scientists, engineers, and technical personnel, NOS has significant capability in: geodesy, hydrography, nautical charting, photogrammetry, aeronautical charting, chart reproduction processes, seismology, geomagnetism, gravity, marine engineering, instrumentation, naval architecture, astronomy, physical oceanography, marine research, modern seamanship, and data processing.

The sophisticated programs and services of NOS are basic to government, the military, and the private sector. In the form of millions of charts, maps, booklets, data sheets, computer printouts, engineering reports and research papers, NOS activities directly and indirectly relate in some way to every American and the way we live.

Today, NOS rides in the vanguard of Federal agencies concerned with the difficult problems of land use, coastal zone management, offshore oil and gas development, coastal shipping traffic control, crowded airways, marine recreation, port development, international marine research, law-of-the-sea negotiations, offshore nuclear power plants, deepwater ports, pollution control, near-shore construction, marine environmental forecasting, and fisheries development.

This brief history of the National Ocean Survey is divided into six parts for convenience in reading: (1) Hassler-The Founding Father; (2) The Bache Era; (3) The Expansion Years; (4) The 20th Century; (5) Recent Years; and (6) The Future.

From its establishment in 1807 until 1836, the organization was named the Survey of the Coast. From 1836 until 1878 it was called the Coast Survey. From 1878 until 1970 it was named the Coast and Geodetic Survey. For 158 years the agency had relatively independent status, until 1965 when it became a part of the Environmental Science Services Administration. In October 1970, the name was changed to the National Ocean Survey when it became a part of the National Oceanic and Atmospheric Administration. Throughout this paper, the organization will be referred to as the Survey.

HASSLER - THE FOUNDING FATHER

Even before the beginning of the United States of America in 1776, waterborne commerce was basic to every facet of life. Concentrated along the Atlantic coastal plain, the young Nation depended on ships for fishing, transportation of raw materials and finished products, imports, exports, and movement of people. The safety of these ships depended on complete knowledge of the coastal waters--depths, tides, currents, location of reefs and shoals, and how the compass behaved at various locations.

In 1776 there was not much of this important information available; only a few charts produced by the British for use in the Revolutionary War based on

meager and incomplete investigations. By 1806 only two localized surveys had been made--in Louisiana in connection with the Louisiana Purchase, and along a portion of the North Carolina coast. In general, mariners acquired their knowledge of coastal navigation from the shipwrecks of others.

As the new Republic grew, so did the number of shipwrecks. It was obvious that better charts and more information were needed, and that some form of survey was required to secure the data. On February 27, 1795, a special committee of the Third Congress of the United States issued a report stating that the coasts of Georgia, South Carolina, North Carolina, and Virginia had never been surveyed and recommended that the President authorize this survey between Chesapeake Bay and the St. Mary's River. This was the legislative beginnings of the Survey.

The Act of 1807 Authorizes the Survey

Following resolutions by subsequent Congresses, a bill authorizing a survey of the coast was reported out of committee on January 6, 1807, and, after amendment, was approved and signed by President Thomas Jefferson on February 10, 1807, and the "Survey of the Coast" was born. Its early years were extremely difficult. Fortunately, it had extraordinarily expert upbringing and, consequently, survived numerous crises.

The new Survey was placed under the Treasury Department, headed by Albert Gallatin. Both he and President Jefferson, recognizing the importance of a proper start, asked the American Philosophical Society to suggest the names of qualified persons and, in turn, to ask each to submit a proposed method of operation. Seven proposals were submitted by accomplished men, including James Madison, who would become President 2 years later.

Of the plans submitted, Jefferson and Gallatin selected the one by Ferdinand R. Hassler, a Swiss engineer who had arrived in the United States in 1805 and was a professor of mathematics at the newly created military academy at West Point at the time. Hassler was appointed the first Superintendent of the new Survey by President Jefferson in 1807.

Ferdinand Hassler is rightly called the father of the Coast Survey, for it was he who started the organization on its true scientific course and set standards that still prevail. Though he was proud and intolerant, and constantly drew official censure upon himself by his irascibility, he nevertheless had an understanding of basic technical procedure and a sense of lasting values. With his indomitable will and sincerity, he successfully resisted those who wanted a quick and cheap job.

Hassler's fundamental plan provided for a division of operations into three branches--geodesy, topography, and hydrography. Of these, he considered the geodetic operation to be the most important, for it controlled the accuracy and final value of the other two. His plan had the approval of the most eminent scientists of Europe and of this country. A tribute to his far-sightedness and genius is the fact that his original plan of organization, broadened and implemented in succeeding years, is still a fundamental element of the Survey.

The difficulties that faced Hassler would have completely discouraged a person with less strength and fortitude. Because instruments necessary for geodetic surveying were not available in this country, Hassler had to prepare his own drawings and designs. Some of the more important instruments, such as theodolites and chronometers, that were eventually constructed for him, bear the impress of his inventive genius. There was no working observatory for training astronomers in this country, and not a single college had a course in geodetic surveying.

Although the need for results was urgent, the level-headed Hassler did not allow himself to be stampeded into haphazard decisions. Instead, he approached the work scientifically and never deviated from his high standards. He knew that the survey of the coast, if it were to have a lasting value, could not be attacked as a problem of ordinary surveying. The operations were to be connected by a trigonometric survey, and executed by the most accurate instruments and the most refined methods available. His plan required the use of triangulation along the coast with each separate unit fitting exactly into the overall scheme. A firm foundation was thus laid for the geodetic operations of the Survey. This was one of Hassler's great contributions. Had he planned to meet only the needs of his time, he would have saved little, and his work would have had to be done over at greater expense in later years. Instead, the first Hassler surveys meet modern requirements and, today, form part of the permanent primary network of the country.

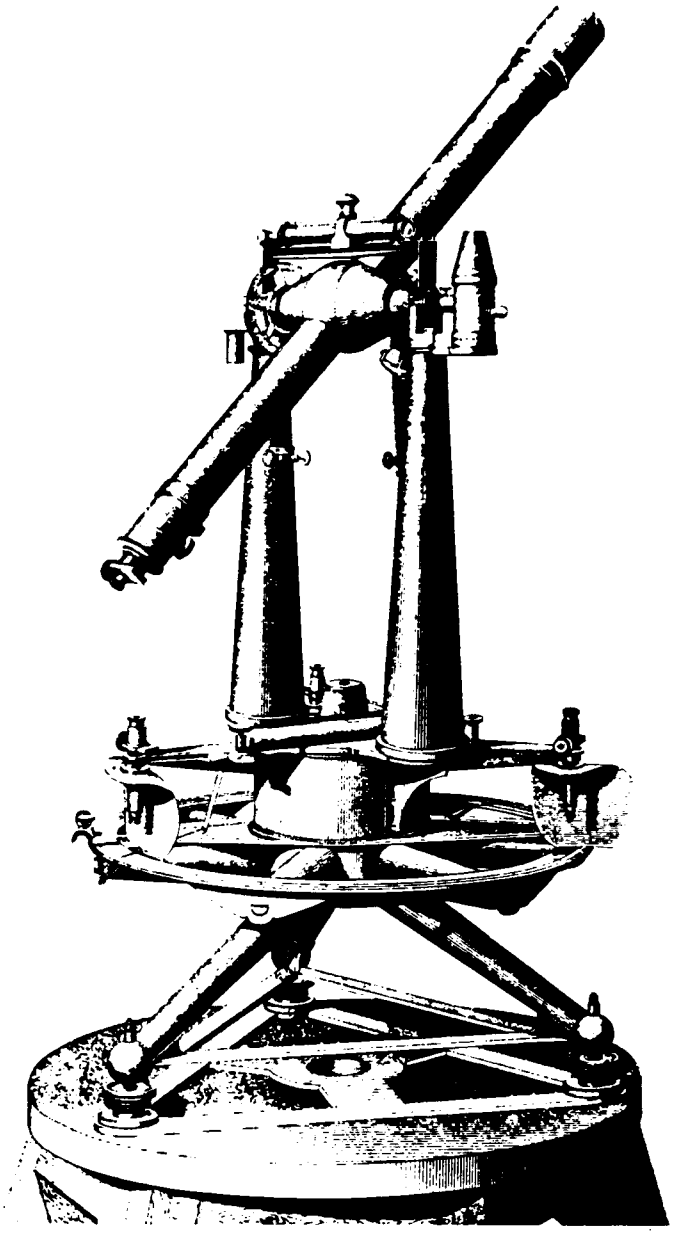
Hassler did not receive any funds for 4 years, due to dissension and unsettled political conditions. Needing a livelihood, he continued teaching at West Point and at Union College at Schenectady, New York, until 1811, when Secretary Gallatin made $25,000 available for the new Survey.

Since there was practically nothing available in this country which he needed, Hassler went to Europe to purchase instruments and equipment. 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. When he originally came to the United States 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, which was an original standard of the International Commission on Weights and Measures. This bar later became the basis for triangulation length measurement.

A Major Delay in Organization

The War of 1812 prevented Hassler from returning as planned, so he spent his time supervising the construction, testing and standardizing of instruments which he had purchased. He returned to the United States in 1815 and finally began geodetic work in 1816.

Despite his complaints about the lack of cooperation with some government officials, he managed to measure two base lines--one in the vicinity of English Creek near Englewood, New Jersey, and one 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, which established the Survey, had been modified in April 1818, taking the Survey out of the Treasury



Thirty-inch theodolite used in 1880's

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 not resumed until 1832, with Hassler again in charge.

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 spent most of the 14 intervening years in privation. His only surveying was on the United States/Canada border under the Treaty of Ghent. 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 worked with vigor and brought the same sound philosophy to this new scientific assignment as he had used in the Survey--making important steps toward uniformity of measures used in commerce and industry. He later incorporated the Office of Weights and Measures into the Survey, where it remained until it became the National Bureau of Standards in the early 1900's.

Original Act Restored

When Florida became a member of the Union in 1832, over 8,000 miles of new shoreline were added to the Nation's coasts. This vast new area to be surveyed, plus many thousands of miles in other states yet to be surveyed, and the growing importance of coastal surveys to defense and military operations created a critical situation. Both Congress and the Navy took a more serious look at the handling of coastal surveys and were much dissatisfied. In fact, it was so bad that the Secretary of the Navy wanted the original legislation restored.

Accordingly, in July 1832, 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 oversized carriage for transporting it.

While methods and equipment were elementary, they produced remarkably good results under Hassler's exacting demands. The huge theodolites were extremely difficult to transport and erect. Astronomical observations employed clumsy and difficult techniques. Topographic work was effected by plane table, without stadia devices or photographic aid. Hydrographic survey soundings were 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 dead reckoning.

First Surveys Made in New York

In 1833, James Ferguson, who had assisted with Hassler in the United States/Canada boundary surveys, was appointed the first Principal Assistant in the Survey. As chief of a field party, he conducted surveys along the north shore of Long Island Sound. Edmund Blunt, the other principal assistant to

Hassler, headed a party on Long Island. Four maps were published in 1834, at the scale of 1:1,000,000, showing the triangulation scheme in the vicinity of New York City, Long Island, and the Connecticut shore; however, hydrographic details of the offshore areas were not included. Latitude and longitude had been determined for each control point in the network.

The first hydrographic survey was conducted in 1834 by the schooner JERSEY under the command of Lt. Thomas R. Gedney, and by the schooner EXPERIMENT under the command of Lt. George Blake in Great South Bay and along the south shore of Long Island. Important early findings included the discovery 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. Named Gedney Channel, it is now one of the main entrances to New York harbor.

The brig WASHINGTON was the first Survey vessel to be used extensively for hydrography. Constructed in 1837 for use as a revenue cutter, she served in that capacity during the winters of 1837, 1838, and 1839. During the summers, the vessel was assigned to the Survey for temporary duty. In April 1840 she was formally transferred to the Survey. The first nautical chart, produced in 1839 using a stone engraving, covers the area of Newark Bay.

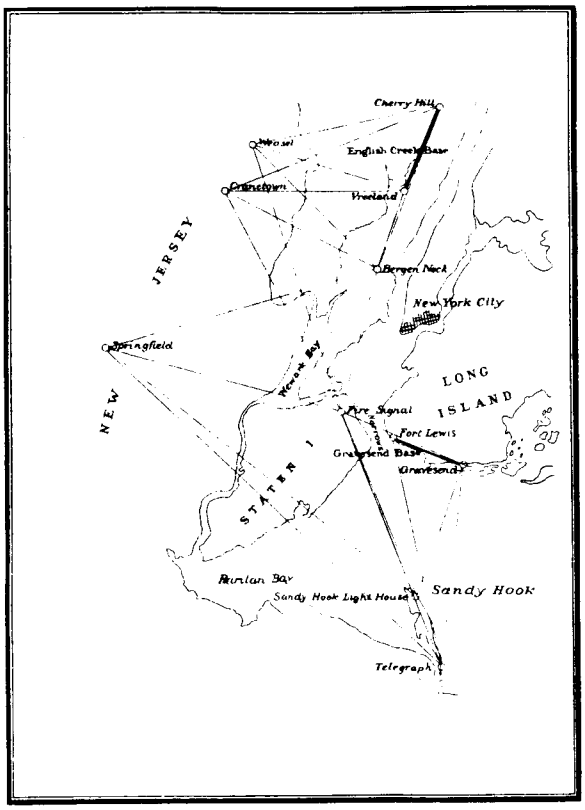
Topographic surveys, based upon previously established control, were conducted during 1836-38 on Long Island and along the coast of New York, Connecticut, and New Jersey.

Copperplate engraving was started in 1840, and in 1842 the first copperplate printing press was obtained. The first chart made from a copperplate engraving, issued in 1844, covered New York Bay and New York Harbor.

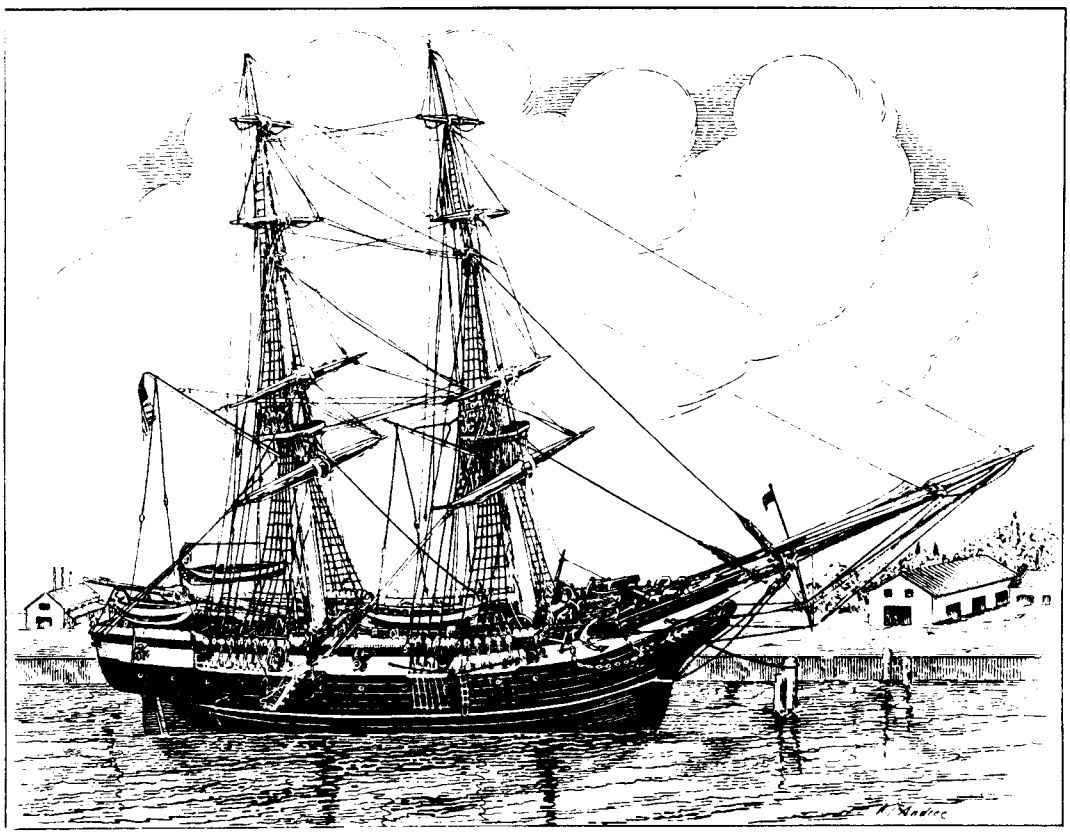
In March 1834 the Treasury became overloaded with work and the Survey was again transferred to the Navy Department, but with Hassler still in charge and the civilian employees retained. Hassler objected, and after he threatened to resign, the Survey was again restored to the Treasury Department in March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

While organizing, planning, and systematizing the work, Hassler trained numerous new assistants, including Navy officers and Army topographic engineers who were detailed for duty with the Survey. Parties were trained for astronomic and geodetic observations, hydrographic work, the study of tides and currents, and for magnetic observations at astronomical sites. He prepared in advance for the compilation and production of maps and charts, including the importing of chart paper, copperplates, and even trained engravers.

In the early 1840's, Congress felt that accuracy was being overstressed in the Survey, and that the result of its work did not justify the expenditures. While Hassler successfully won committee approval 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 in his original proposal of 1807. It defined the requirements for triangulation, topographic, and astronomic work, and in addition called for magnetic surveys and the extension of hydrographic surveys out to the 120-fathom depth.



First triangulation near New York City



Brig WASHINGTON, the Survey's first hydrographic vessel

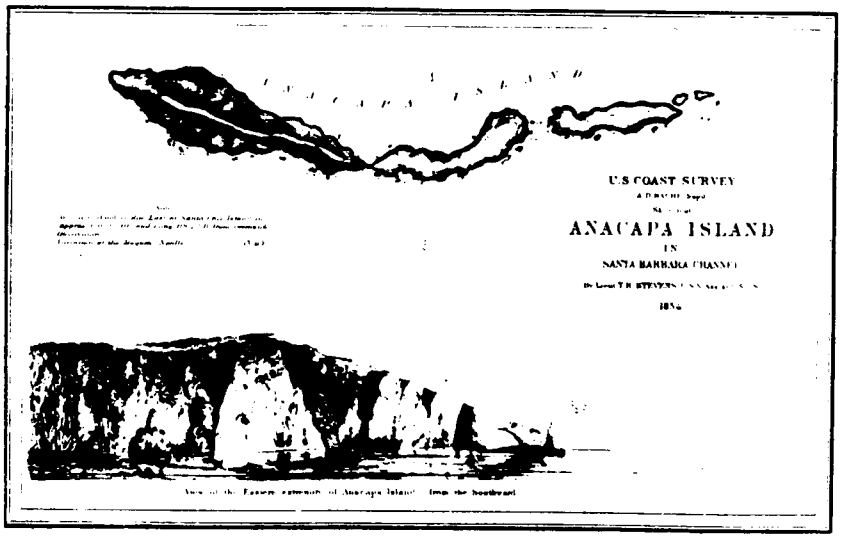
The existing practice of using Army and Navy officers was recognized. Assistants, responsible to the Superintendent, were to be in charge of office work and field parties. The board recommended retention of the Survey in the Treasury Department and the continued employment of civilian personnel. Congress approved the plan in April 1843. This action provided a basis for the Survey which lasted, with some modification, until the Congressional act of 1947 which established a new, but greatly altered, restatement of functions. The 1843 clarification did much to solidify the Survey and to further its effective functioning.

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

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 plotted on topographic sheets. Hydrographic surveys, started near New York, had been extended to include all of New York Bay, Long Island Sound, Delaware Bay, and the Delaware River. Offshore hydrography was almost completed from Montauk Point to Delaware Bay.

Freed from interrogation after adjournment of the Congress in 1843, Hassler spent the fall making geodetic surveys in New Jersey and Delaware. In Delaware he was caught in a severe storm that swept away the tents protecting his instruments. In his attempt to save the instruments, he fell on a pointed rock, suffered an injury in his left side, and lay exposed for several hours 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.

Although his life had been stormy and subject to many trials, he achieved his aim of creating a work of lasting value for America, and he lived to see his work recognized. Hassler's sincerity and integrity won political and public acclaim in the end.



Engraving by James McNeill Whistler in 1854

THE BACHE ERA

When Hassler died in 1843, the foundation for the Survey had been laid. The building of the superstructure fell to his successor, Alexander Dallas Bache, the great-grandson of Benjamin Franklin and a grandson of Alexander Dallas, Secretary of the Treasury under President Madison. The selection of Bache as head of the Survey in December 1843 had the concurrence of all the principal scientific and literary institutions of the country. It was said that no such weight of recommendation had previously been requested in support of a candidate for office on strictly intellectual grounds.

During his lifetime, Bache held many responsible posts, any one of which might have been considered the successful culmination of a life's work and ambition. His rise to positions of prominence in the field of education and science was meteoric. As a West Point cadet he distinguished himself by his scholastic excellence, graduating at the head of his class at the age of 19. At 22, he was named to the faculty of the University of Pennsylvania as professor of natural philosophy and chemistry. After 8 years at the university, he served as President of Girard College and Superintendent of schools in Philadelphia.

Bache won the highest honors the country had to bestow in science and technology. He helped form the National Academy of Sciences, the foremost 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. During the Civil War, he organized and headed the United States Sanitary Commission, forerunner of the American Red Cross.

Bache possessed the talents required for organization and administration as well as personal charm. Where Hassler would have fought at being asked when he would finish surveying the coast, Bache would smilingly ask, "When will you gentlemen stop annexing new territory?"

The plan for the Survey was Hassler's, but Bache gave it form and direction. Hassler built on a rigid scientific foundation; Bache adapted that plan to an expanding America. He determined that the maps and charts of the Survey should be made available to everyone having an interest in commerce, navigation, geography, or science. Under Bache's guidance and sympathetic understanding, the Survey not only kept pace with the progress in science but made many original contributions in practical astronomy, geodesy, hydrography, and cartography.

Some feeling continued in Congress that the Survey work was a naval responsibility and should be transferred to the Navy. With the support of then Senator Jefferson Davis, a bill calling for this transfer was defeated. Feeling that an impartial view was needed to determine where the Survey should be located, Bache encouraged an investigation sponsored by the American Association for the Advancement of Science. A study committee of 20 leading scientists endorsed the Survey, its plans, and its retention in the Treasury Department.

New Organization for a Growing Country

As the country grew, Bache subdivided the coastal area into nine sections, with operations carried on simultaneously in each area. Using his ability to win cooperation, he assembled a strong staff of civilian assistants as well as Army and Navy officers. He was quick to recognize ability and gave credit for accomplishments.

When Texas joined the Union in 1845, with its 3,359 miles of tidal shoreline, the United States tidal shoreline totalled 45,814 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 shoreline to 53,677 miles. Inland territory was also annexed, necessitating the demarcation of international boundaries and ultimately the extension of geodetic control for use in local surveys. More operating districts were formed, and Survey operations increased rapidly.

Reconnaissance hydrographic surveys were started in the Gulf of Mexico in 1845, along the coastal area between New Orleans and Mobile. The brig WASHINGTON carried out observations of the Gulf Stream in 1846 and made surveys seaward at Georges Bank.

Expanded Surveys on All Coasts

In 1848, before the California Gold Rush, the Survey made hydrographic surveys of the California coast with the streamer EWING. Discovery of gold in 1849 resulted in a frantic increase in ship traffic and the need for more surveys. George Davidson, an exceptional assistant whom Bache had been encouraging, was one of four civilians sent west in 1850 to conduct geodetic and topographic surveys. Other ships and personnel were added, and the work progressed at an accelerated rate. By 1857, work was started on the northern boundary between the United States and Canada in the vicinity of the Strait of Juan de Fuca.

In the 1840's, the first automatic recording tide gage was introduced. This development greatly facilitated the processing of hydrographic survey observations for chart compilation.

The purchase of Alaska from Russia in 1867 added 33,904 miles of tidal shoreline, and a survey job only slightly less than required for the United States coastline. This purchase had been anticipated, and by the time of negotiations, Davidson was doing reconnaissance work in Alaskan waters with the cutter LINCOLN. He was followed by others, and the long job of surveying Alaska was under way.

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

Geomagnetic Surveys

Because accurate navigation with the magnetic compass requires specific knowledge of the declination of the magnetic needle from true north, systematic observations are required. Bache personally directed the initial geomagnetic work of the Survey, pursuant to Hassler's plan that "magnetic bearings should be regularly observed at every principal station."

Geomagnetic surveys, provided for by the act of 1843, were extended, and by 1855, isogonic lines were shown on maps. 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 were devised, including a new magnetometer. Assistant Joseph Saxton and Bache himself were prominent in the correlation of data and development of theories, including a theory on location of the magnetic poles. Assistants R. H. Fauntleroy, Julius Hilgard, Charles Schott, and William Mitchell participated in the geomagnetic field work. By 1856, 160 magnetic observation stations had been established.

The Coast Pilots

Much valuable and useful navigation information cannot be put on nautical charts, and accordingly, descriptive texts called Coast Pilots were prepared to supplement charts. The most renowned are the famous American Coast Pilot, or Blunts Coast Pilot, first published in 1796 by the Blunt Company. The Survey did not become involved with Coast Pilots until 1849 when work was started on the first volume which dealt with the Gulf of Maine. It was not published until 1875. Soon after, a Coast Pilot covering the area from Boston to New York was published. In 1867, the Survey 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 Survey.

At the same time, Davidson, who had published his Coast Pilot Notes as a series of articles 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.

New Ships and Science Aid Surveys

Bache inspired 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 (1838), the WAVE (1856), the PHOENIX (1848), and the FORWARD (1880). At first sailing vessels were used, but on the insistence of Bache, steamships were introduced. The first of these was the BIBB, obtained on trial in 1847. In 1849, the Survey employed its first iron vessel, the JEFFERSON; however, 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 to the Survey in support of hydrographic work.

The Bache era was notable for the introduction of new ideas, equipment and techniques--most of which came from officers and civilians of the Survey. New instruments included bottom samplers, a self-registering deep sea thermometer, the introduction of wire line instead of hemp, the use of drift bottles, and a new automatic recording tide gage.

Geodetic work saw notable advancements, including the Horrebow-Talcott method of determining latitude with the zenith telescope which achieved new heights of accuracy.

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

A chronometric longitude difference from European stations was made in 1852-1853 by Assistant B. A. Bould. Base line measurements for triangulation were improved by Assistants F. H. Gerdes and Julius Hilgard. Using apparatus he had devised, Bache himself measured a 7-mile base line on Bodie Island, North Carolina, in 10 days with a total uncertainty of only 1 inch--an accuracy almost unbelievable at that time.

Outstanding Individual Accomplishments

The Bache period developed many men of outstanding caliber. George Davidson was certainly one of these. 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 Assistants Robert H. Fauntleroy, C. O. Boutelle, and William Mitchell. 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 others performed hydrographic work, Davidson headed 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 as a book by the Survey. This volume, containing more than 2,000 manuscript pages with 400 illustrations, is considered one of the best Coast Pilots of all time.

Lt. Mathew F. Maury, who worked so closely with the Survey that he was thought to be associated with it, later became the most famous oceanographer of the Navy and the founder of the Navy Depot of Charts. He led the world in the study of ocean winds and currents and other aspects of physical oceanography.

Lt. Charles H. Davis 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, later became governor of Washington Territory.

James McNeill Whistler contributed little of cartographic importance to the Survey, but during his brief stay in the Survey he made a start toward a brilliant career as an artist. After 3 years at West Point, he was placed in the Survey through his father's influence. He was an indifferent draftsman and did not follow office hours. While he did take an interest in copperplate etching, Whistler preferred caricature and landscape sketching. He executed several headlands and a number of fanciful figures alongside charts. Those decorations are proudly prized by the Survey as Whistler's first etchings.

The Survey in the Civil War

The Survey underwent many changes during the Civil War. At the start of the war there were 12 Army officers and 11 Navy officers on assignment to the Survey. Most of these officers returned to their service units--some Union and some Confederate. Remaining personnel, mostly civilians, spent most of their efforts in support of military field campaigns and war activities.

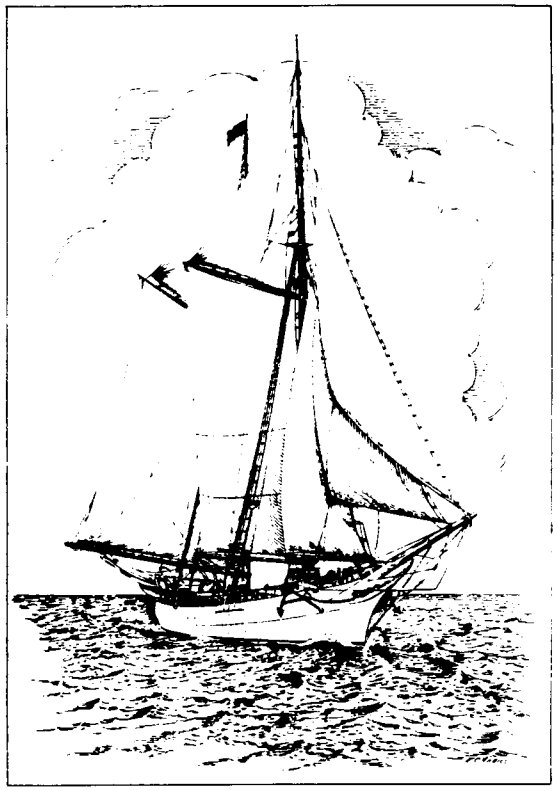
Early in the war there was danger of attack from the Confederacy on many northern cities, particularly Washington, D.C. The Survey was called upon for defense surveys of the waters and land areas around Washington, Baltimore, St. Louis, Philadelphia, and some New England cities were surveyed as far north as Portland, Maine.

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

Survey units were active in many of the field campaigns. Admiral DuPont's assault of forts guarding Port Royal, South Carolina, was aided by sounding and buoy-laying activities performed under fire by Assistant C. O. Boutelle on the VIXEN. Farragut's penetration of the lower Mississippi River was facilitated by the work of Assistant F. H. Gerdes with the vessel SACHEM. The streamer BIBB was used in the examination of Charleston Bar in preparation for an attack in that area, and Survey ships and personnel 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, North Carolina, was aided by Assistant J. S. Bradford, who went in under fire and set the course for the ship LOUISIANA, which was purposely blown up in front of the fort.

Charts were extremely important in the war, and the unprecedented demands for maps and charts strained the resources of the Survey to the utmost. Fewer than 10,000 charts had been issued annually before the Civil War. Production grew to 44,000 copies by 1862 and to 66,000 copies by 1863. The wide distribution of these charts provided much more appreciation and a greater use of Survey charts, and the new high rates of production continued after the war.

With the end of hostilities the Survey readjusted to peacetime activities, increasing its civilian ranks to compensate for the loss of Army officers.



MATCHLESS, one of last sailing vessels

Signalman Jasper Bilby with geodetic field party

THE EXPANSION YEARS

Alexander Dallas Bache died in 1867, honored and recognized as one of the great leaders of the Survey and an outstanding scientist of his time. The service of Hassler and Bache spanned 60 years. They were able to meet many difficult challenges and make significant decisions, many of which continue to influence Survey operations today.

The half century following the Civil War was an era of great expansion for the Survey. During this period eight different men were at the helm, most of whom came from the ranks of the Survey.

Benjamin Peirce, Bache's successor, had worked with the Survey since 1852 as a consultant on latitude problems. He was thoroughly familiar with the work when selected as Superintendent on the recommendation of scientific 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. He retained his Harvard position while serving as head of the Survey.

Peirce 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 urged planning for the great Transcontinental Arc, one of the greatest surveying undertakings of the time. The double burden of two positions proving excessive for Peirce at the age of 65, he resigned and returned to Harvard in 1874.

Carlile P. Patterson was the first Superintendent to be selected from the active working ranks. A former Navy captain, he had been hydrographic inspector for the Survey for a number of years, with outstanding success. He served from 1874 until his death in 1881. During his term, the name of the organization was changed from Coast Survey to the Coast and Geodetic Survey.

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 Transcontinental Arc. In 1879 Congress created the Mississippi River Commission, with provision for a representative of the Survey to serve on the Commission. Patterson was the first member, and Survey representation continues today. He also was a member of the international committee that decided the vital question of building the Panama Canal as a high level lock canal instead of at sea level.

Julius E. Hilgard was the second man from the ranks to become Superintendent of the Survey. He had built a brilliant career and his appointment in 1881 had the approval of scientific groups. Hilgard joined the Survey in 1845 at the encouragement of Bache, and in 1862, in recognition of his work, was put in charge of the Washington, D.C. 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.

Hilgard's administration was beset with troubles. Funds to increase the scope of the work found little support. Although he was ill and lacked his former keen perception, Hilgard 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 followed in 1884-85. Upon urging by the National Academy of Sciences and other scientific organizations, the Committee recommended no action to change the status of the Survey. 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 the Survey, was appointed Superintendent specifically to correct conditions that had caused Hilgard's troubles. Thorn systematized the accounting methods, and became a strong supporter of the organization. Feeling that he had accomplished his purpose, Thorn resigned in 1889 at the end of the first Cleveland administration.

Thomas C. Mendenhall served as Superintendent of the Survey from 1889 to 1894. Despite funding problems, work advanced on boundary surveys, especially on the Alaska/Canada boundary. He served on this boundary commission, and the glacier flowing down from the international boundary near Juneau, Alaska, is named for him. 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 during his tenure. In 1890 he initiated the inclusion of the times of tidal slack water and maximum tidal currents, as informational notes on tide tables.

William W. Duffield, in his seventies when appointed in 1894 to head the Survey, was a professional civil engineer with an excellent record as a Union general in the Civil War. 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, and became a professor at the University of California. Old age incapacitated Duffield, and he retired in 1897.

Henry S. Pritchett served as head of the Survey from 1897 to 1900. 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 also obtained for magnetic observations. He started a systematic magnetic survey of the country and established the Division of Terrestrial Magnetism in 1899.

During the Spanish-American War of 1898 all Navy officers were withdrawn, never to return. After the war, Pritchett resisted transfer of the Survey to Navy control. To replace the loss of naval officers performing hydrographic work, Pritchett hired experienced seamen and established the ranks of deck officer, junior officer, and senior officer, with appropriate uniforms, to work as assistants and aides aboard Survey ships. After 3 years in office he retired to become president of Massachusetts Institute of Technology.

Otto H. Tittmann, last of the old line and well grounded in the traditions of Hassler and Bache, served from 1900 to 1915, the longest term since those of Hassler and Bache. He had seen the vast panorama of change, and was well suited for many new changes and technical advances of a dramatic new era.

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 most of 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.

In 1903 the Survey was transferred to the new Department of Commerce and Labor, and to Commerce in 1913 when a separate Department of Commerce was created.

New Hardware and Techniques

The great expansion of the Survey during the latter half of the 19th century saw many new instruments, adaptations and techniques come into use through the inventive genius and creativity of its own personnel. Some of the Nation's most outstanding scientists and technicians served with the Survey or worked with its staff. In those days ingenuity was more valuable than money.

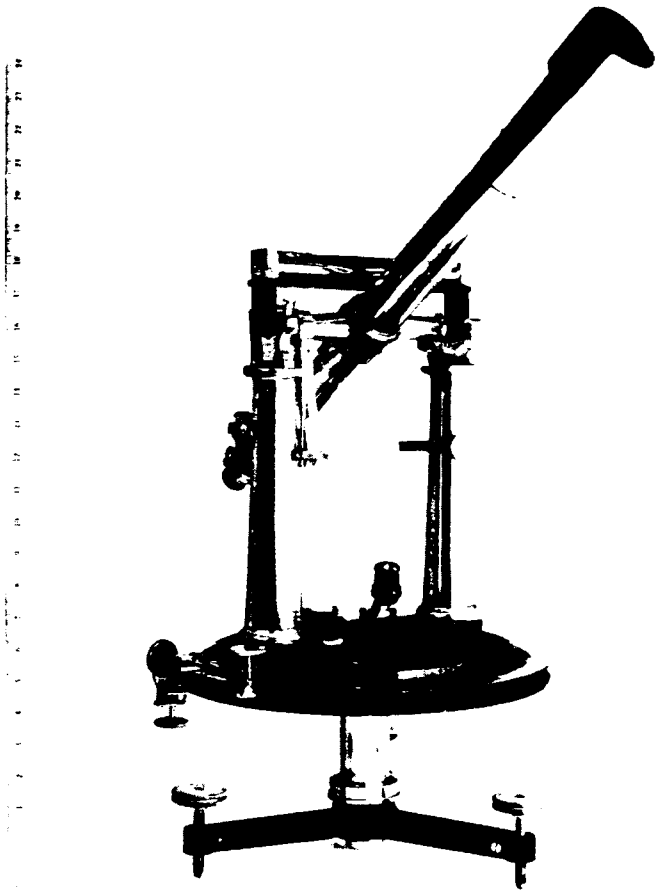
Ocean Observations. A small cup device was devised by Lt. H. S. Stellwagen for taking bottom samples. Wire lines were introduced by Lt. Mathew Fontaine Maury, the famous Navy oceanographer who worked with the Survey. The use of wire instead of hemp permitted much deeper and more accurate soundings. Assistant Joseph Saxton developed a self-registering deep-sea thermometer. George Bache, a brother of the Superintendent, invented a self-closing deep-water sampler.

In the 1870's Lt. C. D. Sigsbee adapted, from Sir William Thomson's machine developed in England, a sounding instrument which automatically registered the length of sounding wire as it was reeled out to determine depth. Sigsbee also developed a more efficient clam-bucket type bottom sampler, and a multiple container for taking simultaneous water samples with automatic registering of the temperature of each sample. For his brilliant service in the Survey and in the Navy, Sigsbee was promoted to the rank of Rear Admiral.

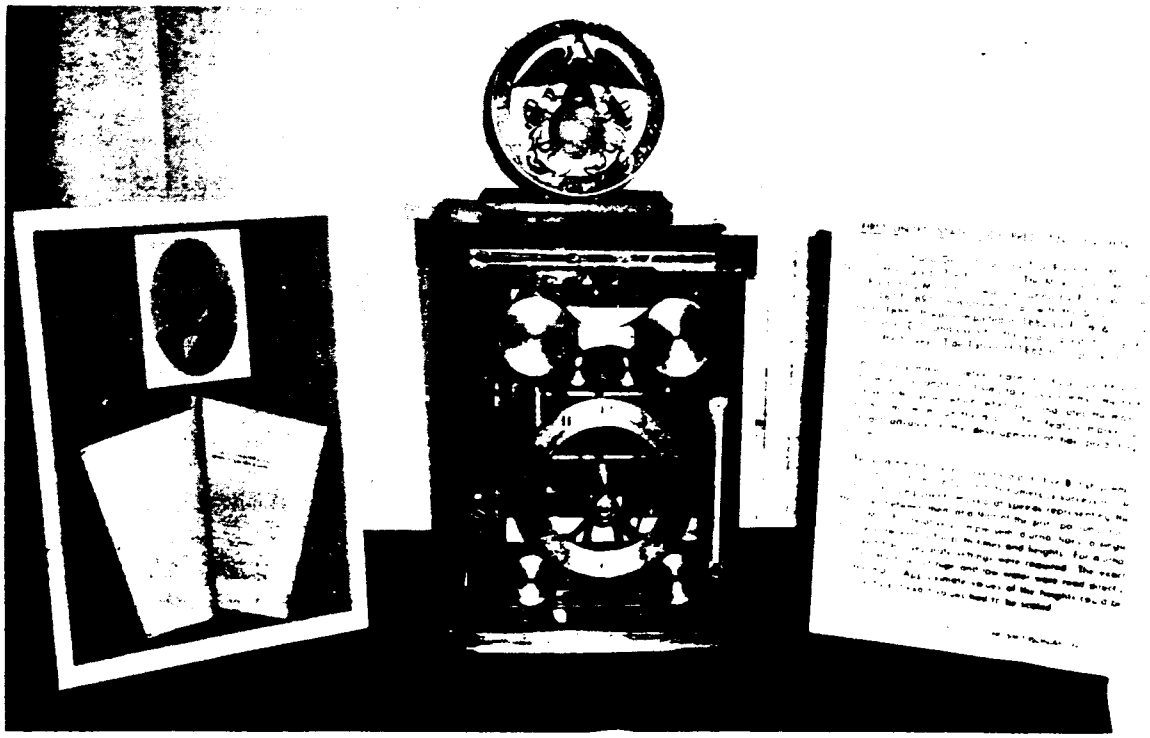
Current measurements were made by tracking the motion of buoys holding weighted cans submerged at various depths. This method was improved when Lt. Pillsbury's current meter became available. It registered velocity by the rotation of a cylinder, and direction by a self-locking fin.

Wire Drag. A significant advance was the use of a weighted wire drag in 1904. Developed by Assistant Nicholas H. Heck, it employed a weighted wire which was supported at a predetermined depth by buoys and towed between two launches. Sweeping an area would reveal submerged rocks and obstructions not shown by soundings. The development of the wire drag was accelerated when the cruiser BROOKLYN struck an uncharted pinnacle near New Bedford, Massachusetts, in 1904. The value of wire drag and up-to-date charts was demonstrated dramatically in 1912 when the battleship TEXAS, using obsolete charts, was damaged on a pinnacle in Penobscot Bay. The rock had been discovered several years earlier by wire drag and was shown on the latest charts of the Survey.

This method of determining depth has been of inestimable value in surveying in the Long Island Sound region where huge boulders were deposited by glacier



Twelve-inch theodolite used in 1860's



Ferrel tide predicting machine used from 1882 to 1914

ice in the Florida Keys where large coral heads rise well above the surrounding bottom and in parts of Alaska and the northern half of the New England coast where great seamounts rise to within a few fathoms of the surface. Water areas have been dragged to depths as shallow as 6 feet for seaplane landing areas and as deep as 350 feet for submarine trial courses.

Many improvements have been made in the wire drag since it was first introduced in 1904. The length of the wire drag in use today can be adjusted to cover a sweep up to 15,000 feet. As a result of successive improvements, the drag is now used to determine whether or not apparently clear water areas are free from obstruction; to discover and locate obstructions in a shoal area; to determine the maximum safe depth of a channel; and to locate submerged wrecks. Two new specially designed vessels now operate the drag--the NOAA ships RUDE and HECK. One officer commands both ships.

Tide Prediction Machines. In the early years, tide levels, a technical necessity in processing hydrographic data for chart compilation, were carried out by visual observations. In the early 1840's an automatic tide recording gage was developed by Assistant Joseph Saxton which allowed systematic observations in wide-spread areas, subsequent data analysis, and preparation of tide prediction tables which were first published in 1853.

In 1882 Assistant William Ferrel, a tidal mathematician, built an analog tide-predicting machine which could be set for the constants representing 19 harmonic components of the tide for a locality, and produce a curve of future tide motions. This machine was used until 1914. In 1910, Rollin A. Harris, a tidal mathematician, and E. G. Fischer, built a mechanical tide predictor which used 37 harmonic components. The one-ton analog computer is 11 feet long, 2 feet wide and 5 feet high. It traced a continuous curve showing tide levels for each day of the year. Dials indicated the time and height of high and low waters. This machine was used until 1966 when electronic computers took over the task of predicting tide levels and tidal currents.

Geodetic Instruments. In the 1870's Superintendent Patterson initiated work on a precise level survey to provide vertical control which would correspond with 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.

Better triangulation instruments and methods were devised. Smaller theodolites were built, among them a 12-inch instrument constructed under the supervision of E. G. Fischer which was easier to transport and faster to operate.

Baseline measurements were improved by use of an extremely precise set of duplex bars developed by Assistant William Eimbeck in 1897. Although a steel tape had been introduced by Assistant 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. The tape was easy to handle and greatly expedited baseline measurements. Leveling work was expedited by the development of a direct-reading level rod in 1899, and by Fischer's precise level first used in 1903.

Chart Production. The first nautical chart printed from a copperplate engraving was produced in 1844. In a short time exceptional progress was made in chart production. More detail was added and copperplate engraving methods were improved. Buoy locations were shown on charts using hand coloring and a new numbering system.

Reproduction was vastly improved with an electrotype process for the mechanical preparation of plate copies of the original copperplate engravings, thereby eliminating the wear on original engravings and the necessity to re-engrave.

The speed of reproduction was so increased that data sent from California to Washington in 1850 appeared as finished charts within 20 days after arrival. Between 1860 and 1863 the annual production of charts increased from 10,000 to 66,000. Color printing was introduced in 1862 with two colors for critical zones on Civil War maps.

Little was added to the reproduction process except color printing and power presses until 1905, when photolithography was introduced. Lithographic stones containing photo impressions were used in special flatbed presses and the use of multi-colors increased. These developments contributed to increases in both production and accuracy. It was then possible to use dry paper and eliminate much of the distortion which is a problem with wet paper.

A much greater improvement, however, came in 1915 when George Hoover, chief of reproduction, introduced the aluminum printing plate which possesses the advantages of the lithographic stone, plus flexibility which permits its use on a rotary press. From the 75,000 copies of charts printed in 1900, chart production increased to 330,000 copies in 1916.

Advances in Geodesy

A comprehensive computation and analysis of geodetic data was carried on by Assistant Charles A. Schott. His work, published in 1878, was acclaimed throughout the world and was the basis for the Survey's adoption of the Clarke Spheroid as a geodetic base in 1880. 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.

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 near perfect theoretical representation of the earth which was called the International Spheroid of Reference. This concept was adopted in 1924 at the meeting of the International Association of Geodesy and was used for a number of years by many countries as a 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 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, in 1901 Hayford established a standard datum for the country which provided a unified survey reference system for mapping and engineering work.

As one of the strongest advocates in modern times of coordinated mapping programs, William Bowie 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.

Rear Admiral Robert E. Peary, a former employee of the Survey, carried out Arctic Ocean tide observations as part of his expedition to the North Pole in 1909. He made numerous astronomical observations at the Pole and turned them over to the Survey upon his return. Because his claims were widely questioned, his observations received critical scrutiny by mathematicians Hugh Mitchell and C. R. Duval of the Survey. Their analysis gave proof of Peary's accuracy and afforded the accepted authenticity of Peary's discovery.

First Comprehensive Surveys in Alaska

Until the discovery of gold in southeastern Alaska in 1882, surveys in this new territory progressed very slowly. George Davidson reconnoitered in southeastern Alaska with the cutter LINCOLN in 1867 and 1868. William Dall conducted extensive exploration surveys between 1871 and 1874, and Assistant Marcus Baker, associated with Dall, 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. The only previous hydrographic data for Alaska came from charts prepared by Russian cartographers.

With the 1882 gold discovery, more funds became available and a systematic survey of Alaska was begun. The ships HASSLER and PATTERSON under Assistants William Nichols and John Pratt were sent immediately, to be joined later by the McARTHUR under Assistant Robert Faris. Those 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. Despite storms, fog, and short working seasons, a number of charts of Alaskan waters were published in the 1880's and early 1890's.

The Klondike gold rush in 1898 gave even greater impetus to Alaskan surveys. As with the 1849 rush in California, there was a dramatic increase in shipping, and more and more charts were needed. Because of the rugged coastal area and other dangers, insurance rates were high. The Congress authorized further expansion, and more detailed surveys were made in harbors and traveled lanes such as the inland passage through southeastern Alaska, and the Yukon Delta in 1899. The PATHFINDER, under Assistant J. J. Gilbert, was used in the surveys of Norton Sound and Fox Islands in the Aleutians in 1900 and 1901. The wire drag was effectively used to locate hundreds of dangerous rocks in Alaskan waters.

Many New Territories to Survey

The Spanish-American War brought the Philippines, Guam, and Puerto Rico under U.S. control in 1898. In the same year, Hawaii was added by negotiation. The Panama Canal Zone was acquired in 1903 and the Virgin Islands were purchased from Denmark in 1916. Other minor territories were added, and the tidal shoreline 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.

As in Alaska, most of the work in the Philippines was done as combined operations in a comprehensive and systematic manner, resulting eventually in some of the best colonial charts in the world. After 1901, the PATHFINDER and the FATHOMER were assigned to survey work in the Philippines, and the MARINDUQUE, the RESEARCH, and the ROMBLON were assigned later. Survey records were initially sent to Washington for processing, but by 1906 a processing office was set up in Manila. Thereafter, most cartographic work and printing were done in Manila.

Geodetic Projects Across the Country

In 1871, Superintendent Peirce convinced the Congress to authorize the great Transcontinental Arc program, a network of triangulation to connect the East Coast and the West Coast along the 39th parallel. This was the start of a survey control system which would eventually link all parts of the country, and the continent. Up to this time geodetic surveys were made only for control of hydrographic and topographic surveys of the coasts and for preparing nautical charts.

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. By 1897, field work was completed on the 2,500-mile Transcontinental Arc, the longest in the world at the time. This work together with the Eastern Oblique Arc, furnished the basis for highly significant geodetic investigations. An interesting part of the continental survey was the field party work on Mount Shasta in California. The party climbed the remote peak, made the geodetic observations, and returned in a total of 9 days--a remarkable accomplishment in the wilderness at that 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 1911.

Between 1903 and 1908, a special triangulation survey of New York City was made with Congressional authorization and cooperation of city officials.

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. The line started at the historical 54-40 parallel, following the 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. The Canadians did much topographic work, introducing a primitive form of photogrammetry as early as 1894, using oblique photographs. The work was finished in 1912.

Between 1891 and 1895 the Survey assisted in remonumenting of the boundary with Mexico, particularly the portion through New Mexico and Arizona, provided for earlier by the Gadsden Purchase.

Systematic, 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 geodetic bench marks established.

New 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 at Gaithersburg, Maryland, and Ukiah, California.

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. In the 1900's a trans-Pacific longitude connection was made by cable with Japan.

Gravimetric observations, begun by the Survey in 1875, continued on a systematic basis. 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 in New Zealand, Australia, and India. Assistants George Putnam and Edwin Smith actively participated in this work.

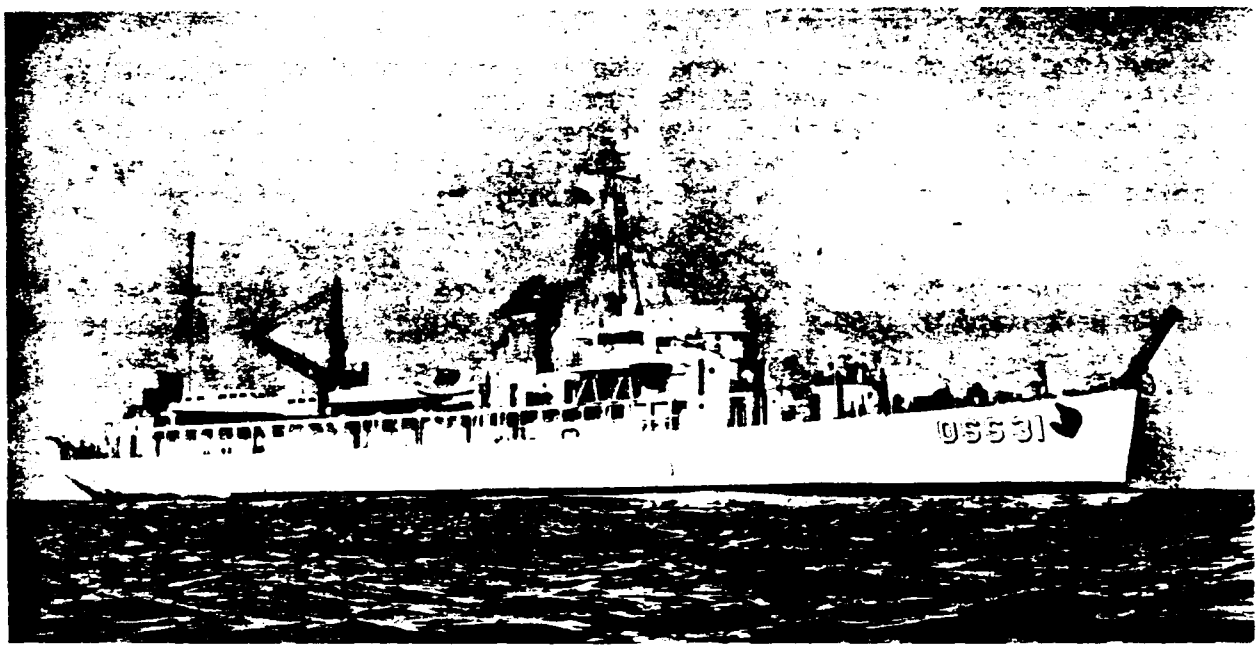
Magnetic surveys, provided for in the Reorganization Act of 1843, were carried out at sites of astronomic observations. These were extended by a series of short-term magnetic observatories. One such survey was conducted in Washington, D.C., from 1867 to 1869.

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 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. By 1900 magnetic surveys were greatly accelerated, and during the next few years five magnetic observatories were established.

The Survey collaborated with the Army Signal Corps in two Arctic expeditions in 1881 and 1882. From 1860 through 1882 the Survey participated in four major scientific solar and eclipse expeditions.

In the late 1860's exploration of the Gulf Stream was resumed after interruption by the Civil War. Assistants Henry Mitchell and F. Pourtales, with the streamer BIBB, began working in the Florida Strait, while Lt. J. E. Pillsbury, with the BLAKE, and Lt. Cdr. C. M. Chester and Lt. W. B. Freemont, with the DRIFT, worked farther north. Between 1885 and 1889, comprehensive work in the Gulf Stream was accomplished by Pillsbury. His extensive observations of currents and temperatures while anchored in the deep water of the Gulf Stream are among the classical data in physical oceanography.

Investigations in tidal hydraulics were carried out with particular reference to the forces and factors at work in channels.



NOAA Ship PIONEER

THE 20TH CENTURY

Two Major Wars and New Technology

The turn of the century marked the beginning of many changes in the world. Science, engineering, technology, economics and invention became the pioneering fronts. The airplane, the automobile, mass production, electronics, communications, and two world wars vastly changed the way of life, and the character and scope of the Survey.

Responding to the increased demands for new products and services, the Survey continued at the forefront in developing new instruments, equipment and techniques to carry out its programs and improve its performance.

Aeronautical charts, first issued in 1927, rose to an annual production of 40 million copies in 25 years. The establishment of the North American Horizontal Geodetic Datum of 1927 provided a single reference for the entire country including Alaska. Electronics and underwater acoustics vastly improved the speed, scope and accuracy of hydrographic surveying. Aerial photography, precision instruments, photogrammetry and computers revolutionized the making of charts and maps. A proliferation of measuring instruments and precision devices came out of Survey shops and laboratories. Despite two world wars and the fast pace of events, the Survey continued to meet the demands of public service with outstanding success.

The Contribution of E. Lester Jones

In 1915 President Wilson appointed E. Lester Jones as Superintendent of the Survey. With expertise in administration, organization and financial matters, Jones had more influence on the course and future of the Survey than any individual since Hassler and Bache. Prior to his appointment he was Deputy Commissioner of the Bureau of Fisheries for 2 years, and had an excellent record in public administration.

Jones immediately saw need for reorganization and made many significant changes, including establishment of the Commissioned Officer Corps. With the help of others, he set high standards for new employees, including high scholastic achievement and training in civil engineering. Like Bache, he attracted able assistants and delegated authority. He placed the technical aspects of the Survey in the hands of experts and devoted his time to reorganization and planning.

On leave from the Survey during World War I, Jones won military honors as a Colonel in the Army. Following the war he was a major participant in organizing the American Legion and its first post in Washington, D.C. When E. Lester Jones died in 1929, the Survey was an aggressive organization well equipped to move ahead in the upcoming age of electronics and new technology.

Formation of the Commissioned Corps

By legislative action in 1917, the Coast and Geodetic Survey Commissioned Officer Corps was formed, primarily through the efforts and persuasion of

Superintendent Jones to satisfy a need for stability, recognition and motivation as part of his reorganization plan. A precedent for commissioned status had already been set by assignment of Navy and Army officers to the Survey. Teamwork prevailed at the time but conditions failed to attract and keep high caliber people. The work required frequent moves by field personnel, 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 move about freely, become familiar with and integrate all phases of the work, command ships and field camps, and work as a large team. The new permanent commissioned status was immediately beneficial to morale.

With the creation of the Environmental Science Services Administration (ESSA) in 1965, the Corps became a part of the new agency. With the formation of NOAA in 1970, the Corps became the NOAA Corps. This is the smallest of the Nation's seven uniformed services, with an authorized strength of 388 officers. All are college graduates, with engineering and scientific backgrounds, and spend about one-third of their careers aboard NOAA ships. They are also assigned to mobile geodetic, hydrographic, and photogrammetric survey parties, other field facilities, and to headquarters laboratories and offices. During times of national emergency, they are subject to transfer to the armed forces. As of January 1, 1976, there were 22 women in the NOAA Corps--all were assigned or will soon be assigned aboard NOAA ships.

Directors From the Commissioned Corps

Raymond S. Patton, the first Director to be named from the ranks of the Commissioned Officer Corps, served from 1929 through 1937. All Directors since have come from the Corps, serving with the rank of 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.

Leo Otis Colbert succeeded Patton in 1938 for a term that was to last 12 years. A career officer of wide experience, he participated in most phases of Bureau activity. He worked in the United States, Alaska, and the Philippines, commanded various Survey ships, and participated in troop movements in World War I. Between 1928 and 1930 he directed Survey operations in the Philippines, and for 5 years before his appointment as Director, he was chief of the Division of Charts. His strong talents in administration saw the Survey successfully through its many important functions during World War II. In 1947 he successfully urged congressional enactment of a new enabling act which concisely restated the Bureau functions and removed numerous areas of uncertainty. Admiral Colbert retired in 1950.

Colbert's successor, 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 was in charge of personnel in the Chart Division during World War II, and was 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. Admiral Studds retired in 1955 after major surgery.

H. Arnold Karo was appointed Director in 1955, with a background of 32 years in the commissioned service. His career included 22 years at sea in surveying the waters of Alaska, the Philippines, the Virgin Islands, and along the Atlantic, Pacific, and Gulf Coasts. As a senior officer, he commanded the largest ships in the Survey fleet. During World War II Karo was transferred to the Army Air Corps. A major assignment included 2 years as commanding officer of the Aeronautical Chart Plant in St. Louis, one of the most important map reproduction plants in the world.

For 4 years immediately preceding his appointment as Director, Karo was Chief of the Division of Charts. When the Survey became a part of ESSA, Admiral Karo was named Deputy Administrator of ESSA with the rank of Vice Admiral.

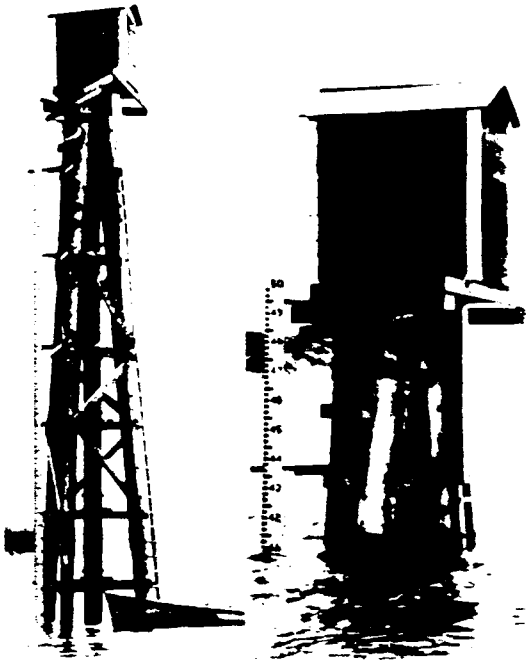
James C. Tison, Jr., served as Director from September 1965 to August 1968. He entered the commissioned service in 1929, serving on various ships and with land-based survey units until 1942, when he was transferred to the Army Air Corps. His military service included charting air routes in South America, survey officer in various air photographic and charting units, and 5 years as surveying, mapping, charting, geodetic, and reconnaissance officer.

Upon his return to the Survey in 1949, Tison was in charge of a geodetic party carrying out triangulations for the Atlantic Missile Test Range. From 1955 to 1957 he was geodetic officer at the Air Force Missile Test Center in Florida. He served as Assistant Director for Administration, in charge of the Division of Instruments and Technical Services, and as Deputy Director prior to his appointment as Director.

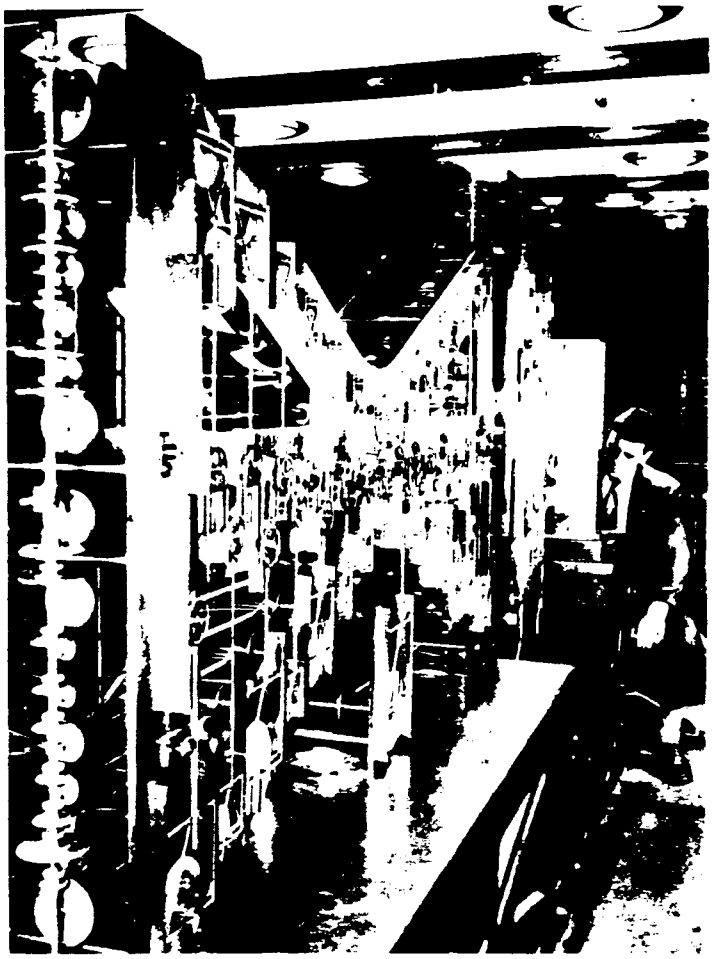
Don A. Jones was appointed Director in September 1968, and served until April 1972, when the present Director, Allen L. Powell, was named. Jones joined the Department of Commerce as a civilian employee in 1933 and was commissioned in the corps in 1940. Like most other Survey officers during World War II, he was transferred to the military. From 1942 to 1944 he was a coast artillery staff officer, surveying and mapping officer, and submarine mine plant commander in the U.S. Army. He served with the Office of Strategic Services prior to transfer back to the Survey in 1946.

Jones was chief of the geodetic project which established ground control for water resources mapping of the head waters of the Blue Nile River in Ethiopia from 1957 to 1961. He was awarded a Gold Medal from the Department of Commerce for this service. As Executive Officer and Commanding Officer of the SURVEYOR from 1963 to 1966, Jones was responsible for a number of pioneering survey and research operations in the Pacific Ocean, involving the evaluation of a new generation of oceanographic instruments.

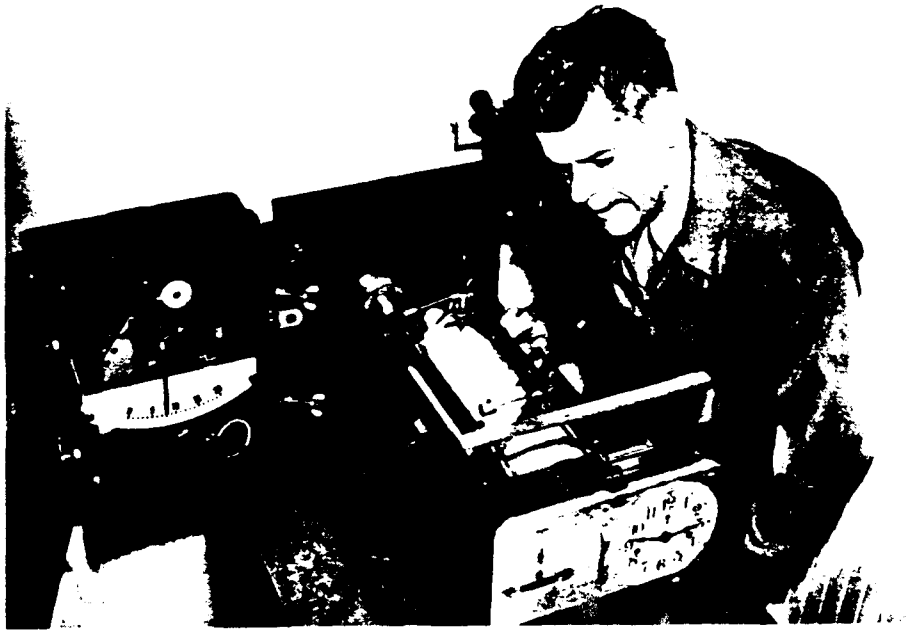
Midway in Jones' term, when NOAA was formed, he served as Acting Director of the new National Ocean Survey, successor to the Coast and Geodetic Survey, from October 1970 until January 1971, when his appointment as Director was confirmed by the Senate.



High and low tide in Alaska



Harris-Fischer tide predicting machine



Standard analog tide recorder with telemeter

More Surveys in Alaska and the Philippines

A comprehensive survey of the entire Philippine Archipelago approached completion prior to World War II and the Japanese occupation. This vast project was organized and carried out largely as a separate activity. A local Philippine Survey 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. After the war the new Republic of the Philippines took over responsibility for its Survey. Operations began on a substantial foundation of excellent surveys and charts provided by the U.S. Survey over a period of 40 years. The new agency, designated the Philippine Coast and Geodetic Survey, was closely patterned after the United States organization.

In Alaska, surveys were extended into the Aleutian Islands, the Bering Sea, and other remote areas. The wreck of the U.S.S. TAHOMA in Alaskan waters in 1915 resulted in 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 marine commerce. 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. Surveys were carried toward the extremity of the Aleutian chain, to the Bering Straits area, and throughout the entire Arctic Coast west of the Canadian border. Wire drag surveys were made 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 hydrographic 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 and important additions made to knowledge of the general bathymetry of the Pacific.

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

Tide Observations and Tide Predictions

The number of tide observation control stations was increased considerably, with data being used for both hydrographic surveys and for engineering information. In 1867 the Survey issued two volumes of tide tables containing predictions for 19 reference stations and 124 subordinate stations. By 1967 the number of tide table volumes had increased to six, including two for tidal currents, with predictions for 251 reference stations and 7822 subordinate stations.

Tidal data gathered from many locations over the world on an exchange basis begun in 1896, eventually permitting the publication of complete tables of predicted tides for widely separated places in the world.

To satisfy growing needs for complete 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. During World War II, the Tide and Light Diagrams, prepared as supplements to special tides and tidal current reports, were issued to provide information for 1 month for a particular location. Data included time and height of tide, daylight, three stages of twilight, darkness, moonrise and moonset, dim and bright moonlight, monthly mean air and sea temperature, and monthly winds. Over 1150 monthly diagrams for 112 locations were prepared, mostly for the Pacific area.

The period from the 1890's into the 1920's witnessed a flowering of some of the best minds in Survey tide work: Rollin A. Harris, a mathematician who originated the stationary wave theory for open ocean tides, wrote a comprehensive tides manual, and with E. G. Fischer, designed the second generation tide predicting machine; Leland P. Shidy, a mathematician who served 57 years with the Survey and developed various methods and devices for data reduction; Harry A. Marmer, a mathematician who authored numerous articles on tidal datums and tide action; and Paul Schureman, a mathematician who wrote a manual on harmonic analysis and prediction, a tide glossary, and made special analysis. Walter B. Zerbe, an oceanographer with the Survey from 1926 until 1956, carried out experimental research to calculate earth tides from water level measurements in the David Taylor Model Basin, provided critical tide data during World War II, and conceived the Tsunami Warning System.

Crustal Movement Studies in California

As part of its geodetic work, the Survey originally established a primary triangulation scheme in the San Francisco area in the period 1880-1885. Following the 1906 earthquake, this primary triangulation was reobserved to determine the extent of horizontal movement. Again in 1922 the net was reobserved. The results disclosed by these resurveys formed the basis for a program of special pattern surveys to monitor crustal movement at places along the San Andreas fault.

In cooperation with the California Department of Water Resources, in 1963 the Survey established 22 small fault crossing figures along the route of the California aqueduct to monitor crustal movement. These figures, reobserved at 1- to 3-year intervals, provided crustal movement information for use in construction of the aqueduct.

Geodetic Surveys Following World War I

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 Authority. Major 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 accurate geodetic control. Much of the advance in geodetic techniques and increased survey activity were the result of his inspiration.

By Supreme Court order, the accurate measurement of the arc-of-circle boundary between Delaware and Pennsylvania was accomplished. Of an extremely technical nature, this operation reaffirmed an accurate survey made by the Survey in 1892.

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

The 1927 North American Datum was established as a result of an ingenious new process devised by William Bowie and Oscar Adams for completing a new adjustment of the triangulation of North America. This was the best theoretical adjustment of all horizontal control data available at the time, and made possible the connection of all surveys and maps on a uniform base.

During the depression of the 1930's, some geodetic work was accomplished through use of unemployed persons in government-financed relief and recover projects.

After World War II, great 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 triangulation of the United States and Alaska was completed. After the war other arcs were pushed north to Point Barrow and west to the end of the Aleutians. These connections, along with those made by the Inter-American Geodetic Survey with Survey assistance, provided continuous triangulation for nearly 10,000 miles--from one end of the North American continent to the other.

First-order triangulation was pushed further into the interior of northern Alaska, along the coasts of the Bering Sea and the Arctic Ocean. A basic net was extended through the western Aleutians and to St. Lawrence Island in the Bering Sea by trilateration using Shoran techniques. Even the remote St. Matthew Island was connected by exceptionally long lines measured by the Electronic Position Indicator (EPI) 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. By 1956 there were more than 160,000 precisely determined points.

In 1929 a general adjustment of level lines was made, placing vertical control on a uniform basis analogous to the triangulation datum.

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. This effort was complemented by 166,000 miles of second-order lines, and connection with a large network in Canada. By 1956 there were

nearly 425,000 miles of lines, considerably more than half of which were of first-order standard or accuracy. Special leveling was performed, such as the studies of land subsidence in California, studies of tectonic problems associated with reservoir loading at Lake Meade, and for investigation of sea-level problems in many places.

Plans for extension of geodetic surveys called for placing primary horizontal control points at average distances of about 7.5 miles, with a point in each 50 square miles of area. At the end of 1956 approximately 30 percent of the country had been surveyed on this basis.

Vertical control points of basic accuracy were planned to be established at distances of 1 mile or less along lines not more than 6 to 8 miles apart. As part of an international study of the shape of the earth, it was intended to complete a chain of astronomic observations about 18 miles apart along the entire 35th parallel in the United States. The gravity control network was to be expanded to provide a station about every 100 miles.

In 1932 a system of state plane coordinates was established to facilitate the use of geodetic data by all engineers and surveyors. Oscar Adams and Hugh C. Mitchell developed the mathematics for horizontal geodetic data processing in each state and for the state plane coordinate system. Geodetic coordinates of latitude and longitude, expressed in plane coordinates, were eventually provided for each state. By eliminating complex mathematical procedures, these coordinates have contributed much to a more general use of systematic geodetic control. Lansing G. Simmons, with the unique ability to blend geodetic theory and field surveying, was a major force in presenting geodesy to local governments and local surveyors. In 1974, special base lines were established in several states for use by local engineers and surveyors to calibrate electronic distance measuring equipment.

Geomagnetic Observations

Originally magnetic data collected by the Survey was used in preparing navigation charts and for surveying. Over the years the users and requirements increased: geophysical exploration for earth minerals; study of the earth's interior; upper air studies; telecommunications, cosmic ray investigations; solar-activity investigations; space physics; the ability to measure extreme variations in transient fluctuations; and new formats for magnetic data presentation.

At the turn of the century, Survey programs in geomagnetism were greatly expanded and operated at higher technical levels to meet new requirements.

The first control station in the United States to be operated on a sustained basis was built in 1901 in Cheltenham, Maryland. It was the first of five magnetic observatories built within a 2-year period. The others were located at Baldwin, Kansas; Sitka, Alaska; Honolulu, Hawaii; and Viegues Island, Puerto Rico. The temporary Baldwin station was replaced in 1909 with a premanent station at Tucson, Arizona; and the Puerto Rican installation was ultimately moved to a more suitable site near San Juan in 1926. The main Cheltenham Observatory was shifted to a site near Fredericksburg, Virginia, in 1956.

Magnetic observatory in Virginia

Sensing element for automatic magnetic station

During World War II in Alaska the lack of magnetic data became critical with demands by the military for data on radio propagation and navigational aids. Since the Sitka Observatory did not provide the required information, the Department of Terrestrial Magnetism of the Carnegie Institution of Washington operated a provisional observatory at College, Alaska, near Fairbanks, but the data did not fulfill the long-term requirements associated with the huge area of Alaska. Accordingly, the College installation was upgraded to a first-class observatory and added to the Survey network in 1948, and Barrow Observatory was added in 1949. These two observatories were located to meet scientific requirements in addition to those of navigation, radio propagation, and land and geophysical surveying. The north polar cap and its boundary, the auroral zone, are very important features in the upper air study of solar wind, magnetic storms and space activity. The College Observatory is within the auroral zone and the Barrow Observatory is within the polar cap. Each area has significantly different magnetic characteristics.

As investigation and study of the earth's magnetic field progressed, it became obvious that additional stations were needed to provide data for geographical areas between existing stations. As funds became available, stations were constructed at Guam in 1957; at Boulder, Colorado, in 1963; at Dallas, Texas, in 1964; at Castle Rock, California, in 1965; and at Newport, Washington, in 1966.

By 1966, magnetic observations had been made at thousands of locations in the United States including nearly all of the more than 3,000 county seats in the country. At that time 40 magnetic observatories had been established since 1900, with 14 operating to measure and record both fluctuations and gradual changes in earth magnetism. The Fredericksburg station was equipped with the most advanced instrumentation for earth field measurements, and with facilities for development of magnetic instruments, magnetic research, and testing and calibration of geomagnetic instruments.

The slower magnetic changes are monitored at about 150 selected stations where "repeat" observations are scheduled at 5-year intervals.

The development of airborne magnetometers in the late 1940's provided data at flying levels used in air navigation and in 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 for the United States and territorial areas have been produced regularly since 1950. Beginning in 1950, isomagnetic charts of the world were compiled by the Survey for publication by the Navy Hydrographic Office under an agreement of 1947, which centralized all United States magnetic chart compilation in the Survey. This centralization was implemented by legislation in 1947, which also designated the Survey as the United States central repository of world magnetic data. In 1956 extensive preparation was made for magnetic observation work at many temporary stations in Alaska, the western Pacific area, and in Antarctica as part of the International Geophysical Year program. This effort also included the collection of microfilm archives of magnetic recordings from observatories around the world.

Seismic Observations

In 1925, Congress designated the Survey as the Government agency responsible for the study of seismology and dissemination of information to the public. The Survey also assumed responsibility for general coordination of seismological work throughout the country, and assisting private operators and institutions with the loan of apparatus, technical advice and assistance. Prior to this time, seismographs had been in operation in the Survey's magnetic observatories, primarily to investigate the effect of seismic disturbances on magnetic recordings.

The most direct approach to providing information on how to avoid earthquake damage has been the strong-motion program, begun in 1932, whereby instruments that measure the forces produced by strong earthquakes are operated in localities where earthquakes are considered most likely to occur. These instruments operate only during an earthquake, since they are activated by the first motions of the tremor. By 1966, 114 strong-motion seismograph stations were in service. A number of other countries have adopted strong-motion programs patterned after that of the Survey. Thousands of strong-motion records have been obtained and information from them has contributed substantially toward reduction of earthquake hazard. After an earthquake occurs, questionnaires are sent to selected persons in the affected area in order to collect eyewitness information about the effects of the earthquake, the nature and duration of the shaking, and similar details.

The Survey maintained world leadership in the location of earthquakes or "epicenters." For these determinations, 10 Survey stations were used in cooperation with 14 stations operated by institutions and nearly 1,000 world-wide independent stations. As epicenters are located, reports are sent to the cooperating stations in exchange for their data and to any others who desire them. In the Fiscal Year 1964, epicenter information was distributed on the location of about 5,000 earthquakes that occurred in all parts of the world. This work was done by manual computation until 1960, when electronic computer methods were adopted.

In 1960 a group of 125 seismograph stations in 65 countries and islands were organized into a network for the teleseismic program. These stations contain standard instruments specifically developed for this program with the objective of obtaining standard response characteristics and records from which reliable quantitative measurements can be made.

In conjunction with this network, a Data and Analysis Center was established for collection and photographing of data on 70 mm film, from which a complete archives is assembled. Copies made from this master file are sent, upon request, to research scientists around the world. An analysis group is engaged in research on basic seismic problems such as wave path, velocity, magnitude, and energy propagation using data obtained from the network.

Seismic Sea Wave Warning System

Following the destructive seismic sea wave or tsunami, caused by earthquakes on April 1, 1946, the Survey organized a system to warn coastal communities in the Hawaiian Islands of the potential danger of sea waves originating from submarine earthquakes.

The system involved the cooperation of seismograph stations at several Survey observatories, surveillance reports of tide observers, special sea-wave warning devices, and an integrated communication network centering on the Honolulu Observatory. The seismograph stations, equipped with visual recorders and automatic alarm systems to alert the observer at any hour if an important earthquake occurs, enable observers to exchange information and determine quickly where the earthquake occurred. The tide stations in the system are equipped with wave recorders which are tuned to sound an alarm in reaction to the special frequencies of seismic sea waves. A by-product of sensitive seismographs developed for scientific study of the earth's interior, this system was subsequently expanded to warn the entire Pacific basin from Japan to Chile and from British Columbia to New Zealand.

In September 1971, about 1 year after the formation of NOAA, the Office of Seismology and Geomagnetism was transferred to the NOAA Environmental Research Laboratories. Shortly thereafter, the field operations and research programs for seismology and geomagnetism were moved to the Geological Survey, the data banks for these surveys and observations were made the responsibility of the NOAA Environmental Data Service, and the Tsunami Warning Service was moved to the NOAA National Weather Service. The monitoring of crustal movement for the purpose of maintaining the geodetic networks remained in the Survey.

Introduction of Aeronautical Charts

Passage of the Air Commerce Act in 1926 gave the Department of Commerce, among other things, the authority and responsibility to chart airways and to publish charts of these airways. With its century of experience in compiling and printing charts, the Survey was called on to produce these new charts.

The first aeronautical chart, published in 1927, was in strip form and covered the air route from Kansas City to Moline, Illinois. This early chart portrayed prominent topographic features for contact flying and the newly installed airport lighted beacons for night flights. The 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 visual flying.

With the advent of radio navigation aids, all-weather flying, controlled air traffic, and more aircraft operating at faster speeds and higher altitudes, new types of charts were required. The result was two new categories of charts--for visual flying, and for instrument navigation. The visual series included: local charts, sectional charts, planning charts, world aeronautical charts and jet charts--for visual flying and auxiliary use of radio navigational aids. The instrument series included: enroute charts, instrument approach, arrival and departure charts, and aircraft position charts--for all-weather flying and showing almost no topographic information for use as landmarks.

By 1957 there were 1,533 different aeronautical charts listed in nine separate series at various scales and for various uses with a production of nearly 44 million copies that year. By 1972 production reached a record high of 70.7

million copies annually. Since that time production has declined as a result of less frequent issue in a given period. Last year production was at a level of 43.5 million copies annually.

A large part of the information portrayed on aeronautical charts was initially taken from existing maps and source data furnished by other Federal and state agencies, with limited field work. However, flight-checking is performed extensively 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. The Federal Aviation Administration now supplies much of the information appearing on aeronautical charts.

Visual aeronautical charts now published include: two planning charts, issued every 4 months; 54 sectional charts, with the majority issued every 6 months and others annually; 21 VFR terminal control area charts, issued every 6 months; 26 world aeronautical charts, issued annually; 1 helicopter chart for the Los Angeles area, issued annually; and 1 local chart for Puerto Rico and the Virgin Islands, issued annually.

Instrument aeronautical charts now published include: 20 radio facility en route charts, issued every 56 days; 2 high altitude enroute charts and 5 high altitude navigation charts, issued every 56 days; 1 standard terminal arrival route volume, issued every 56 days; one Alaska terminal volume, issued every 56 days; over 4,000 instrument approach procedures plus supplementary data and 200 taxi charts, issued as required; 7 aircraft position charts, issued every 6 months; 1 Alaska supplement, issued every 56 days; 1 Pacific supplement, issued every 56 days; and 2 standard instrument departure volumes issued every 56 days.

Service in Two World Wars

While the Survey had been considerably involved in all major conflicts during its existence, it became almost totally involved in World War I. Recognizing the expertise and capability of the Survey, Congress enacted special legislation which transferred personnel and ships to the Navy and Army during World War I. More than half of the engineers and officers of the Survey were commissioned as civilian engineers or military officers. The remaining corps carried out special hydrographic and geodetic surveys required by the military.

In the Navy, officers served as navigators, watch and division officers on combat ships, as executive and commanding officers of Navy auxiliaries, and as experts on investigations of submarine detecting devices. In addition, they assisted with the design and installation of navigation equipment on Naval vessels. Some had extended duty on troop transports on many voyages across the Atlantic through the submarine zone between New York and Brest, France.

Officers transferred to the Army served with the Corps of Engineers in charge of military mapping, and in the Artillery as orientation and fire control officers.

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. The SURVEYOR saw extensive convoy duty in the Atlantic Ocean and the Mediterranean Sea. She participated in several submarine engagements, including an attack, in May 1918, by two German submarines on a convoy to which she was attached as an escort. One of the submarines was the U-39 which had sunk the LUSITANIA. After launching a torpedo which grazed the bow of the SURVEYOR, the wake of the sub was picked up by the SURVEYOR and she was able to deliver an effective depth charge. The ship could not leave the convoy to finish off the submarine, but the U-boat was disabled to the extent that it was compelled to enter the port of Cartagena, Spain, where it was interned. At the end of hostilities the SURVEYOR, as well as other Survey ships, was returned to Survey duty. During the remainder of her years of service in surveying waters under the jurisdiction of the United States, the SURVEYOR proudly displayed a large star on her smokestack, signifying the Navy commendation for her part in the engagement.

At New London, Connecticut, Lt. Cdr. 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, used with some success during the war, became the basis of the postwar development of echosounding and radio-acoustic ranging, and was the forerunner of vast developments in sonic and sound-ranging techniques for naval purposes.

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, complied 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 charts and maps were made for instruction of officers and troops in all branches of the armed forces.

World War II placed unprecedented demands and unique problems on the Survey. In addition to conducting major survey projects, the Survey provided numerous specialized services in instrumentation, graphical techniques, geodetic and geophysical applications, and expert consultation. Again, more than half of the commissioned officers of the Survey served in the Army, Navy, and Marine Corps, and a large number of civilian employees joined the military forces.

The war required enormous quantities of nautical and aeronautical charts. In a 5-year period, nautical chart production increased 10 times, and aeronautical chart production increased 25 times. An extensive war project of major importance was the production of more than 2 million copies of target charts for aerial bombing. Over 2,500 different target charts were prepared including those of such important objectives as the Ploesti oil fields of Romania, and the cities of Hiroshima and Nagasaki in Japan.

Commissioned officers of the Survey were selected for special assignments in the branches of the military service where their technical training and experience best fitted them. These included the training of amphibious troops in seamanship and navigation; duty at artillery schools to develop control survey methods for use in directing mobile artillery fire; as battalion observation officers; and the execution of hydrographic surveys in advance

of fleet operations in the Aleutains and the western Pacific. Some served on engineering construction work with the Navy Civil Engineer Corps. Others were assigned to the Air Corps to participate in a world-wide aerial mapping program, development of an aeronautical charting program, and for development and application of electronic methods for distance determinations.

Six of the Survey's nine major vessels were ordered to duty with the Navy. The PATHFINDER was active in the Pacific, surveying channels, anchorages, and beachheads, often surreptitiously at night. She sustained a kamikaze hit at Okinawa, losing a crew member and narrowly escaping destruction. She discovered the Pathfinder Reef 300 miles northeast of Guam. Although "Tokyo Rose" reported her sunk several times, 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 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 surveys and charts of the Philippine Islands made by the Survey over a period of 40 years were of great value during World War II. Fortunately, copies of all Philippine charts were on file in the United States. These charts were used by General McArthur during his reconquest of the Philippines in October 1944, showing details of offshore reefs, the character of beaches, safe channels, and the location of navigation hazards.

A major contribution to the war effort was the survey of the Alaska Peninsula and the Aleutian Islands. Prior to the war, survey of these regions had been on the basis of a gradual westward extension of required surveys. 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 engaged in this work.

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 copies during the war. Comprehensive tide and current data covering the entire world were prepared for the Navy, particularly for amphibious operations, including 68 special reports made from various files and translated captured documents.

Surveys were made for cable laying, equipment testing, ship launching, fleet anchorages, troop landings. Topographic surveys were made in many areas, including 16,000 square miles of shore areas using the Survey's nine-lens aerial camera. Geodetic field surveys and astronomic observations were extended into critical areas in the Aleutians and the Caribbean. Triangulation was extended through Canada, following the Alcan highway to connect geodetic work of the conterminous United States with that in Alaska.

Numerous other projects included the accurate location of battery emplacements, fire control centers, aircraft spotting towers, and similar installations in a large number of defense areas along our coasts; establishment of aircraft 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.

Magnetic observatories of the Survey 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.

Survey 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 equi-distant projection. Dr. Walter D. Lambert co-authored formulae and tables for the reduction of gravity measurements in the International Ellipsoid. Tables for the computation of geodetic positions were based on formulae developed by Lansing G. Simmons for the Clarke Spheroid of 1866.

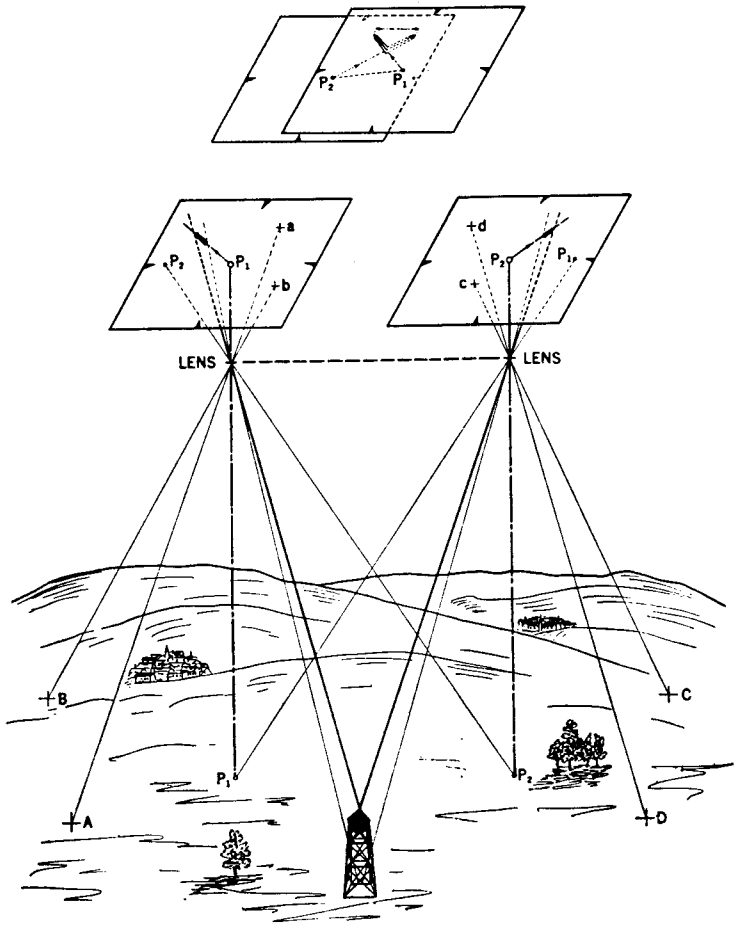
Photogrammetric Mapping

An important feature of the nautical chart is the land area, with its characteristic shore forms, landmarks, elevations, and depressions. For inshore navigation, a mariner relies a great deal on prominent shore objects to fix his position and sometimes even uses the configuration of the shoreline for identification.

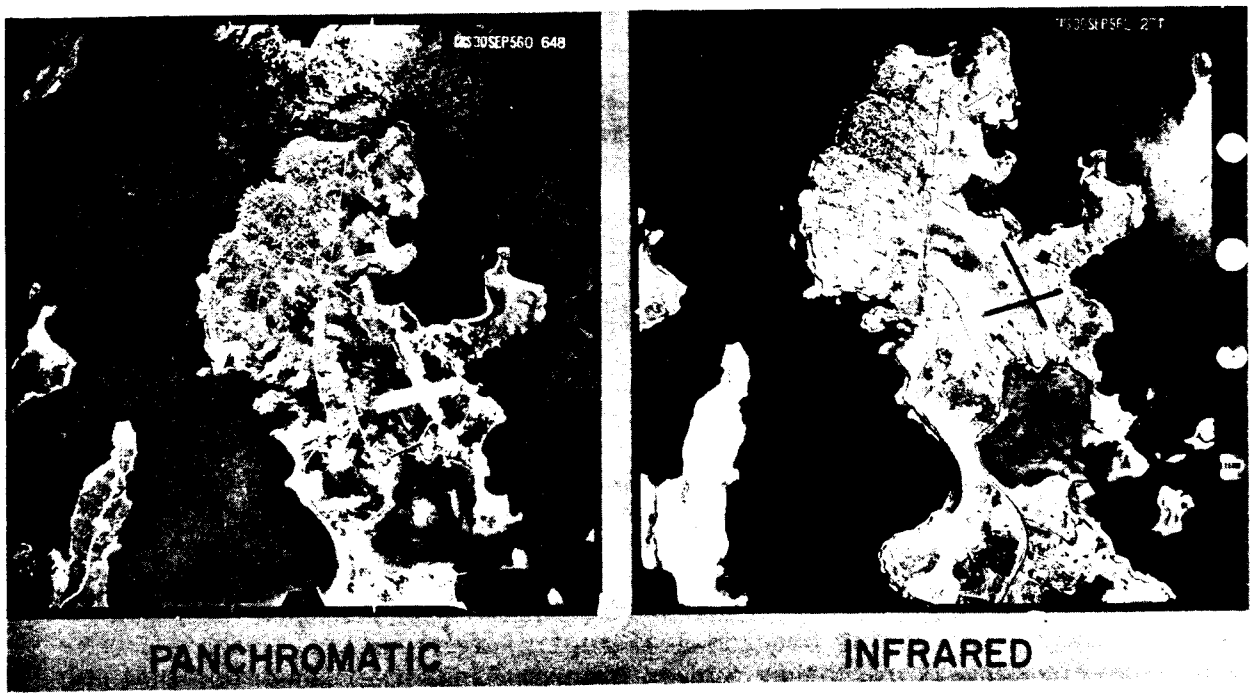
From the beginning, the principal instrument used by the Survey for topographic surveying was the planetable. The introduction of the telemeter rod, about 1865, for measuring distances with the alidade, greatly facilitated the surveying of complex shorelines and gave the chart increased fidelity.

The years preceding and following World War II saw the emergence and flowering of the new science of aerial photogrammetry--the greatest advance in topographic mapping since the planetable prototype was developed by Johann Praetorius, in 1590. Ground topographic methods were replaced by the more economical and efficient method of mapping from the air. The wealth of information and fullness of detail captured in an aerial photographic survey far exceeded other practicable methods of surveying.

Photogrammetry was first used by the Survey in the Alaska-Canada boundary surveys made in the 1890's using photographs taken from known high points on the ground. During the 1920's air photos were used to a very limited extent for mapping and charting, including single-lens photos of the New Jersey coast,



Concept of photogrammetric mapping from aerial photos



Simultaneous aerial photos showing shoreline detail with infrared

the Mississippi Delta, the Lake Okeechobee area in Florida, and other inaccessible areas.

With development of multiple-lens cameras and more reliable photography in the late 1920's, the Army Air Corps began to supply aerial photos for photogrammetric mapping. From this time, the methods of aerial photography and photogrammetry became more complete in coverage and less tedious in application, and soon demonstrated a superiority over ground planetable surveying.

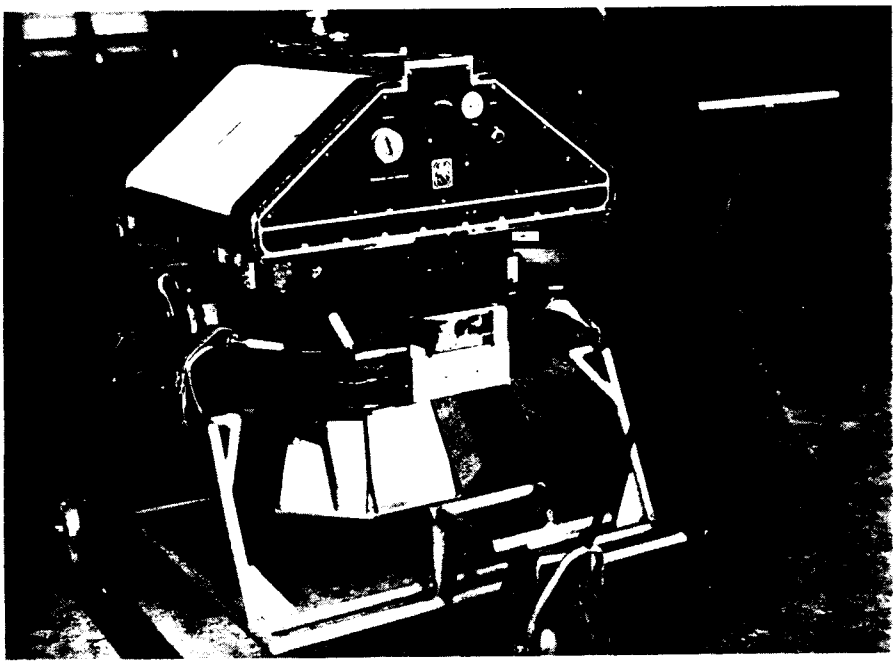
Photogrammetry provides maps of the coastal land area which are used for construction and maintenance of nautical charts. Large-scale shoreline maps are made prior to hydrographic surveys to show shoreline detail, including slightly submerged features near the shore, and for hydrographic control stations. Photogrammetric mapping of the coastline is also done by stereoscopic instruments, directly onto the nautical chart drawings. Landmarks and aids to navigation are located photogrammetrically.

In 1926, Lt. Cdr. O. S. Reading designed a precision nine-lens aerial camera which revolutionized mapping in remote areas. Development of this camera was another in the long list of significant achievements by staff scientists and engineers of the Survey, as they continually advanced the state of the art in geodesy and hydrography. This camera, together with transforming, rectifying, and stereoplotting equipment, was of great value to topographic survey work in Alaska. Its use permitted the bridging of difficult and inaccessible terrain with a minimum of ground control. This unique nine-lens camera was used for a quarter of a century, taking its last photographs in 1961. It covered 124 square miles in a single picture, on a scale of about 3 inches to the mile, at a flying altitude of 14,000 feet, and thus considerably reduced the ground control required for mapping. Reading also developed a 50-inch precision camera in 1933 for accurate preparation of chart reproduction negatives.

A considerable effort is devoted to monitoring the coastline and correcting chart drawings directly from new aerial photography by means of stereoscopic plotting instruments. Repeat aerial photography and repeat surveys are essential for the up-to-date maintenance of nautical charts. Consequently, the Survey's files of aerial photography and archives of survey records, including the planetable surveys of the coastline made prior to photogrammetry, contain a unique record of coastal changes over a period of 140 years.

Survey aircraft, fitted for simultaneous photography with two cameras, are used to take panchromatic, infrared, and color photography with wide-angle and superwide-angle, single lens, precision mapping cameras. In general, the photography is taken on film; however, glass plates are used for more precise work. Most aerial photography of the Survey covers two primary areas of activity: the coastline of the United States and commercial airports.

Photogrammetric operations in oceanography include the measurement of tidal currents, deep-sea stereoscopic photography for studies of the ocean floor, and various research and development studies. Photogrammetric operations in geodesy include satellite triangulation, research and development studies toward the application of analytic aerotriangulation to the measurement of crustal movement, and to the breakdown of control for mapping. Special photogrammetric surveys for other Survey programs and other agencies include:



Precision nine-lens aerial camera

Commercial echosounders on Survey vessel in 1967

aerial photography for the study of faulting and changes following earthquakes; boundary surveys; cadastral surveys; mapping with infrared photography; and advice and assistance in the application of photogrammetry to surveying and mapping problems.

Aerotriangulation

Aerotriangulation is a method of photogrammetry that uses aerial photographs to determine horizontal and vertical position of terrain points. The process, in strips or blocks of photographs, starts with rather widely spaced stations of the basic geodetic control network, established by the geodetic surveys, and determines the horizontal positions and elevations of additional terrain features at closer intervals for map compilation and other purposes.

An early procedure employed in World War II was the determination of horizontal ground positions using so-called "radial plot," which was based on the concept that an aerial photography transforms the terrain into a central perspective projection. This method had many serious shortcomings, but it was fast and economical and provided horizontal positions adequate for mapping. In general, the horizontal accuracy of points determined by radial plotting was about 0.2 mm to 0.3 mm (0.008 in. to 0.012 in.) at the mapping scale.

The experiences during World War II and the rapid growth of aerial photography in postwar years provided the impetus for development of instruments and procedures for the compilation of planimetric and topographic maps. Stereoscopic analog instruments became widely used for processing higher altitude photographs. Analog instruments such as the Zeiss Stereoplanigraph and the Wild Autograph were used to orient successive pairs of photographs in a continuous strip and to record measured XYZ coordinates of selected ground points in a single three-dimensional instrument coordinate system. The selected points included control stations whose geodetic positions were known by previous classical surveying measurements on the ground. Graphical methods were then used to "adjust" the remaining ground points for systematic "bending" of the strip between bands of known position. The final product provided adequate geodetic control in each pair of photographs, from which instruments of lesser accuracy could be scaled and leveled to compile a portion of a map. Published accuracies of this system were reported to be in the neighborhood of one part in 5,000 of the flight altitude.

In the late 1950's the process of adjusting ground points was changed from graphical to numerical analog using small electronic computers such as the IBM 650 and 1620. However, the accuracy of the systems was still limited by the analog instrument itself, which prompted an investigation of numerical or analytical photogrammetry. Analytical aerial triangulation is a method in photogrammetry whereby the simulation of the stereo-intersection is entirely mathematical. That is, the observations in the system are limited to precise measurements of coordinates of images on the photographs, and the determinations of ground coordinates of these images are made by a mathematical model simulating the geometry of overlapping aerial photography. The accuracy of the system is limited only by the precision of measurement and the exactness of the mathematical simulation. The Survey investigated several approaches, and by 1966 had an operational block adjustment process capable of handling up to 200 photographs. Capt. G. C. Twinkel was a leader in the group effort to develop analytical photogrammetry.

The analytic method is very adaptable. It can be applied with photographs from any precision mapping camera and photography of different scales, made with cameras of different focal length and angular fields, and can be combined in a single strip or block aerotriangulation.

Chart Production in the Millions

The constantly expanding areas of the oceans requiring charting and the growing requirements of marine commerce created a tremendous increase in the work of compiling and publishing charts. Before World War I the Survey's catalog listed 658 nautical charts, with 128,000 individual copies published annually. By 1918 the number of copies increased to 264,000. The World War II peak years required more than 21 million copies annually of all kinds of charts. New presses had to be installed and operated on three shifts. Special charts were printed for the Navy Hydrographic Office, the Air Corps, and other agencies. By 1956 the catalog listed 806 different nautical and 1,533 aeronautical charts. Total production was near 44 million copies.

Contributing to this tremendous increase in the volume of chart production was the issuance of many new harbor and Alaska charts, a new series of general charts designed for coastal navigation, and a new Intracoastal Waterways series of charts. The big growth in charting, however, resulted from tremendous increases in the use of aeronautical charts.

The greatest single contribution the Survey has made in the reproduction process has been the development of negative engraving (referred to as "scribing"), around the turn of the century. This technique was first used as a more economical means of revising nautical charts. Revisions were applied directly to the wet-plate glass negatives using the conventional engraving needles then in use. Later, entire nautical charts were reproduced by this method. The compilation manuscript was photographed on glass negatives. These were then coated with an emulsion that was pervious to light and so afforded the engraver a facsimile of the manuscript.

In 1935, the first engraving tool for specific use on glass negatives was designed. A special assignment for reproducing maps for the Tennessee Valley Authority gave impetus to the design of additional tools, and by 1940 most of the basic instruments and techniques in use today had been perfected in the Survey. Today, stable plastics are the primary media for negative engraving.

Two five-color presses, three two-color presses, and a single one-color press are used to print the millions of copies produced each year. Printing plates up to 47 1/4 inches by 60 inches are used, and color process printing techniques are used to imprint 12 different colors on an aeronautical chart with a single pass through the five-color press. Extensive photomechanical equipment such as a 50-inch precision camera and finishing equipment, such as multi-station collators, support the reproduction process.

New Instruments for the Electronic Age

As the preceding text shows, the Survey remained at the technical forefront in developing instruments, equipment and techniques for use in conducting its

missions in geodesy, hydrography, topography, ocean research, cartography and related projects. Born out of necessity to improve efficiency and production, most developments were carried on because the required equipment was not commercially available.

Depth Sounding. In 1923 the braided-wire-center cotton cord was introduced for sounding, with the advantage that it did not substantially change length because of stretching. To permit deeper sounding than was formerly possible with a moving ship, elaborate trolley rigs were devised, about 1916, to carry the lead a ship-length forward of the sounding instrument and give it more time to settle to the bottom without stopping the ship.

A major 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, and without stopping the ship, merely by allowing the tube to trail astern until it had reached bottom. Depths as great as 600 feet could be sounded with sufficient accuracy for charting purposes.

Great ingenuity was used to develop methods for fixing the position on sounding lines offshore and beyond sight of control points. Celestial sights were used with refinement far exceeding ordinary ship navigation practices. Dead reckoning was used with attention to all details.

Arrays of survey buoys were laid out in the shallow continental shelf waters of the Atlantic and Gulf Coasts. They 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, with the distance between them being measured by known lengths of piano wire stretched along the lines. Azimuths or bearings of the lines were determined by simultaneous vertical and inclined sextant angles to the sun.

One of the most significant developments in hydrographic surveying was the use of underwater acoustics for measurement of both depth and horizontal distance, as an outgrowth of World War I submarine acoustic research.

In the early 1920's a private firm developed the fathometer, an echosounder 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 measuring the time required for a sound signal to travel from an oscillator to the sea floor and back. It was extensively tested by the Survey and adopted in preference to a Navy device for echosounding which was also tested. Cooperation of the Survey in this development contributed in large measure of the eventual success and general use of sonic sounding methods. Dr. H. G. Dorsey developed a flashing red light that obviated the difficult and uncertain readings of the original fathometer. He participated in the development of the Radio Acoustic Ranging system, carried out studies in sea water physics, and did research in the field of underwater sound propagation.

By the late 1920's fathometer soundings became routine procedure, permitting continuous observations while the vessel was underway. In the years just prior to World War II, recording fathometers were introduced and were considerably improved with advances in electronics.

Radio Acoustic Ranging. About the same time that the fathometer was being developed, the Survey was developing a system for measurement of distances by timing the travel of underwater acoustic signals. Sound waves created by small TNT explosions at the ship were picked up by shore-based hydrophone stations, and immediately relayed as radio signals back to the ship for position plotting. Called Radio Acoustic Ranging (RAR), this was used on the GUIDE as early as 1924, and gradually became an accepted system, although it had limitations.

To improve the RAR system, Survey scientists in 1932 developed an automatic sono-radio buoy. Anchored at known positions in relation to fixed control points on shore, the buoys automatically performed the same function as the original RAR shore stations. They were much more efficient, provided better signals and operated over greater distances which extended survey ranges. These instruments were the forerunners of many types of sentinel and detector buoys used by the Navy in World War II.

Essential to the determination of the velocity of sound in water is knowing the values of temperature, salinity, pressure due to depth, and other physical properties at the same time velocity is being measured. The inability to secure accurate data for these parameters over wide areas made radio acoustic ranging inaccurate for some applications, but it nevertheless was used to conduct hydrographic surveys at considerable distances offshore with better accuracy than was possible with previously available systems and techniques. Combined with echosounding, RAR gave the Survey a new conception of speed and accuracy applied to offshore hydrographic surveying, and laid the foundation for development of a new type of nautical chart which showed depth contours. The first such chart was published in 1939.

A major benefit of RAR was its use in the discovery and interpretation of the Sofar layer in the early 1930's by Cdr. 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 employed in the well-known Sofar signaling system developed by the Navy for distress calls.

Modified Shoran System. In their search for a system which would eliminate the undesirable features of the RAR system, Survey scientists turned to electromagnetic radiation in the atmosphere. They elected to work with Shoran. The Survey was the first agency to use Shoran, a form of radar, for position control of survey vessels. Shoran, a very high frequency pulse system employing responder stations at fixed locations, operated in all types of weather and at any time of day as a line-of-sight system. Its maximum range was 50 to 75 miles offshore with an accuracy of several hundred feet. First used by the Survey ship EXPLORER in 1945 for Aleutian Island surveys, the system was a modification of special type radar used for controlling the position of aircraft during a bombing mission. The standard airborne equipment was modified for use as the fixed shore station beacon. The position of a survey vessel was determined by measuring the elapsed time between a transmitted pulse and the return signal from two fixed stations.

Electronic Position Indicator. Faced with the problem of accurate position control at distances greater than the range of the Shoran system, Survey scientists developed a new system called the Electronic Position Indicator (EPI). This system combined the frequency and modulation (long range) of Loran with the high frequency pulses (distance measuring) of Shoran. This combination made possible the determination of a ship's position at distances up to 400 miles with an accuracy of 250 to 500 feet. Maximum range was 550 miles.

EPI operated in the low-frequency range of about 2 megacycles per second and utilized the ground wave, so that its distance range did not depend upon the elevation of the control stations. The principles of position fixing with EPI are essentially the same as with Shoran--both involve the measurement of small time intervals on the order of one ten-millionth of a second.

Shoran and EPI were used from the late 1940's through 1960 to control all offshore hydrographic surveys.

Commercial Positioning Systems. In the late 1950's the Survey began testing a number of commercially available electronic positioning systems for use to accurately determine the position of survey vessels, including Raydist, Decca Hi-Fix and Loran.

Raydist DM is a radiolocation phase system which repeats itself every half wavelength in the 300 KHz range or with a lane width of about 150 feet. Today's models of this system operate with a distance range of about 250 miles during the day and 150 miles at night with accuracies of several feet. Decca Hi-Fix is also a phase system operating in the 1700 KHz range or with lane widths of about 300 feet. It can be used as a range-range or hyperbolic system. The accuracies of Hastings and Decca systems are about the same. Both have been used on Survey vessels since the 1960's.

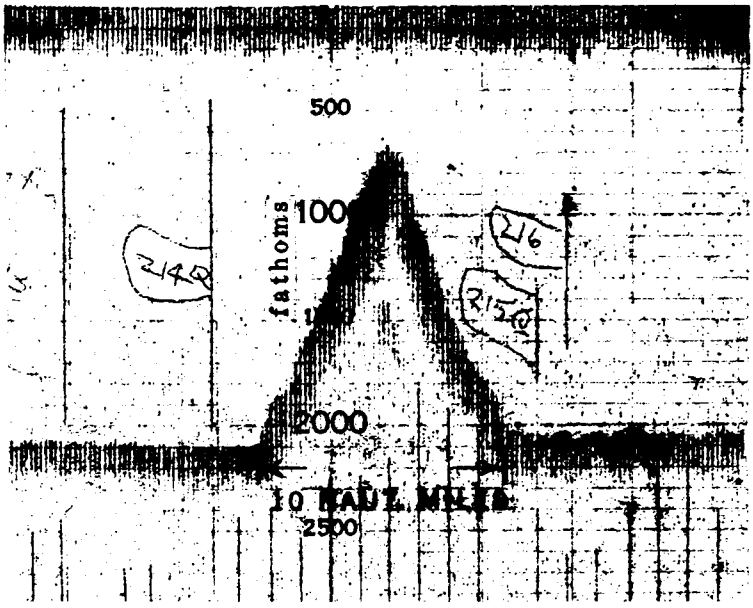
For longer ranges Loran C is used. This is a hyperbolic system using a pulse and phase combination operating at 100 KHz. Accuracy depends on range, which varies from 1,000 feet at 1,000 miles to less than 100 feet at 100 miles. More recent longer range navigation and positioning systems now being used aboard Survey vessels include Loran C, Omega, the Navy Navigation Satellite system.

Several of the new generation short-range electronic navigation and positioning systems have been used including the Del Norte system.

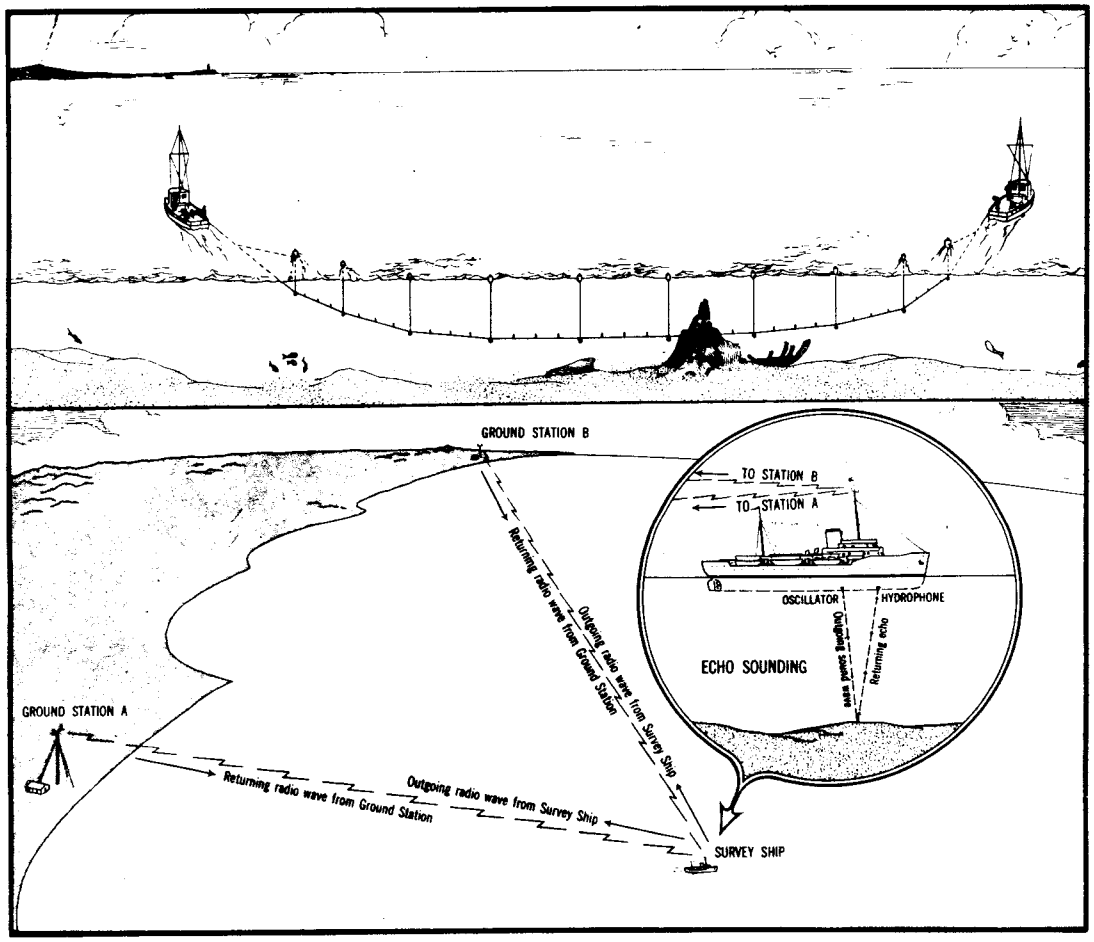
Tide and Current Instruments. A portable automatic tide gage, developed by Rude and Fischer in 1923, greatly expedited tidal work in hydrographic surveys.

In the late 1940's, in response to a need to measure sea waves on a broad scale, a recorder and a highly specialized detector were developed by Survey scientists to sound an alarm in response to the special frequencies of seismic seawaves.

Current observations were expedited by the invention and development of a radio current meter by Elliott B. Roberts in the late 1940's. Meters, suspended at predetermined depths from a buoy, transmitted current speed and direction data by radio to the tending vessel. One field party could operate several installations simultaneously.



Echosounding of a seafloor volcanic cone



Upper diagram, wire drag to locate obstructions
Lower diagram, electronic determination of depth and position

Geodetic Measurements. The limitations of long lines and difficult visibility resulted in exhaustive efforts to improve sighting and measurement methods. Acetylene lights were used from 1902 to 1916 for primary triangulation surveys. Introduction of the electric signal lamp in 1916 allowed daytime surveying on triangulation lines that could not be sighted in the daytime with previously used lights. The use of electric lamps at night permitted observations with refraction errors largely reduced. Simultaneous sights on air-dropped flares were also used.

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 surveying. 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 the time required for a wooden tower.

Geomagnetism and Seismology. On the basis of magnetic instruments developed for submarine detection in World War II, an airborne induction magnetometer was designed for the Survey by the Navy. This was the first instrument capable of magnetic field measurements entirely free of shock and accelerations. In 1957, magnetometers employing nuclear resonance effects were studied 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 eventually followed by other countries.

Modifications to standard instruments included viscous coupling in the McComb-Romberg seismometer to compensate for instrument tilt. A low cost seismometer with high precision performance was developed by the Survey. New instrument developments included the Neumann-LaBarre vibration meter, and a torsion seismometer developed by National Bureau of Standards for the Survey. Accelerographs were designed by the Survey staff for quantitative recordings of ground motions in the conduct of engineering-seismology investigations. Carder displacement-meter components were later added to this instrument.

Permanent recording methods and telemetering were developed for use in data processing via cable and radio links for field work and seismic seawave warning systems.

Advances in Nautical Charting

Like most programs of the Survey in the first half of the 20th century, nautical charting saw many significant improvements. A nautical chart is the sum total of geodetic, topographic, hydrographic and tidal surveys plus photogrammetry, cartography and lithography, and thus its progressive improvements over the years can be viewed as a composite of the improvement in each phase and step in its creation.

As the preceding parts of this section on the 20th century show, marine surveying advanced from random observations to systematic surveying with vastly improved ships, instruments, equipment and techniques.

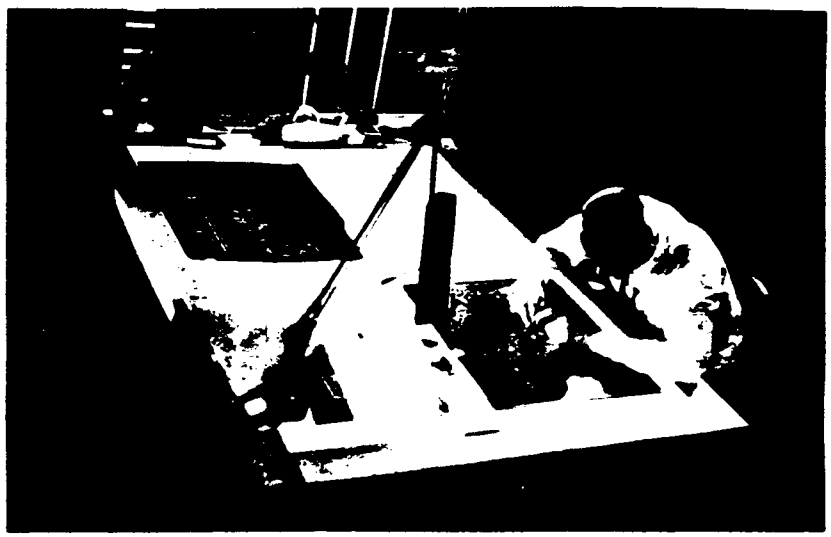
Establishment of the North American Horizontal Geodetic Datum of 1927 was a monumental step in chart making for it meant that every point on every nautical chart of the Atlantic coast, the Gulf Coast, the Pacific coast, Alaska, and the Bering Sea was referenced to one common position of longitude and latitude on a universally accepted spheroid. Thanks to the insistence of Hassler for high accuracy triangulation as the basic control for nautical charts, the United States achieved an enviable position in the world.

The advent of electronic and acoustic systems for determining water depth and a ship's position almost instantly provided tremendous increases in the area of ocean that could be surveyed and the accuracy of measurements made. This too was a revolutionary advance in nautical charting.

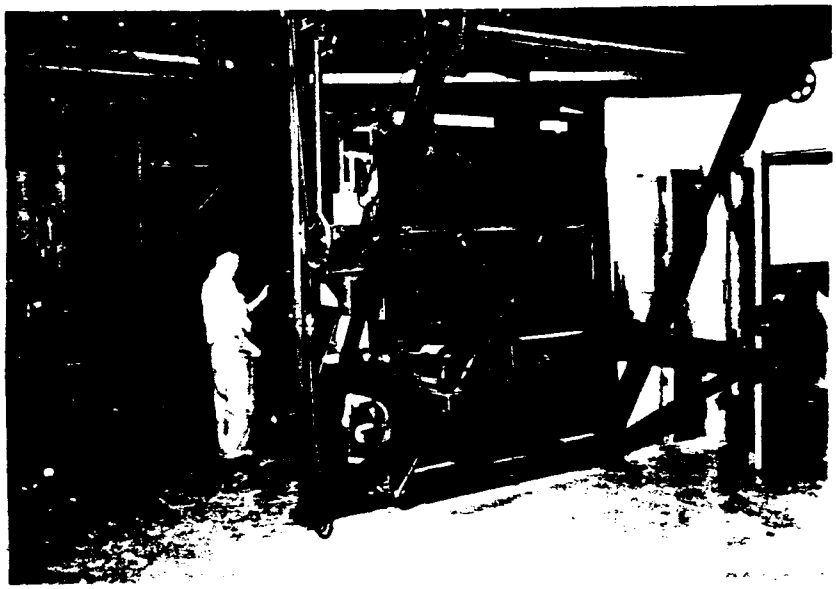
Equally significant in chart making and map making was the introduction of aerial photography and the use of photogrammetry. As with electronic instruments for hydrographic surveying, photogrammetry provided tremendous increases in shoreline areas surveyed, the accuracy of charting, and the ability to quickly revise existing charts.

The most significant advance in nautical chart design, since the introduction of color, was the special emphasis on depth contours which appeared on a chart issued in March 1939. The installation of echosounding instruments on merchant ships, commercial vessels and naval vessels called for a new type chart--one that would enable the navigator to utilize fully this new sounding technique for fixing his position at sea. The more faithfully the chart portrays the submarine relief, the greater will be its usefulness to the navigator. The answer was not an increase in the number of soundings charted; this was already a characteristic of the conventional chart. A method was needed which would utilize the wealth of submarine detail provided by modern hydrographic surveys, and portray this detail in a simple and useable manner. The new depth contour chart was the result. In drawing the contours, full use is made of all the soundings obtained on the hydrographic survey. Characteristic features of the ocean bottom are brought into prominence. These features, comparable to permanent landmarks, provide the navigator with a simple method for checking his position by comparing a line of echosoundings with the charted depth contours.

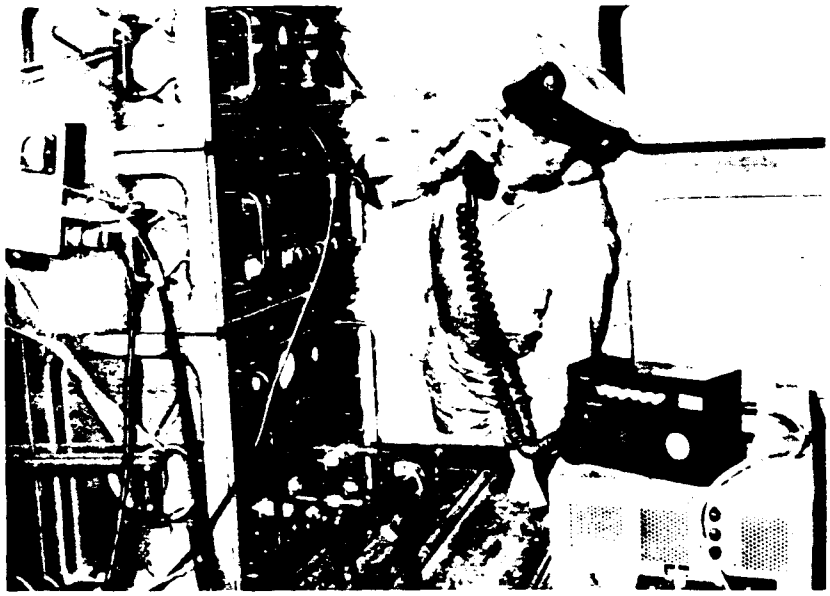
Another significant innovation in nautical charting took place after World War II when the U.S. Coast Guard established Loran A transmitting stations along the United States coasts to aid coastal navigation. Because the hyperbolic lines of position for Loran do not lend themselves to ready plotting on a nautical chart by a navigator, the Coast Guard developed a system for combining hydrographic information and Loran information on a nautical chart without confusion. Loran charts, which provide coverage of the Atlantic, Pacific, and Gulf Coasts, are now basic to marine navigation. In the 1960's Loran C began replacing Loran A, which will be officially phased out in the next 7 years. The placement of Loran C lines of position on nautical charts started in 1964 with the issuance of two such charts.



Engraving nautical chart negatives



Fifty-inch precision camera makes chart negatives



Shore station for electronic positioning system

RECENT YEARS

The Survey enjoyed tremendous success in carrying out its scientific and engineering programs in the first half of the 1900's, not withstanding the potential for negative impacts from two world wars.

In the early 1950's, a number of new forces began to influence the Survey--the growing acceptance of the importance of oceanographic exploration, the demand for new marine hardware, more arguments supporting a single Federal agency for marine science and engineering, a growing realization of the potential economic value of world ocean resources, and environmental protection.

As 1960 came into view, a significant new amalgamation of ocean/marine interests bagan to occur. The participation came from all quarters--the United States Congress, the civilian Navy, the military Navy, the academic community, nonmilitary Federal agencies with ocean/marine activities, private research organizations, and major industrial firms interested to secure government contracts and build ocean hardware and systems.

As a result of these concerted interests, two major oceanography/environmental reorganizations occurred in the Federal government within 5 years--the formation of the Environmental Science Services Administration (ESSA), and the formation of the National Oceanic and Atmospheric Administration (NOAA). Both directly involved the Survey.

Formation of ESSA

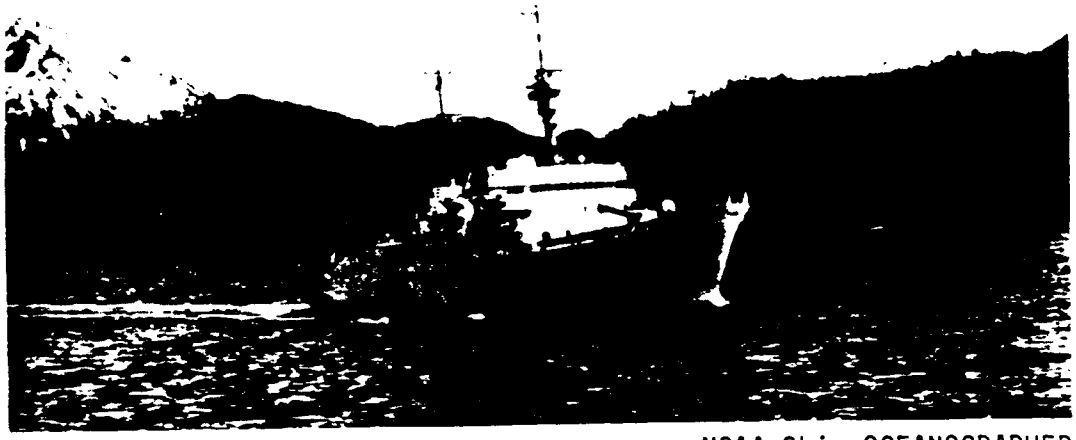
In July 1965, the Survey became a part of ESSA, which was formed to provide a single national center to describe, to understand, and to predict the state of the oceans, the state of the upper and lower atmosphere, and the size, shape and structure of the earth. ESSA had five major elements: Environmental Data Service, Weather Bureau, Institutes for Environmental Research, Coast and Geodetic Survey, and National Environmental Satellite Center.

Under ESSA, the Survey had five major components: geodesy and photogrammetry; seismology and geomagnetism; hydrography and oceanography; aeronautical charting and cartography; and executive and technical services.

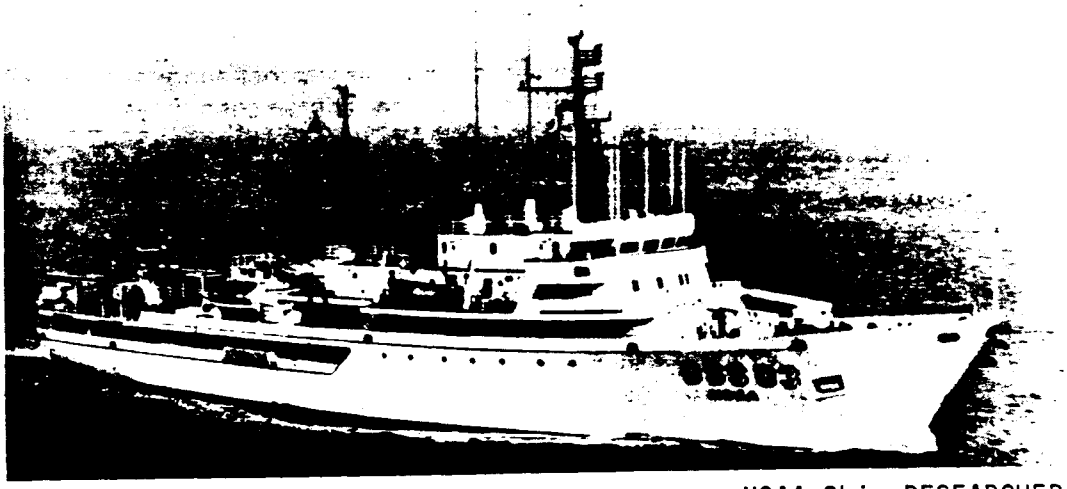
In the reorganization, earth sciences and oceanographic research personnel and facilities of the Survey were transferred to the new Institutes for Environmental Research.

Formation of NOAA

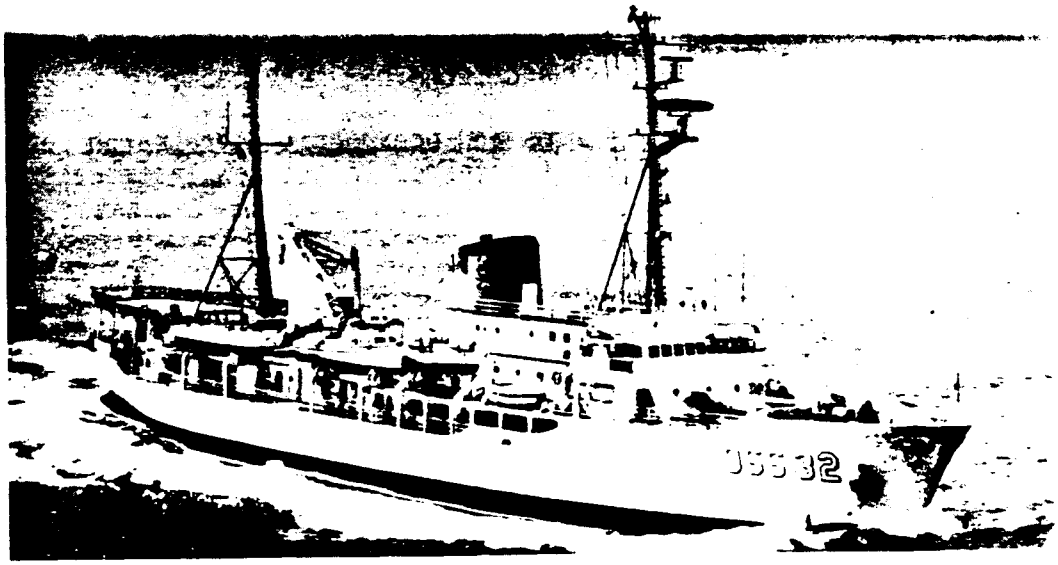
Within a year after ESSA was formed, the Marine Resources and Engineering Development Act of 1966 was passed by the Congress. It called for a Commission on Marine Sciences, Engineering and Resources to carry out a comprehensive study and report to the President and Congress. After a 2-year exhaustive and far-reaching study, the top-drawer, blue-ribbon group issued the now famous Stratton Commission Report, which was chaired by Dr. Julius A. Stratton, chairman of the Ford Foundation.



NOAA Ship OCEANOGRAPHER



NOAA Ship RESEARCHER



NOAA Ship SURVEYOR

Of the several recommendations made by the commission, one called for "a plan of government reorganization best adapted to the support of Federal ocean/marine programs and to indicate the expected costs."

As a result of this recommendation, various administration proposals and Congressional proposals, NOAA was established on October 3, 1970, as part of a presidential environmental reorganization plan. The purpose was to create a civil center of strength for expanding effective use of ocean resources; for monitoring and predicting conditions in the atmosphere, oceans and space; and, for exploring the feasibility and consequences of environmental modification. The new NOAA combined ESSA with several other Federal agencies to become the largest operating agency in the Department of Commerce, with a current budget of nearly $700 million and more than 13,000 employees. There are eight major operating groups in NOAA:

1. National Ocean Survey (formerly C&GS),
2. National Marine Fisheries Service, which combines the functions of the former Bureau of Commercial Fisheries and the Marine Game Fish Research Program,
3. National Weather Service, formerly the U.S. Weather Bureau,
4. Environmental Data Service, which combines the functions of the ESSA Environmental Data Service and the National Oceanographic Data Center,
5. National Environmental Satellite Service, formerly the ESSA National Environmental Satellite Center,
6. Environmental Research Laboratories, which combines the functions of the former ESSA Research Laboratories and the Marine Minerals Technology Center,
7. Office of Sea Grant, which administers cost-sharing marine programs at the state level through universities and colleges, and
8. Office of Coastal Zone Management, which administers a cost-sharing program of coastal zone planning and management at the state level.

Expansion of the Fleet

The year 1960 marked the beginning of a major change in the size, age and capabilities of the Survey fleet. In the decade of the 1960's, the entire fleet of 14 ships was replaced with new, larger and more sophisticated ships which were designed and constructed specifically for hydrographic and oceanographic survey and exploration. Up to this time in the 125-year history of hydrographic surveying, the C&GS fleet was made up mostly of converted, leased, and loaned vessels from private citizens, the Navy, and commercial shipyards. Very few were originally designed for ocean surveying.

During the 1940's and World War II, more than 25 different vessels were commissioned and decommissioned by the Survey to meet its requirements and to support the military effort, most being Navy and Coast Guard ships. During the 9 years between 1950 and 1959, only one vessel was put into service--the BOWIE in 1950, and this ship was Navy surplus.

By 1957, most of the 14-ship Survey fleet was grossly inefficient and obsolete. The four major vessels which were the beginnings of the modern fleet were not young anymore--the EXPLORER and the PATHFINDER (built in the 1940's), the

NOAA FLEET - SUMMARY AND DESCRIPTION OF VESSELS

Name	Class	Year Built	Length Feet	Disp. Tons	Range N. Mile	Total Berths	Home Port	Program Use - Observations
OCEANOGRAPHER	I	1966	303	3,959	15,200	110	Seattle	Oceanographic: hydrography, magnetism, gravity, temperature, bottom photography, bottom samples, bathymetry, meteorology, water samples, biology, coring, 5 labs, computer controlled data acquisition.
DISCOVERER	I	1966	303	3,959	15,200	110	Seattle	Oceanographic: hydrography, magnetism, gravity, temperature, bottom photography, bottom samples, bathymetry, meteorology, water samples, biology, coring, 5 labs, computer controlled data acquisition.
RESEARCHER	I	1970	278	2,772	13,000	79	Miami	Hydrographic: magnetism, gravity, meteorology, coring, bathymetry, seismic, biology, water samples, submersible launch, 7 labs, computer controlled data acquisition.
SURVEYOR	I	1960	292	3,150	12,800	129	Seattle	Hydrographic: bathymetry, magnetism, gravity, currents, water samples, seismic, biology, 4 labs.
FAIRWEATHER	II	1968	231	1,800	8,000	78	Seattle	Hydrographic: bathymetry, BT, water samples, bottom sampling, currents, magnetism, 2 labs.
RAINIER	II	1968	231	1,800	8,000	78	Seattle	Hydrographic: bathymetry, BT, water samples, bottom sampling, currents, magnetism, 2 labs.
MILLER FREEMAN	II	1967	214	1,782	16,000	43	Seattle	Fisheries: high seas trawling, biology, plankton, water chemistry, 5 labs.
MT. MITCHELL	II	1967	231	1,800	8,000	78	Norfolk	Hydrographic: bathymetry, BT, water samples, bottom sampling, currents, magnetism, 2 labs.
PEIRCE	III	1963	163	760	4,500	40	Norfolk	Hydrographic: bathymetry, BT, water samples, bottom sampling, currents, gravity, plankton, 3 labs.

WHITING	III	1963	163	760	4,500	40	Norfolk	Hydrographic: bathymetry, BT, water samples, bottom sampling, currents, plankton, 2 labs.
McARTHUR	III	1966	175	995	6,400	40	Seattle	Hydrographic: tides, bathymetry, BT, water samples, bottom sampling, STD, plankton, magnetism, 3 labs.
DAVIDSON	III	1967	175	995	6,400	40	Seattle	Hydrographic: bathymetry, BT, water samples, bottom sampling, currents, plankton, magnetism, 3 labs.
OREGON II	III	1967	170	906	10,700	29	Pascagoula	Fisheries: high seas trawling, exploratory fishing, biology, oceanography, 5 labs.
GEORGE B. KELEZ	IV	1944	177	936	7,300	25	Norfolk	Oceanographic: bottom sampling, currents, STD, BT, fishing, biology, plankton, physical water, 2 labs.
ALBATROSS IV	IV	1962	187	1,089	9,000	36	Woods Hole	Fisheries: hydrography, dredging, acoustic, bottom sampling, biology, 5 labs.
TOWNSEND CROMWELL	IV	1963	163	652	10,000	21	Honolulu	Fisheries: trawling, biology, chemical, oceanography, 3 labs.
DELAWARE II	IV	1968	155	680	8,000	23	Sandy Hook	Fisheries: stern trawler, otter trawls, bongo nets, neuston nets, biological, wet lab.
FERREL	IV	1968	133	360	2,700	18	Norfolk	Current Survey: current direction and speed, temperature, salinity, depth, meteorological.
DAVID S. JORDAN	IV	1965	171	890	9,000	29	San Diego	Fisheries: trawling, biology, hydrography, coring, acoustics, 3 labs.
RUDE	V	1966	90	190	800	10	Norfolk	Hydrographic: RUDE and HECK operate together for wire drag surveys, 10,000 ft. wire, 2 launches.
HECK	V	1966	90	190	800	10	Norfolk	
OREGON	V	1946	100	410	4,800	15	Kodiak	Fisheries: purse seiner, high seas fishing, biological, physical oceanography, plankton, bottom trawl.
JOHN N. COBB	V	1950	93	250	4,800	13	Seattle	Fisheries: purse seiner, high seas fishing, biological, physical oceanography, plankton, bottom trawl.

Name	Class	Year Built	Length Feet	Disp. Tons	Range N. Mile	Total Berths	Home Port	Program Use - Observations
MURRE II	VI	1943	86	295	1,800	9	Juneau	Fisheries: oceanography, biology, freight hauling, 2 labs.
GEORGE M. BOWERS	VI	1955	74	125	2,000	10	Miami	Fisheries: shrimp trawler, oceanography, fishing, 1 lab.
Program Managed NOAA Ships								
RORQUAL	VI	1942*	65	90	1,600	6	Sandy Hook	Fisheries: physical oceanography, trawling, plankton, bottom sampling, diving, coring.
KYMA	VI	1942	65	90	1,600	6	Sandy Hook	Fisheries: physical oceanography, trawling, plankton, bottom sampling, diving, coring.
VIRGINIA KEY	VI	1952	65	90	1,600	6	Miami	Oceanographic: STD casts, XBT casts, bottle casts.
SHENEHON	VI	1953	65	90	2,100	8	Detroit	Limnology: temperature, hydrography, bottom sampling, waves, meteorology, bathymetry, 1 lab.

* converted 1961

Class I	5501-9000 HPT
Class II	3501-5500 HPT
Class III	2001-3500 HPT
Class IV	1001-2000 HPT
Class V	500-1000 HPT
Class VI	up to 500 HPT

HPT = numerical sum of vessel shaft horsepower plus gross tonnage

HYDROGRAPHER (built in 1931), and the PIONEER (converted in 1943). The old age, inefficiency and poor condition of most of the vessels was a deterrant to carrying out mission requirements, much less meeting the requirements for needed new ocean surveys.

This situation, coupled with the growing interest in ocean research and exploration, brought about a number of proposals for a long-range program of oceanographic shipbuilding for government agencies, nonprofit research organizations and educational institutions. Fortunately for the United States, the decade of the 1960's saw a large increase in the number of its ocean exploration and survey vessels.

In this 10-year span from 1960 to 1970, the Survey commissioned 14 new vessels, all designed and constructed to meet specific program requirements in hydrographic and oceanographic surveying. While the number of new vessels alone was significant, of more importance was the capability to carry out multiple marine research and exploration programs of the new ESSA earth science and oceanographic laboratories which came into being in 1965.

Shortly after establishment of NOAA late in 1970, the Office of Fleet Operations was organized in the Survey to manage the NOAA fleet, and program-related ships, which at that time totalled 32 vessels. This included the 15 hydrographic and oceanographic vessels previously operated by the Survey, 14 fisheries vessels previously under the Interior Department's Bureau of Commercial Fisheries, and three vessels previously operated by the Corps of Engineers for survey in the Great Lakes. The Office of Fleet Operations is responsible for operational support of NOAA vessels at the Atlantic Marine Center at Norfolk, Virginia, and the Pacific Marine Center at Seattle, Washington. In addition, ships are berthed at Miami, Florida; the Lake Survey Center in Detroit, Michigan; and National Marine Fisheries labs in Brunswick, Georgia; Sandy Hook, New Jersey; Kodiak, Alaska; Pascagoula, Mississippi, Woods Hole, Massachusetts; Honolulu, Hawaii; San Diego, California; and Juneau, Alaska.

Between 1970 and 1973, seven vessels were deactivated primarily for budgetary reasons, and two of these were subsequently sold. The five remaining vessels have been reactivated. At the time of this report, the NOAA fleet and the program managed vessels totalled 29 vessels. These are tabulated on the next pages. The original cost of the 25 vessels in the NOAA fleet was $76 million.

The current budget for operating the 25 vessels and providing shore base support is $32 million. This provides for approximately 4,500 days at sea in support of hydrographic and bathymetric surveys, oceanographic data acquisition, marine charting, research and assessment of living marine resources, dynamic water column surveying, and outer continental shelf surveys. These are programs of the Survey, the NOAA Environmental Research Laboratories, and the NOAA National Marine Fisheries Service.

Foremost in the NOAA fleet are the 303-feet-long OCEANOGRAPHER and DISCOVERER--$10 million (1966 dollars) floating laboratories, outfitted with the latest electronic and oceanographic instrumentation and capable of virtually any oceanographic, biological, meteorological and hydrographic observations and measurements. Both ships are outfitted with closed circuit television in the machinery spaces, centralized engine room control, a sophisticated computer for both ship operation and for collecting and processing of marine data. Deep

sea anchoring equipment and a 400-hp bow thruster enable the ships to carry out deep ocean coring, dredging, bottom profiling, and photography at fixed positions in extreme ocean depths. These ships can operate for 150 days at sea with a cruising range of 15,200 miles to carry out a great variety of ocean data acquisition projects. The three oceanographic winches carry more than 22 miles of mechanical and electromechanical cable. Each ship has over 4,100 square feet of laboratory space--gravity, oceanographic, photographic, plotting room, and meteorological.

When the ship is underway, the data acquisition system secures, records, and processes geological, geophysical, oceanographic, hydrographic, and meteorological data on a routine basis; ship position is logged continuously; and the computer can be used for concurrent processing of nonroutine scientific data. When the ship is on-station, the data acquisition system samples and processes data sensed by shipboard instruments and by an underwater multisensor package. The automatic data processing system frees many specialists from the routine task of sorting and analyzing a great amount of data, a task which usually consumed months of painstaking effort.

The equipment measures and records the ship's course and speed, magnetic field intensity, gravity, surface current and temperature, temperature at depth, and ocean depth.

Subbottom profiles can be taken while the ship is underway to show structure of the ocean floor beneath bottom sediment. The ship takes water samples at various depths and is equipped to obtain 100-foot core samples from the deepest ocean floor. A unique feature of these two vessels is a bow chamber 15 feet below the water line with six glass ports for underwater viewing.

The RUDE and HECK, the only wire drag vessels in the United States, are specifically designed to locate underwater hazards to navigation. Operating up to distances as much as a mile apart, they tow a steel wire suspended by buoys at depths up to 100 feet to locate and indicate clearance depths over obstructions.

The FERREL is specifically designed to carry out tidal current observations and dynamic water column surveying.

Although eight vessels were designed and outfitted specifically to carry out hydrographic surveys, most vessels in the NOAA fleet can be used to secure hydrographic data. Likewise, all vessels have some capability to secure oceanographic data, as required.

Marine Centers Established

For many years, Survey ships have berthed at various docks in the Norfolk, Virginia, area and the Seattle, Washington, area. In the early 1960's, plans were started for a marine center in each area which would have dock facilities, offices, shops, laboratories and storage areas, and would consolidate all Survey functions being carried on at different locations in each area.

Operations at the present site of the Atlantic Marine Center (AMC) in Norfolk began in 1961. Since that time, the number of personnel has increased from 18 to 140. Today, this Center operates ship bases at Norfolk and Miami,

operates shore facilities for processing oceanographic data and compiling photogrammetric survey data, directs the operations of ocean survey vessels, and directs field survey operations. Plans have been drawn for expanding the piers, office space, warehouses, and ship repair facilities at the AMC.

The Survey moved into the present Pacific Marine Center (PMC) facilities in Seattle in 1963. This Center carries on essentially the same functions as the AMC. Plans are now being finalized to relocate all present PMC operations and several NOAA West Coast operations into a northwest center for oceanographic, fisheries and weather activities at a 100-acre site at Sand Point on Lake Washington.

The Lake Survey Center (LSC) at Detroit became a Survey facility in 1970 when it was transferred from the U.S. Army Corps of Engineers with the formation of NOAA. The LSC directs hydrographic surveys and land survey operations, processes and verifies survey data for charting, maintains the water level network, maintains vertical geodetic control network files, provides marine engineering services, and operates survey vessels.

Automated Shipboard Survey Systems

Following World War II, hydrographic surveying methods improved radically. New electronic echosounding equipment provided consistent, continuous and reliable depth soundings. Electronic navigation and position control systems increased the accuracy of vessel course and location. While these advancements did much to enhance the accuracy and completeness of hydrographic surveys, the recording, processing and plotting of survey data was severely impacted. These steps still had to be done manually. The application of computers to automate these data processing steps offered many possibilities to improve productivity and reduce the time required to publish new nautical charts.

In 1960, a program was initiated to develop a computer-assisted system of data acquisition and processing. At first, the data acquisition capability was limited to semiautomatic and manual data loggers which produced punched paper tape to be further processed ashore. These early field techniques were developed aboard the Survey ship HYDROGRAPHER in the Gulf of Mexico under the command of Cdr. Raymond M. Stone. This computer-assisted system became operational in 1963.

The paper tapes were sent to the Pacific Marine Center in Seattle where they were processed by an IBM 1620 computer into punched cards. The final survey soundings were then plotted by a Gerber digital plotter, which was soon dubbed the "IRON ENSIGN," as a result of its untiring performance.

With the advent of reasonably priced mini-computers and the initiative and determination of Capt. Emerson E. Jones, the Survey was able to improve the data acquisition part of the system by installing a prototype hydrographic computer/plotter configuration aboard the Survey ship WHITING in 1967.

In 1969, experimental computerized equipment was installed on a high-speed 59-foot survey launch under the direction of Cdr. Clinton D. Upham. This application proved that large-scale hydrography could be conducted at speeds up to 20 knots using commercially available hardware and regular Survey personnel. Productivity was increased 25 percent in addition to data plotting in real-time.

By 1971, third generation systems had been installed on three hydrographic vessels and six launches. Now, all six NOAA survey vessels and 12 ship-based survey launches plus other launches are equipped with the computerized data acquisition and processing systems. The complete system, called "Hydroplot," provides real-time output or handles data after the fact. "Hydrolog," another version of the system, is the same as the Hydroplot system, but does not have plotting capability. Major components of the Hydroplot system are: computer, teletype, paper tapereader/punch, graphic plotter, system controller, digital depth recorder, and navigation position input unit. Vessel runs to secure soundings are steered on straight line instructions, which are issued by the computer to the helmsman by means of a left-right steering indicator. A digital sextant, the first of its kind, was developed for this system, which also accepts input from most of the standard electronic positional devices in use today.

In addition to real-time field sheet plots, these systems produce digital punched paper tape which is used as input to shore-based computer/plotter systems at the Atlantic Marine Center, Norfolk, Virginia, and the Pacific Marine Center at Seattle, Washington. At these centers, which now have magnetic tape and disk capability, raw data is merged with final correctors, verified, and used to produce final "smooth" hydrographic survey sheets.

The Hydroplot system, now recognized as the first and most practical automated hydrographic survey system in existence, ranks as a major achievement in the long list of Survey developments.

Computer-Assisted Nautical Charting

To fully develop the shipboard data acquisition system, and to design and implement a computer-assisted system for the total process of nautical charting, the Marine Data Systems Project (MDSP) was established in 1970. As a detailed plan was being formulated, the Hydroplot and Hydrolog systems were further improved, the automated system at the Atlantic Marine Center was upgraded, and a completely new system was installed at the Pacific Marine Center.

A 5-table integrated digitizing system was placed in operation at Rockville, Maryland, headquarters for systematic in-house conversion of graphic chart data to digital format. Other chart data was converted at the NOAA National Climate Center in Ashville, North Carolina. This digital data, plus the inflow of digital data from automated survey vessels, became the base for a comprehensive nautical chart data bank.

Two large flat bed plotters were installed at Rockville for data check plots, for graphics program testing, and to provide automated plotting and scribing support for manual cartographic operations. During 1973 and 1974, three nautical charts were scribed on the plotters from digital data for direct chart reproduction. This step provided visual evidence of the feasibility and practicability of the concept.

During this same period, specifications were prepared for a data storage, retrieval and update system which will enable the nautical chart cartographer to fully utilize data from the bank. This system is also designed to facilitate the process of metrication and development of new chart formats. Procurement of the hardware and software is now in progress with installation and operation to be completed within 3 years.

Last year, a laser-raster production plotter was installed for production of chart reproduction negatives directly from the digital nautical chart data bank. These negatives are used for preparation of chart printing plates. The total nautical chart automation project is scheduled for completion by 1980. The 5-table digitizing system and the laser-raster plotter are the first units of their types in operation for production of charts.

Tide Observations and Predictions

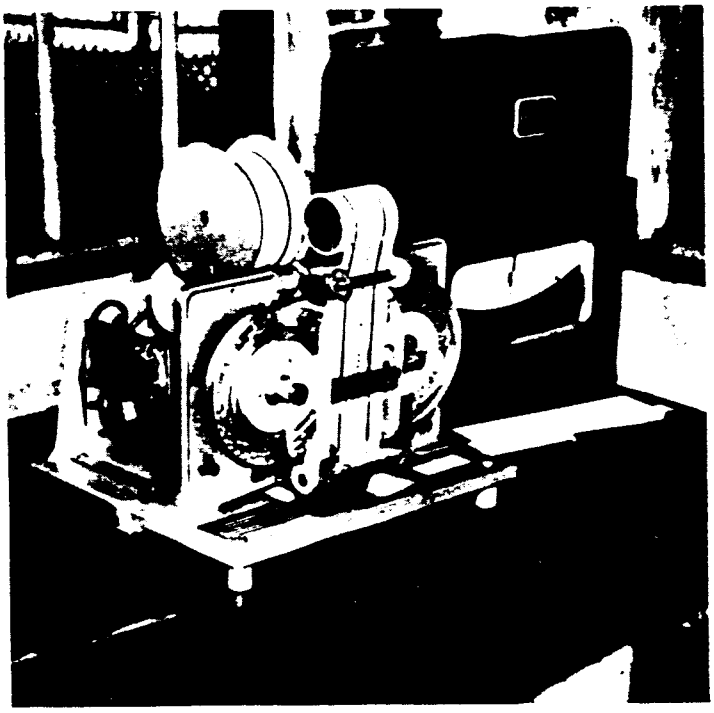
In 1966 the electronic digital computer was first used for computation of standard published tide predictions, using computer programs developed by Robert A. Cummings, D. Lee Harris, and N. Arthur Pore. About the same time the Survey started a program of replacing analog recording tide gages with a new electro-mechanical digital tide gage which records tide levels as punches on a special chart in standard binary-decimal code. This data format significantly reduces data processing time by eliminating the manual conversion of analog chart traces to digital form. Approximately 70 percent of the 132 control stations and 486 secondary stations for the United States shoreline are now equipped with the new instrument. All stations are scheduled to have the new instrument as funds are made available.

The Survey is presently conducting engineering research, development, testing and evaluation to further improve the digital tide gage, to develop a digital recording pressure-sensing tide gage, and to further improve the automated processing of tide data. Program plans call for 78 additional primary control stations and a fourfold increase in secondary and tertiary stations. This increase in tidal observations will greatly benefit the quality and geographic coverage of the prediction tables. As new stations are observed and previous stations are reobserved, each is evaluated for use in improving predictions.

The present international tide prediction tables published by the Survey are based on 251 reference stations and about 8,000 subordinate stations. The Survey continues to be the national focus for research in tide-related phenomena. In 1963 a group was established in the Survey to conduct tide and ocean research. It was headed by Bernard D. Zettler, who is noted for his basic research in the fundamentals of tides. Three years later this group was transferred to the ESSA Institute for Oceanography, with the Survey still required to conduct applied research in the tides area. In 1972 a Survey committee was organized to study the relationship of tidal datums and marine boundaries, and to establish standards and procedures for the determination of tidal datums and the demarcation of marine boundaries using the applicable datums. This study established the Tidal Datum and Marine Boundary Surveys Program. In 1975 the Environmental Protection Agency requested that the Survey also study the relationship of tidal datums and types of vegetation located at the upper limits of coastal marshlands. The results of this study are incorporated in the guidelines of the U.S. Army Corps of Engineers for implementation of the Federal Water Pollution Control Act.

Another significant applied research effort of the Survey is the study of offshore tides in response to the increased demand for detailed charts of offshore waters and the requirement for greater accuracy in measuring offshore tides and reducing soundings to chart datum. In the late 1960's the Survey developed a deep-sea tide gage which was principally used for basic tidal research until 1974, when it was deployed during the Southern Coastal Planes

NOAA Ship FERREL supports water circulation surveys



Electro-mechanical digital tide gage

TICUS current survey system

Expedition (SCOPE) to verify that offshore tidal reducers were consistent with surveying standards. This deep-sea tide gage was also deployed as part of an array of tide stations used to test a model for determining tide effects over an area. This model has subsequently been applied to other offshore projects.

A more recent innovation has been the development of instrumentation to telemeter tidal data in real-time to the field unit conducting a hydrographic survey. In the past, the hydrographer could apply only predicted tides to sounding data, and after the fact, he could apply observed tides from gages that operated during the survey. Since predicted tables are based on astronomic effects only, and the fact that water levels will change significantly due to meteorological effects, it was necessary to provide the hydrographer with real-time water level information. The advent of automated hydrography enabled the hydrographer to combine real-time information with an estimated tidal datum and, in addition, to use the tidal model scheme as a means to have a realistic overview of the tide's effect on the area surveyed. After the survey is completed, observed tide data is used to compute accurate tidal datums, verify the tidal reducers used, and "tune" the model for each area's local effects. These values are then used to prepare the hydrographer's "smooth sheet."

Tidal Datum and Marine Boundary Surveys

In general, coastal boundaries are defined by the intersection of one of several different types of tidal datums with the shore. These datums are computed by averaging the rise and fall of the tide over long periods related to astronomic cycles. Mean-high-water and mean-low-water are examples of such tidal datums. As a natural consequence of its responsibility to determine tidal datums, the Survey has been involved in the legal aspects of determining marine boundaries, including the determination of Federal, state and international boundaries. The courts, as well as parties involved in boundary litigation, have consistently looked to the Survey as the principal source of expertise in the United States on the determination of marine boundaries.

The Supreme Court of the United States has specified that the procedure and methodology used by the Survey to determine the mean-high-water line shall be used to determine the seaward boundaries of any Federal grant. This was specified in the celebrated Borax versus Los Angeles case in 1935 which accepted the Survey's definition of mean-high-water to be the average of high waters at a place over a period of 19 years.

The Survey provides data for establishing base lines of the United States coastline which are in turn used to provisionally delimit the territorial sea, the contiguous zone and certain internal waters. These are shown on 160 charts which are maintained by the Survey in cooperation with the State Department.

One of the early surveys conducted by the Survey, specifically to satisfy marine boundary requirements, was made in the late 1950's, as a part of establishing title to submerged lands along the Gulf of Mexico. Since the late 1960's, demands have increased for precise tidal datums at specific locations to determine marine boundaries and property lines. In addition to

the demands for more shoreline data, tidal datums must be provided at more locations and in more detail than has been needed to produce nautical charts. Consequently, the Survey has developed and is implementing a comprehensive plan for tidal datum surveys and marine boundary determination in 33 states and coastal areas covering 89,971 miles of shoreline at a cost exceeding $125 million over a 20-year period. The Survey has provided assistance on marine boundaries in a number of states since the mid-1960's--Florida, South Carolina, North Carolina, New Jersey, California, Texas, Washington, and Georgia.

Marine Boundary Maps

The first cooperative effort in coastal zone mapping started in 1969 with the State of Florida. These very precise maps, at a scale of 1:10,000, are prepared with the combination of orthophoto techniques, nautical charting, and planimetric mapping.

Mean-high-water lines and mean-low-water lines are mapped from black/white infrared, aerial photographs taken at the time when the actual tide level is at the elevation of the designated tidal datum. The land/water line is highly visible. Using photogrammetric techniques, the marine boundary and inland features are accurately shown in three-color orthophoto maps. Land areas are shown in the orthophoto base and printed with screen to show details. These maps are certified to be accurate within 16 feet for horizontal accuracy, and field surveys indicate the maximum error to be within 9 feet. When greater accuracy is required in determining a marine boundary, conventional geodetic leveling is employed using tidal bench mark sheet data. To map the entire tidal shoreline of the United States, Puerto Rico, and the Virgin Islands requires a total of 5,794 maps. To illustrate the scope of this work, Florida requires 355 boundary maps and Alaska requires 1,038 maps.

Coastal Water Circulation Surveys

The traditional tidal current predictions made by the Survey since 1867 are primarily for the safe navigation and maneuvering of commercial ships, military vessels and private boats in channels, harbors and coastal areas. Predictions are now being made for time of slack waters or minimum currents, speed of current, and direction of maximum tidal currents for 35 coastal and harbor stations in the United States. Empirical constants are used for predictions at about 2,000 additional locations. Also, 12 tidal current prediction charts are available for 10 major United States harbors and estuaries.

These tidal current predictions are considered technically adequate for most purposes; however, they are not sufficiently detailed for many of the traditional users with more precise navigation requirements, and the many new users with requirements for knowledge of coastal water circulation not related to navigation, such as pollution control and coastal zone management.

In addition, there are coastal areas with high concentrations of activity that have never been surveyed or only partially surveyed.

To satisfy the requirement for more detailed surveys and new surveys, in 1965 the Survey began development of instruments, ships and operational techniques for water circulation studies. In 1973 the capability to measure tides was also included in this program in order to correlate the horizontal and vertical components of circulation.

The first step in developing a total water circulation survey capability was the design and fabrication of a new generation current meter. The result was the TICUS system which became operational in 1967. This is a self-contained in situ instrument which measures current speed and direction, temperature, and conductivity versus time. The meters are suspended at various depths from a surface buoy. Data is acquired in digital form and telemetered by radio from the buoy to the support vessel and recorded on magnetic tape for partial processing aboard the vessel. Additional processing and analysis is done at Survey headquarters.

The second step was the construction of the FERREL, specifically to support and carry out water circulation studies. This is a 133-foot ship built from standard offshore workboat design with slight modification to carry the TICUS system. She was commissioned in 1968 and works along the Fast Coast and the Gulf of Mexico.

The next step was development of a system capable of surviving the environmental conditions encountered on the West Coast and in Alaska. The result focussed on the use of the commercially available Aanderaa system. This is a self-contained in situ unit which measures current speed and direction, conductivity, pressure, and temperature versus time. Meters are attached at predetermined depths along a "low drag force" subsurface mooring system. All data is recorded digitally and internally by a battery-powered tape recorder and recovered periodically for processing. This system became operational in 1972.

The McARTHUR, a 175-foot vessel built in 1966, supports the Aanderaa system and works along the West Coast and in Alaskan waters.

Within the last 10 years, eight major water circulation projects have been carried out. The most recent and highly successful project was in Cook Inlet, Alaska, which was completed 2 years ahead of schedule. A comprehensive, 6-year study is now underway in Puget Sound, and a 4-year study of Prince William Sound will commence this year.

The objective of water circulation studies is to secure sufficient environmental data and, if necessary, mathematically model a given water system in order to reasonably predict its behavior and dynamic characteristics. The data is also used to establish base lines for future marine ecosystem studies and for outer continental shelf environmental assessments. A comprehensive program plan for circulation studies along the entire United States coastal area is now being developed.

The Survey participated in the first of the NOAA Marine Eco-Systems Analysis (MESA) projects which started in 1973 in the New York Bight area. Cdr. R. Lawrence Swanson was transferred from the Survey to be project manager. A modified Aanderaa meter system was used to measure currents in the area and the FERREL was used in 1973 and 1974 to support this system. In addition, the Survey established new tide stations on Ambrose Light Tower and along the

southern shore of Long Island to support existing tide control. The survey has also processed all tide and current data for the project and coordinated analyses with the NOAA Atlantic Oceanographic and Meteorological Laboratory.

A second MESA-type study was started last year in Puget Sound, Washington, and the various waterways approaching Puget Sound. Data from the Survey tides and current program already underway in Puget Sound will provide valuable base line data for the MESA effort. In addition, the Survey is studying the circulation of Puget Sound and approaches in cooperation with the NOAA Pacific Marine Environmental Laboratory.

In 1974 the Survey established a Marine Environmental Assessment Projects (MEAP) Office to coordinate efforts, wherein the Survey is assisting the Bureau of Land Management (BLM) in its program to increase the availability of National energy-related resources, especially on the continental shelf. The Survey has prepared bathymetric charts of proposed lease areas, conducted a scientific analysis of existing physical oceanographic data in the South Texas Continental Shelf area, and is participating in the NOAA Marine Environmental Assessment of Alaskan waters.

Southern Coastal Plains Expedition (SCOPE)

With passage of the National Environmental Protection Act in 1970 and the Coastal Zone Management Act in 1972, the demand increased rapidly for more information about the coastal zone. It was obvious that conventional marine survey programs would not meet these demands in the time frame needed by Federal agencies, state governments and private interests. As a result, the Survey developed a multi-year concentrated study of selected coastal areas.

The first survey was the Southern Coastal Plains Expedition (SCOPE), encompassing a 38,000 square nautical mile area of coastal waters off North Caroline, South Carolina, Georgia, and Florida. Completed in 1974, the project compressed an original 15-year plan into 2 years. Involved were tide and current surveys, bottom topographic surveys, coastal water hydrographic charting, physical oceanographic measurements, delineation of the Gulf Stream, and aerial photography. The products of these surveys include: tidal datums and bench mark descriptions, tide and tidal current prediction tables, shoreline maps, various forms of aerial photos, salinity tables, temperature data, and coastal water survey sheets. Data was made available within 12 months of the surveys. Ordinarily, data processing for this type of effort would take about 5 years.

Based on the highly successful completion of Project SCOPE, the same type of concentrated survey was carried out in the New York Bight area in 1975. One of the most heavily sued marine areas around the United States coast, this 11,500 square mile ocean region extends from Montauk Point, Long Island, to Cape May, New Jersey. In addition to providing hydrographic, tidal and bathymetric data for nautical charting requirements and coastal zone planning, the New York Bight survey has provided data for the Marine Eco-Systems Analysis (MESA) program.

The third survey will continue this year, covering the area south from Cape May, New Jersey, to Cape Hatteras, North Carolina.

Marine Engineering Developments

When NOAA was established in 1970, the Office of Marine Technology was organized as part of the Survey. It is made up of the original Coast and Geodetic Survey instrument development group, now called the Engineering Development Laboratory; the NOAA Data Buoy Office, originally in the Coast Guard; and the National Oceanographic Instrumentation Center, originally in the Navy.

Engineering Development Laboratory. From the inception of the Survey, one of its highest priorities has been the constant attention to development and application of the best possible equipment and techniques in order to achieve better results at lower costs. Survey scientists, engineers and technicians have been at the forefront in developing instruments and procedures for work in geodesy, hydrography, mapping, marine surveys and ocean invesitgations. This tradition continues today.

As nongovernment research organizations increased their capability to develop new equipment, and commercial manufacturers increased their capability to meet the requirements of Survey programs; greater dependence was placed on these sources for both design and fabrication.

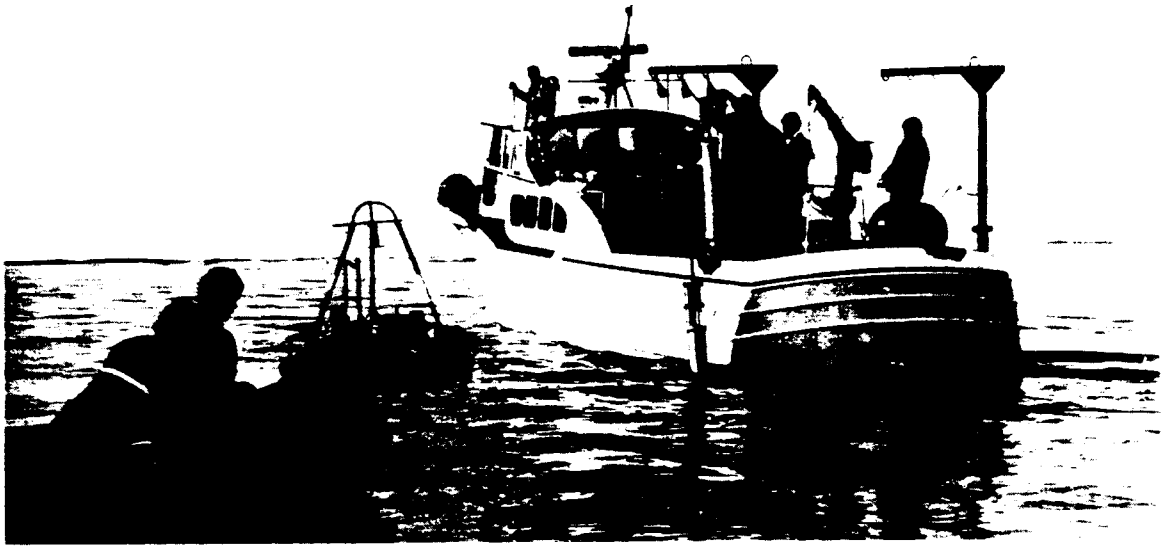
The Engineering Development Laboratory today is organized into three program areas: (1) Oceanographic Systems Development in support of tide observation and data processing, water circulation surveys, wave measurements, and related instrumentation; (2) Hydrographic Systems Development in support of hydrographic surveying, position fixing, communications, and continental shelf equipment; and (3) Water Quality Assessment Systems Development in support of shipboard underway real-time water quality measuring systems.

Environmental Data Buoy Program. This program is an outgrowth of the buoy project established by the Coast Guard in 1967 to conduct research, development, test and evaluation of unmanned buoys to acquire marine environmental data. The NOAA Data Buoy Office, with offices and shops in Bay St. Louis, Mississippi, operates as a technical/engineering developmental management organization. Contractors are used to carry out development projects and to refurbish, retrofit and maintain deployed buoys. Coast Guard ships are used for towing, retrieval and service trips.

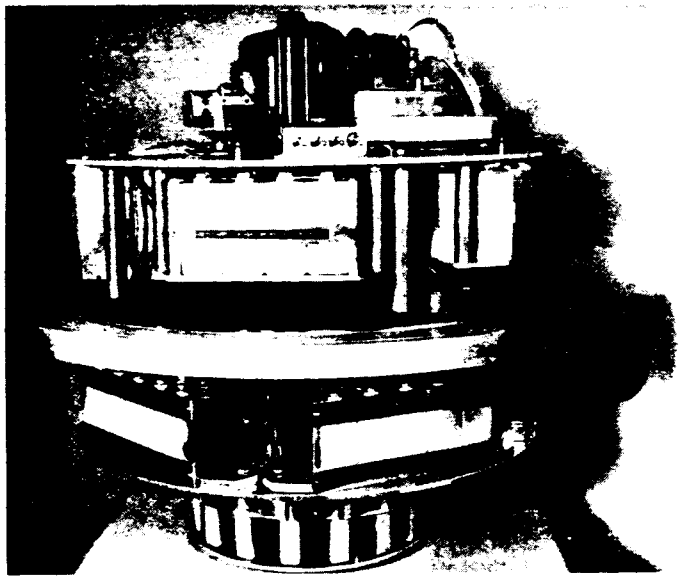
The NOAA Data Buoy Office has three major programs: (1) Deep Ocean Moored Buoys; (2) Drifting Buoys; and (3) Continental Shelf Moored Buoys.

Nine deep ocean moored buoys are now operational, in the initial phases of the "Federal Plan for Environmental Data Buoys," which specifies a schedule to have 36 deep ocean moored buoys in operation by FY 1981. A total of 32 buoys would be deployed at various strategic locations in coastal waters around the United States with 16 in the Pacific Ocean, nine in the Atlantic Ocean, four in the Gulf of Mexico, and four in the Great Lakes. Five buoys will be used for replacement of deployed buoys which are drydocked after 3 years for overhaul.

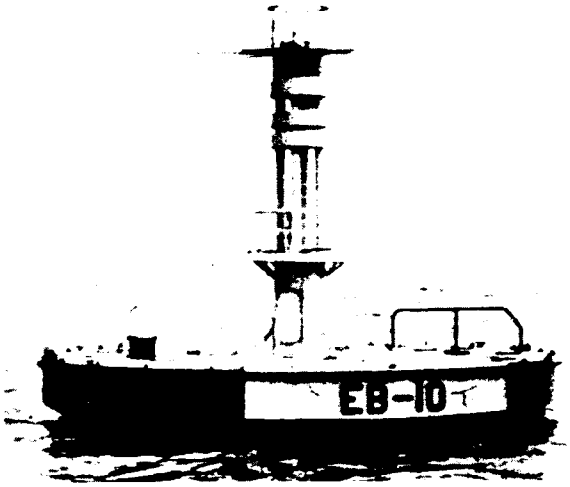
These buoys are outfitted to measure surface air temperature and pressure, wind speed and direction, sea surface temperature, wave patterns, and subsurface temperatures to 300-meter and 600-meter depths. Data is acquired, processed and stored aboard the buoy for transmission to shorebased stations on command. Both HF and UHF radio systems are being tested for communication with both satellites and shore stations.



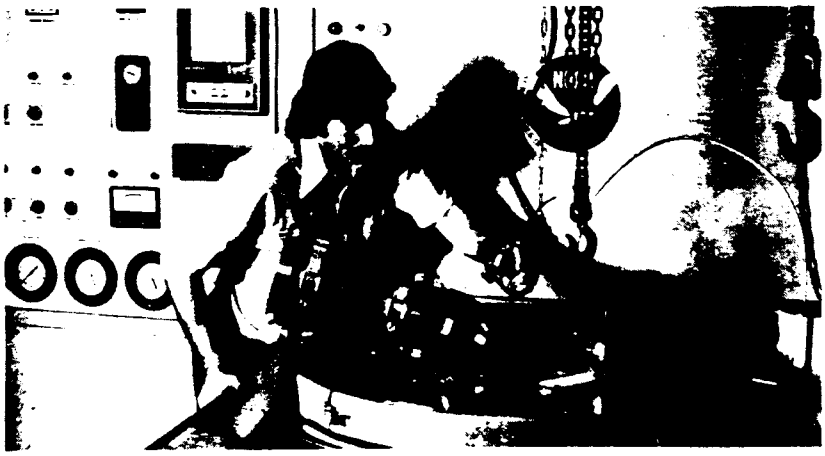
Chester River tidal current survey



Internal module for deepsea tide gage



Environmental ocean buoy



Temperature/salinity instrument testing

A second generation deep ocean moored buoy was recently deployed off the West Coast. It can transmit data both via surface HF radio and by satellite UHF. A project is underway to measure atmospheric temperatures from these buoys up to an altitude of 6,000 meters by use of remote sensors located on the deck of the buoy. Plans are being finalized to combine this capability with those of remote downward-looking sensors carried by satellites.

Drifting buoys are being developed for Arctic ice conditions following successful prototype operations using satellite telemetry in 1972. Prototype ocean drifting buoys are now under test with the recently launched NIMBUS-6 satellite to measure basic meteorological parameters. Sixty drifting buoys are under production for use in tracking ocean currents using satellite telemetry.

The test and evaluation program for continental shelf moored buoys has been completed with the development of three different hull shapes, sensor types and electronic packages. A cluster buoy experiment is planned for an area off the United States East Coast in FY 1977 to evaluate instrumentation and subsurface communication systems.

National Oceanographic Instrumentation Center. This organization was originally formed by the Navy to test, evaluate, calibrate and set procurement standards for Navy ocean instruments and systems. In 1969 it was made a national center, and in 1970 became a part of NOAA with headquarters in the Washington, D.C. Navy Yard, and three regional calibration centers in Seattle, Washington; San Diego, California; and Bay St. Louis, Mississippi.

The Instrumentation Center is basically an engineering service organization with three major programs: (1) Ocean Instruments Testing; (2) Metrology; and (3) Calibration. The basic objective of these programs is to assure that the nation's multimillion dollar oceanographic data acquisition systems and instruments provide valid and reliable data of a known quality.

The testing program involves the actual testing of commercially available ocean instruments to determine specific performance characteristics (accuracy, range, linearity, repeatability, etc.) and how well they operate in the severe marine environment. Prototype sensors and instrument systems are also tested. Test results are published and distributed to the oceanographic community. Most instruments tested fall into one of five types: conductivity, salinity/temperature/depth sensors; current meters, water quality instruments; wave and tide gages; and acoustic instruments.

The metrology program is carried out to provide a clearly defined chain of measurement accuracy from basic national and international standards down to field application. The purpose is to know and define the quality of data being provided by instruments which are used to make marine environmental measurements. This program involves standards, methods of making measurements, calibration procedures, and interlaboratory calibrations.

The calibration program consists of the operation of instrument calibration and repair facilities at four locations for use by government agencies, research organizations, and the private sector. Use of these facilities insures a tie-in to a total metrology calibration chain with known performance and acceptance by other parties.

New Adjustment of North American Horizontal Datum

When the horizontal geodetic reference system serving government and industry in the United States, Canada, and Mexico was adjusted in 1927 to the North American Horizontal Datum, it was satisfactory at the time, supporting an accuracy of never less than 1 part in 25,000. Over the years, accuracy requirements have increased. Now many users need an accuracy of 1 part in 100,000, which is available only in minor portions of the 1927 datum.

As a result of the need for greater accuracy, the Survey developed an 8-year plan for a new adjustment of the 1927 datum, working in cooperation with Canada, Mexico, Denmark, and the Central American countries. The automation of observational data started in July 1973.

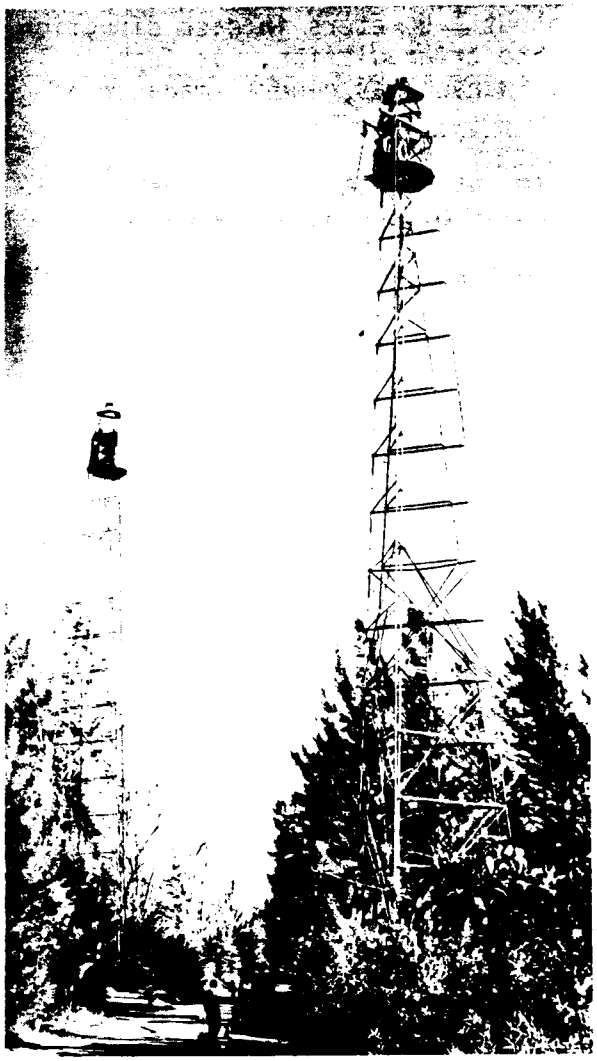
The new adjustment will incorporate high accuracy traverses, additional base line measurements, plus satellite and astronomic observations. The adjustment is an enormous mathematical process of manipulating various observational data so as to optimally distribute discrepancies in the measurements. The computation involves the simultaneous solution of 3.2 million linear equations (one for each observed quantity) with 500,000 unknowns (two for each control point). The Helmert-Wolf blocking method will be used. A new astrogeodetic geoid for the United States was computed in support of the new adjustment.

Satellite Triangulation

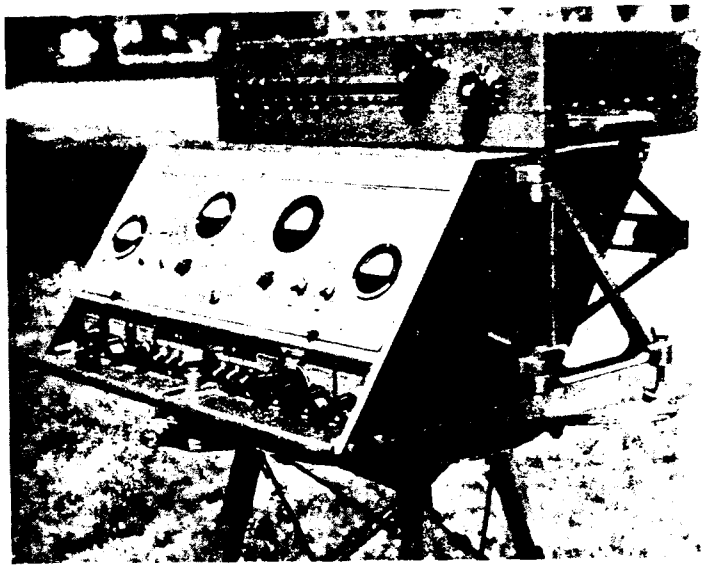
The use of earth satellites to measure distances and establish position on the earth surface was a monumental step in geodesy. With this procedure it was possible to measure very long lines across continents and oceans and to create a three-dimensional worldwide geodetic reference system free from the influence of both the direction and magnitude of gravity.

Research and development began as early as 1954 in an attempt to design a system capable of providing accurate geodetic data over great distances. In 1962 the Survey received its first instrument system consisting of the sophisticated Wild BC-4 ballistic camera and a precise electronic timing system. Both the ECHO I and ECHO II satellites were photographed by these cameras against a star background using glass plates. Simultaneous observations and photographs were made from two or more camera stations. Using photogrammetric techniques, the apparent right ascension and declination of the exposed satellite images were determined, and the angular relationships between the ground observing stations were determined. The network thus created was without scale (or dimension). To provide scale to this network and also to strengthen the National Geodetic Network, precise ground measurements, or transcontinental traverses, were obtained which included land-based geodetic positions at the various satellite camera stations. These traverses were accurate to one part in one million. By 1965 the Survey had eight BC-4 camera systems in operation across the country, in Alaska and in Canada.

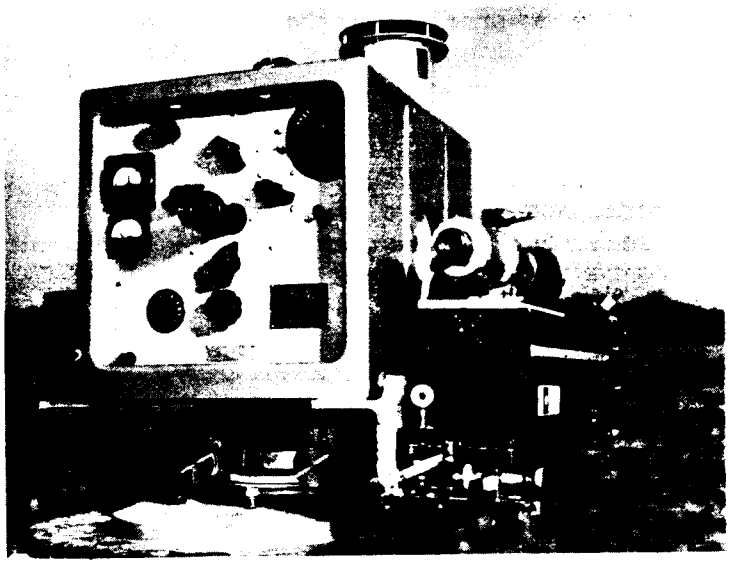
In June 1966, the passive satellite PAGEOS was launched in a near-polar orbit, near-circular orbit at 2,800 miles altitude for use by the worldwide Geometric Satellite Triangulation Network. This global network is made up of 69 spherical triangles formed by measurements at 45 camera stations. Observations of the satellite by ground station cameras were made on a cooperative basis by the Survey, the U.S. Army Map Service, and with cooperation of host countries. The end result was three-dimensional coordinates at 45 stations



Triangulation from Bilby towers



Geodimeter, used for distance measurement



Geodimeter with laser light source

throughout the world to a standard error of about ± 5 meters in each direction. Hellmut Schmid, a pioneer in geometric satellite triangulation, was Technical Director of this NOS program, and Capt. L. W. Swanson was general manager of the project.

The next phase in satellite geodesy included the use of the Doppler principle, by making Doppler shift measurements during orbits of the Navy Navigation Satellite System. Tests conducted by the Survey using its own data and that obtained cooperatively with the Defense Mapping Agency indicated an excellent potential for this technique. In 1973 the Survey purchased two satellite tracking receivers and began measurements at selected sites throughout the United States, along the transcontinental traverse, and at the BC-4 camera stations. A two-man team can secure a position accurate to about ± 1 meter in each direction after 40 satellite passes. Satellite tracking units have been located in Alaska to measure crustal movement resulting from the 1964 earthquake, and on offshore platforms to determine their position. The Survey has plans to provide geodetic positions using the Doppler principle at about 200 locations in the conterminous states, Alaska and Hawaii.

Special Geodetic Projects

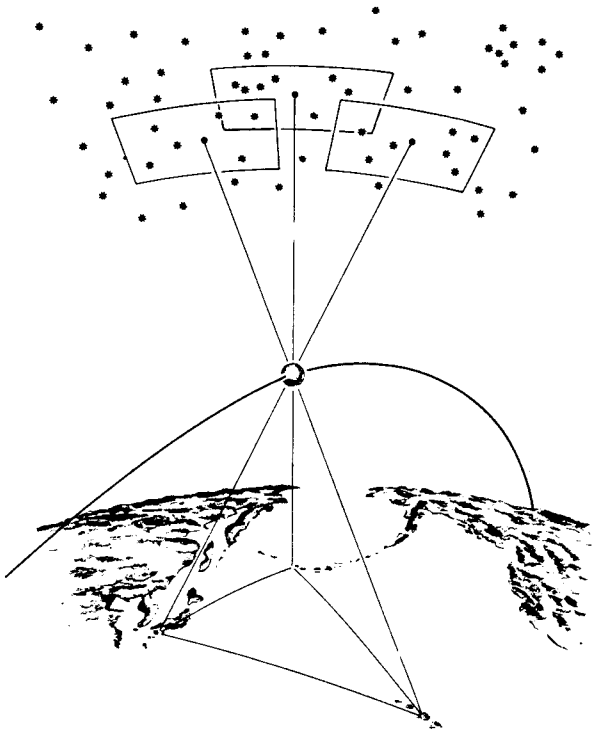
In 1955, two special-purpose triangulation parties surveyed along the Louisiana coast to accurately locate drilling platforms as offshore petroleum activities accelerated in the Gulf of Mexico. The most distant platform was about 28 miles offshore.

During the years 1954-56, there was an increasing demand for horizontal and vertical control along superhighways. Even before the enactment of the Interstate Highway legislation, some states had requested assistance in placing control points along the routes of superhighways. Following passage of the legislation, additional states requested that these surveys be made. This work will continue for many years, since the specifications for the construction of highways require surveys of geodetic accuracy.

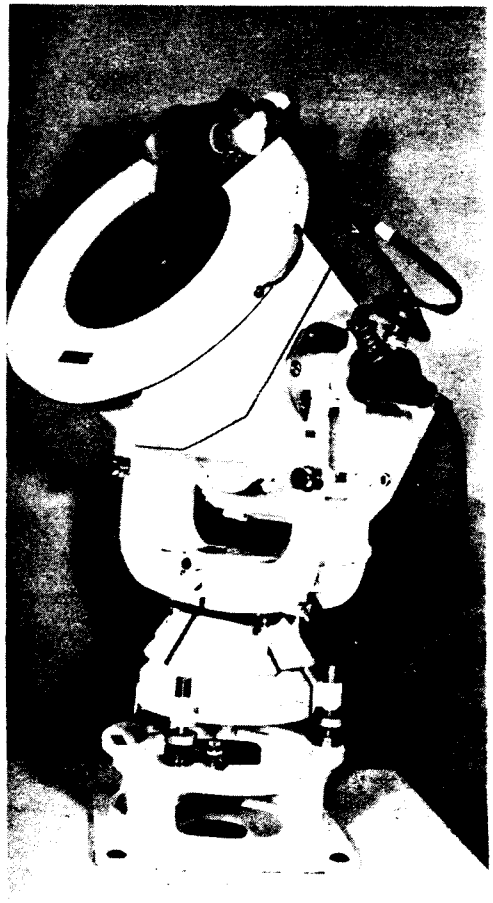
During 1956, work was begun on an astrogeodetic profile of the geoid on the 35th parallel across the United States, with stations observed at approximately 18-mile intervals.

Late in 1956, at the request of an international commission and the Ethiopian government, the Survey began a 5-year geodetic control survey of the drainage basin of the Blue Nile River. Field operations, started in 1957, involved first-order triangulation, including base lines, first-order leveling, and first-order astronomic observations. Connections were made to the geodetic surveys in the Sudan which were connected to the African Datum which, in turn, is tied to the European Datum. Under direction of Capt. Don A. Jones, the project was completed in 1961.

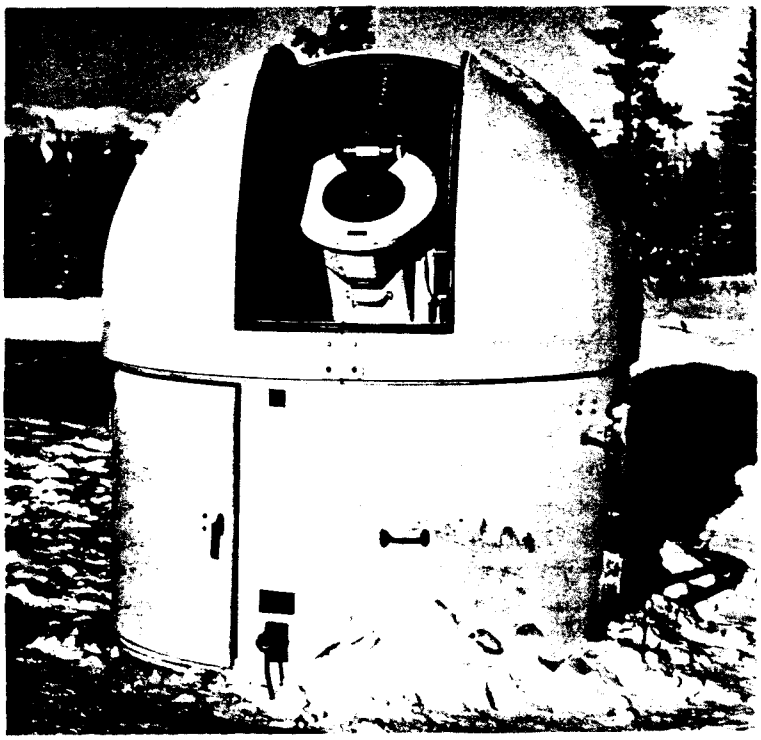
A project of historical importance in 1962 was a resurvey of the north-south boundary between the States of Delaware and Maryland at the request of officials of the two states to restore and preserve the boundary monuments established 200 years earlier by the two English surveyors, Mason and Dixon. It was significant that a large majority of the new monuments were in the exact same position or very close to their original positions as established by Mason and Dixon.



Concept of satellite triangulation



Wild BC-4 satellite camera



Satellite camera station

In 1964, the Survey cooperated with the States of California and Arizona to determine fixed points along the Colorado River for use to locate the boundary between the states which is in the middle of the river channel. This unique project required both geodetic techniques and a well-integrated aerotriangulation scheme.

A National Gravity Base Network was established in 1966-67 through the cooperation of several government and academic organizations. The measurement, consisting of two phases, were made by personnel of the Survey, U.S. Army, U.S. Air Force, and the University of Hawaii. A reobservation of the net was begun in 1975.

In 1969, the Survey completed a super precise alignment survey of the Holloman AFB high-speed test track using specialized optical plummet and adjustable tribrach to hold points within 0.3 mm. This was one of the most accurate surveys of its type ever made.

In 1971, the Survey undertook a tidal survey and performed a 934-mile geodetic level survey along the shores of the Chesapeake Bay, to establish firm control of tidal datums at tide stations for use in the design and verification of a working hydraulic model of the Bay. The world's largest estuarine model, it will be used for resources evaluation, environmental control, ship channel maintenance and overall study and planning.

A major accomplishment in 1973 was the simultaneous adjustment of geoid heights at 2,586 astrogeodetic deflection stations in the United States, and development of a program for automatically plotting the individual geoid height values in digital form. A contour map was also produced to facilitate interpolation of the data in various geodetic applications.

Work was completed in 1975 on the Selenocentric Reference System project under contract from NASA. Inertial orientation of the lunar axis and the lunar rotational rate were obtained by photogrammetric analysis of Apollo 15, 16, and 17 photography for use as independent check on dynamically-determined methods. Block adjustment programs were completed and applied to portions of the data from NASA.

Following the Alaska earthquake in 1964, the Survey carried out a comprehensive combined survey involving survey vessels, aircraft and field parties. This effort included reobservation of the primary triangulation in the Anchorage-Prince William Sound areas, a Tellurometer Traverse around Kenai Peninsula, and other geodetic surveys.

Charles A. Whitten established procedures for geodetic computation on large electronic computers, and made special investigations of crustal movement. B. K. Meade developed a technique for determination of crustal movement, and procedures for adjustment of the horizontal control network and the Transcontinental Traverse. Donald A. Rice prepared material on time in surveying and mapping, and on deflections of the vertical from gravity anomalies. Howard S. Rappleye developed a technique for more rapid leveling.

New Equipment for Geodesy

In 1958, the Survey first used the Tellurometer-a precise electronic distance measuring instrument capable of determining distances of 20 to 30 miles with an accuracy better than 1 foot. The instrument was first used experimentally by the Survey ship EXPLORER to establish horizontal control in the Aleutian Islands.

In the early 1950's, the Geodimeter was first used by the Survey for distance measurements. This electro-optical instrument, operating on three frequencies, was larger and heavier than other equipment, but provided more accurate measurements. Later this instrument was improved by Survey personnel by the addition of a laser beam as the light source.

A new method was developed and field tested in 1958 for second-order astronomic position observations, which permitted direct coordination of star pointings with the audible 1-second WWV time signal pulses.

In 1961, a new Worden temperature-controlled gravity meter was put into service in the field as a replacement for pendulum observations to establish gravity base points.

High-precision surveys with accuracies approaching one part per million were started in 1961 to fulfill a request for positioning satellite cameras at various places north and south of Cape Kennedy, Florida. To fulfill this requirement a system of high-precision traverse was developed, which generally followed existing arcs and main-scheme triangulation. Auxiliary stations were established at every other point along the traverse route. This high-precision survey technique was used for the transcontinental traverses.

National Geodetic Data Bank

This year the Survey began a multi-year program to streamline and automate the processing of data for the National Geodetic Control Data Bank. Both vertical and horizontal control station descriptions will be converted into computer readable format on magnetic tape for input, storage, retrieval and printout. At present, data are available in text format for 500,000 vertical and 200,000 horizontal control points. To this will be added data on approximately 620,000 control points from the U.S. Geological Survey, and data on approximately 100,000 control points from the Defense Mapping Agency domestic data file. The National Geodetic Control Data Bank is expected to contain data on more than 1.4 million control points in the next few years.

Aeronautical Charting

A significant achievement in aeronautical charting was the implementation of an intra-governmental program to eliminate duplication in the production of aeronautical charts by various government agencies. Today all government produced domestic aeronautical charts issued for government and civil use are prepared from reproducible materials provided by the Survey. This program not only saves money, but promotes safety in the airways through the availability and use of a common chart by air traffic controllers, civil pilots, and military pilots.

A major development in aeronautical charting is the preparation of chart cartographic data in a digital format for direct input to automated air traffic controller systems and computerized navigational systems. The Survey now provides detailed cartographic chart data for individual air routes on magnetic tape to FAA air traffic controllers and manufacturers of sophisticated electronic navigation systems. This controller chart supplement series provides data for nine different aeronautical chart groups. The same information is also printed in catalog form directly from the magnetic tape.

A second program involves the presentation of cartographic data in forms other than printed paper charts is the Radar Video Mapping System. In this program, chart data is prepared on special glass slides for use by FAA to overlay air traffic controller radar displays. By superimposing airway designations, hazards to flight, navigation aids, airport configurations, and other important information directly on an active radar screen, this system allows air traffic controllers to observe real-time aircraft flight in relation to scaled cartographic features. In 1975, this program involved more than 450 different radar video map overlays.

Programs are now underway to further automate the presentation of aeronautical chart cartographic data using state-of-the-art electronics, optics, and automated systems.

Responding to the almost daily changes in flight procedures and physical changes along airways and at airports for commercial aircraft, general aviation and military aircraft, the Survey constantly updates existing charts and other products, and prepares new material. Typical new products and services include: extension of The World Aeronautical Chart coverage to include Mexico, Central America, Gulf of Mexico, and the Caribbean area in cooperation with the Defense Mapping Agency; a new chart for pre-flight and enroute planning under visual flight procedures; a new three-chart series for use by air traffic controllers for high altitude flights; a helicopter chart for the Los Angeles area; a redesigned chart which broadens coverage of Puerto Rico and the Virgin Islands; and a prototype bound-book format for Instrument Approach Procedure charts to evaluate user acceptability and cost reduction.

Major Changes in Nautical Charts

In the two decades following World War II, nautical charts underwent more radical changes in appearance and increased usefulness than in any similar period in the history of the Survey. The vast amount of detailed knowledge of the ocean floor secured by echosounding provided more and more nautical charts with valuable depth information. Greater use was made of color, with as many as ten different colors appearing on some charts to show individual kinds of information and data. More land details such as contours, bluffs, and elevated structures were added to assist in safer navigation. New photogrammetric techniques provided additional data and detail for land areas. The general improvement in hydrographic survey equipment and the application of new technology raised the level of precision. Loran lines of position were carried to provide for the increased use of electronic navigation aids.

Along with these improvements in nautical charts came the requirement to meet the needs of millions of new ship and boat owners as the size, speed and

number of private, commercial and military vessels increased. These changes impacted to require new charts, more charts and more up-to-date information for safe navigation.

To secure more information on a more frequent basis, as a supplement to hydrographic data acquired by the Survey, a cooperative agreement was made with the U.S. Power Squadrons and the U.S. Coast Guard Auxiliary. Under the agreement, the Survey provides copies of the latest editions of nautical charts, related publications, reporting forms, along with instructions to the organizations, and they in return supply chart correction data through a chart surveillance program in United States waters. With a total membership of more than 125,000 and more than 50,000 vessels of opportunity, these two organizations offer a unique potential for data input. The Survey supplies marked copies of nautical charts with a listing of items to be examined, and these in turn are forwarded to appropriate Districts for assignment to specific individuals. Among the items which are included on the check list are: new structures requiring landmark evaluation; marine facility examinations; special surveys of uncharted inland waters; charting recommendations in local waters; statistics of marine activity in areas proposed for charting; identification of features revealed by aerial photography; user evaluation studies; and field check of new nautical charts.

During 1974 volunteer observers from the two organizations provided 21,794 items for consideration in preparing new charts and updating existing charts.

Introduction of Small-Craft Charts

In response to the increased demands of the growing number of small boat owners, a new type of chart was introduced in 1959--the Small-Craft Nautical Chart Series. Today 94 different Small-Craft Charts are published. In addition to standard nautical chart details this series presents an additional variety of information such as tide tables, current data, weather data and broadcast schedules, rules-of-the-road regulations, docking facilities, locations of marine supplies and services, and marina locations in a pre-folded small size format. Just recently, a new redesigned format chart was issued to provide even greater ease and handling in the cockpit of a small boat.

Orthophotography in Nautical Charting

As improvements continued in aerial photography, photogrammetry and chart design, it was obvious that orthophoto techniques offered many advantages as a means of showing land area detail on nautical charts and maps. The wealth of information and the many details captured by an aerial photograph tremendously increase the usefulness and value of a map or chart. With the use of orthophotography, time-consuming drafting and scribing are eliminated.

The first application of orthophotography was in preparation of coastal zone marine boundary maps in a cooperative effort with the State of Florida which started in 1969. These three-color, highly precise, multi-purpose maps are made with a combination of orthophoto techniques, nautical charting and planimetric mapping. Mean-high-water and mean-low-water lines are mapped from tide-coordinated infrared photographs in combination with field data.

The prototype nautical chart employing orthophoto techniques was completed in 1972 and placed on issue soon thereafter. Standard hydrographic procedures are used to show details of the water portions of the chart, and orthophotos are used to show land details. Here again, time-consuming drafting and scribing are eliminated.

This year the Survey completed a series of prototype coastal zone maps of the Ft. Pierce area in Florida, as the first step in a cooperative effort between states and Federal agencies to show detailed land/water interface of the coastal zone. All measurements, elevations, and water depths are shown in metric units. This is the second series published by the Survey using metric units.

Photobathymetry

After several years of development and field testing, the use of photogrammetric bathymetry techniques are now operational for ocean bottom mapping. Field operations have been completed in Puerto Rico, U.S. Virgin Islands, and three areas in North Carolina--Bogue Inlet, Beaufort Inlet, and Oregon Inlet. In shoal areas where water conditions permit light penetration, the use of aerial color photography to "see" the bottom is much faster and more economical than using surface craft in hazardous shallow water areas.

Water penetration photographs are taken through a 420 millimicron glass anti-vignetting filter using reversal type broad-band color positive film to accommodate the wide range of spectral transmission found in coastal waters. A second camera, equipped with a 740 millimicron filter, is used for synchronous infrared photography to capture images of moving surf and delineate the water line at the time of photography. Images on the infrared photographs reduce the vertical control requirements by enabling stereoscopic transfer of discrete "water level" points along the beach from the infrared to the color photographs. Adjustment to establish horizontal and vertical control is then completed using block analytical aerotriangulation techniques.

Storm Evacuation Maps

In cooperation with the NOAA National Weather Service, the Survey is producing a series of storm evacuation maps covering the Atlantic and Gulf Coasts. As of this report, a total of 42 maps have been published. This year, second editions of six previously issued maps of the Galveston-Houston, Texas, area were published to show land subsidence up to 1973.

Bathymetric and Geophysical Maps

Several years ago the Survey initiated a program to produce a series of maps for coastal areas and the continental shelf showing bottom topography, gravity anomaly data, and magnetic data. As of this report a total of 99 maps had been published--74 bathymetric maps, 10 gravity maps, and 15 magnetic maps. This series has proved to be of great value in crustal and sediment studies, offshore oil and gas development, facilities siting, ocean dumping, environmental studies, and coastal zone planning. Overlays, data lists, printouts,

tapes and technical reports are prepared to accompany the basic maps. Maps of the continental margins are prepared at a scale of 1:250,000, and at 1:1,000,000 for the deep ocean areas. During this past year the Survey produced a total of 12 bathymetric maps for offshore areas showing oil and gas well lease blocks at a scale of 1:250,000 for the Bureau of Land Management's Outer Continental Leasing Program.

International Nautical Charts

The Survey has recently published the first of five new international nautical charts it will produce as part of a multi-nation program to provide a new series of small-scale charts covering the entire world. Sponsored by the International Hydrographic Bureau of Monaco, the program calls for standardized presentation of navigational information such as depth curves, sounding spacing, aids to navigation and nautical symbols. All depths and elevations are shown in metric units. Scales will be 1:3,500,000 and 1:10,000,000. Fifteen nations are producing charts, with each authorized to reprint charts in its own language. The United States five-map series will cover the northern Pacific Ocean and the Bering Sea. The first map, at a scale of 1:3,500,000, will cover an area off the West Coast of the United States and Canada. This is the first metric-unit nautical chart published by the Survey.

Nautical Charting Production

The Survey's present nautical charting program consists of nine catagories of charts and publications, with a production of over 2.1 million copies during the past year.

(1) Sailing Charts with scales smaller than 1:600,000 are used for planning and navigation in open coastal waters and between ports. (29 charts)
(2) General Charts with scales from 1:150,000 to 1:600,000 are designed for visual and radar navigation offshore using landmarks. (92 charts)
(3) Coastal Charts with scales from 1:50,000 to 1:150,000 are for navigation nearshore, in harbors, in bays and in inland waters. These are the most widely used nautical charts. (172 charts)
(4) Harbor Charts with scales larger than 1:50,000 are for navigation in harbors and smaller waterways, and for anchorage. (574 charts)
(5) Small-Craft Charts with scales from 1:10,000 to 1:80,000 include specific information pertinent to small craft operators. They show a great variety of information such as tide and current data, marina and anchorage facilities, courses, etc. They are published in several different formats for convenience in handling on small boats. (94 charts)
(6) Coast Pilots and Great Lakes Pilots are published in nine volumes to provide detailed navigation information which cannot be conveniently shown on charts such as radio service, weather service, port data, sailing directions, natural features, etc.
(7) Nautical Chart Catalogs are issued as required to show all of the nearly 1,000 different charts available for coastal waters of the United States, Puerto Rico, the Virgin Islands, Hawaii, Guam, Samoa Islands, and the Great Lakes. The publication Dates of Latest Editions of Nautical Charts is a separate publication.

(8) Special Maps and Data, by-products of the nautical charting program and generally for non-navigational uses, include: topographic surveys and planimetric shoreline maps, aerial photographs, hydrographic smooth sheets, graphic depth records, descriptive reports of surveys, and sedimentology sample data.

(9) Notice to Mariners is a pamphlet issued weekly by the Defense Mapping Agency in cooperation with the Survey, the Coast Guard and the Corps of Engineers to keep mariners advised of new publications and information on marine safety.

In July 1974 the Survey started using a new numbering system for its nautical charts. Developed in cooperation with the Defense Mapping Agency Hydrographic Office, the new system provides a uniform worldwide system for identifying nautical charts.

For greater efficiency in producing the Notice to Mariners documents, data is formated for computer input and output and listed according to chart number and geographical location.

Survey archives now hold data from more than 9,500 hydrographic surveys covering the 2.5 million square miles area for which the Survey is responsible.

In terms of new charts and chart revisions, the average annual production during the last 10 years has been from 6 to 20 new charts each year, and about 500 revised and reprinted charts each year.

International Cooperation

Almost from the beginning, the Survey has exchanged and shared its fundings with many other nations of the world, and actively participated in international projects and scientific programs in the fields of geodesy, hydrography, geomagnetism, seismology, sea level studies, ocean research, earth gravity, photogrammetry, and aeronautical regulations.

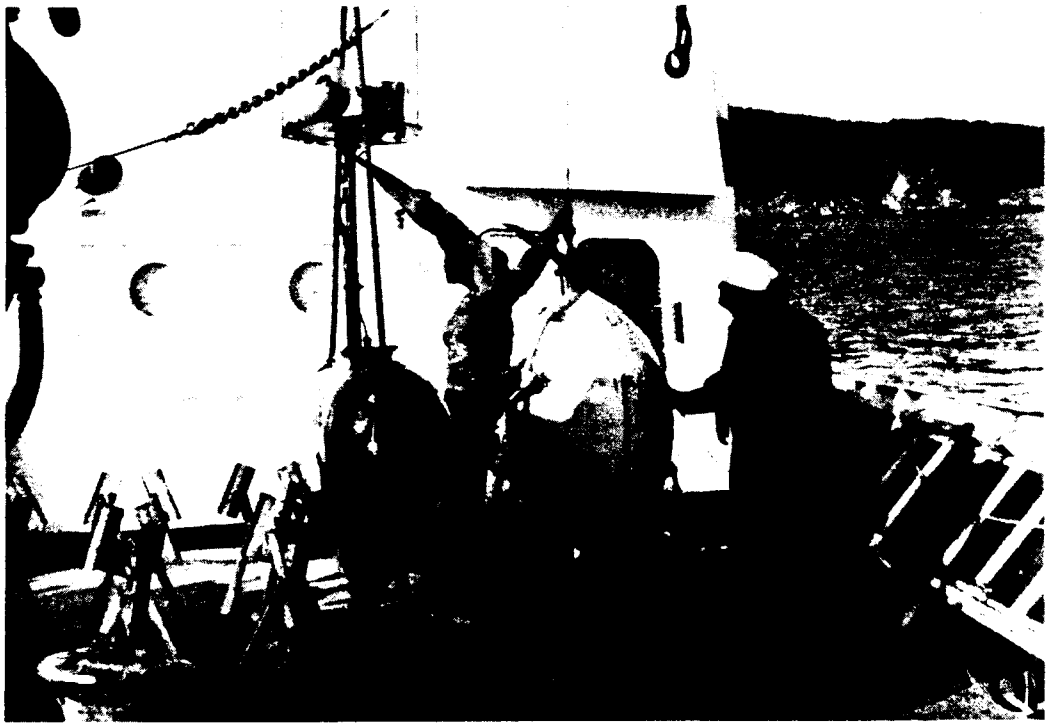
Typical of Survey participation in international projects was an international determination of longitude in 1926 under auspices of the International Geodetic Association, and in 1946, assisting in organizing the Inter-American Geodetic Survey, an organization created to coordinate and promote mapping in Latin America. For many years the Survey has taken part in foreign aid projects, and conducted training programs in surveying, cartography, hydrography, geophysics and related subjects, including programs under the International Cooperation Administration. The Survey was a major participant in the International Geophysical Year in 1957, and the Indian Ocean Expedition.

Too countless to detail, are the hundreds of survey projects and cases of expert assistance which the Survey has provided to scores of countries around the globe as a most eminent authority in geodesy, hydrography and earth sciences.

Over the years the Survey has participated in activities of many organizations working to establish agreements and standards at the government level. Typical such groups are the International Civil Aviation Organization, the International Hydrographic Bureau, the Pan American Institute of Geography and History, the North Sea International Chart Commission, and the United States-Canada Charting Advisors.

Employees of the Survey have been active in affairs of many professional organizations which function primarily for international collaboration and exchange of information. These groups include the International Society of Photogrammetry, the International Union of Geodesy and Geophysics, the International Astronomical Union, the International Association of Geodesy, the International Seismological Association, and the International Association of Geomagnetism and Aeronomy.

Digital computer charting plotting system



Buoys being readied for water circulation surveys

THE FUTURE

The greatest impact on the Survey in the near future will probably come from the growing activity in the coastal zone and on the outer continental shelf--offshore oil and gas development and production, offshore nuclear power plants, onshore facilities related to offshore energy installations, deep water ports, expanded coastal shipping, pollution control, coastal zone management policy, marine research, fisheries development, law-of-the-sea negotiations, marine boundaries, marine recreation, ocean mining, near-shore construction, and harbor development.

Interwoven with these activities are the world-wide problems of population increase and the accelerating dependence on resources of the oceans. Because we are only on the threshold of knowing how to intelligently develop, manage and use these vital resources, and the pace of acquiring knowledge of the oceans is far too slow in order to meet the inevitable need, the conclusion is obvious. We must increase our efforts to explore and measure the world oceans, and develop more efficient ways of working in the marine environment if we are to avert the disastrous consequences of not being able to utilize the ocean's resources.

These are not academic conclusions, they are hard facts that we must face. The question is not if we do it. The question is when. How long can we wait? When do we seriously start to consider that earth resource depletion is not academic? When do we seriously start to establish and implement a total effort to survey and understand the oceans? Now is the time. Because the task is long, complex, and costly, our Nation must start now to again look at our total effort in the oceans. For each day we delay, the task becomes more difficult and more expensive. The challenge is to bridge the gap between our present efforts and a realistic, coordinated plan for the future.

Ocean/marine affairs involve scores of government groups, academic institutions, and the private sector of the ocean/marine community. The Survey is an important member of this community. For nearly 170 years it has contributed basic data and knowledge of the oceans and the coastal zone through programs in hydrography, geodesy, charting, and mapping. More significant, however, are our opportunities to provide both leadership and basic data in the future. This the Survey pledges to do.

Following are a number of important program developments and plans which will enable the Survey to continue to meet its objectives, serve the Nation, and the world.

National Climate Plan

Fluctuations in regional climates around the world are coming into sharper focus as the crisis of food and energy intensify and polarize. These fluctuations, whether naturally occurring, resulting from man's activities, or resulting from both, may be responsible for new global climate regimes with widespread effects on food production, energy consumption, and water resources. Much more data must be acquired to determine the nature and extent of climate changes and to anticipate the effects of these changes, both in this country and around the world.

A United States Climate Program has been suggested which includes various long-term monitoring programs to meet the need for more data. A significant part of the program involves ocean/marine data acquisition. Following are six such monitoring programs which the Survey could undertake:

- Monitor the distribution of sea-surface temperature by ship, moored buoy, drifting buoy, and coastal measurements.
- Monitor the heat storage in the surface layer of the ocean by use of moored and drifting buoys.
- Monitor the volume and heat transport of the major ocean currents (e.g. Gulf Stream) utilizing data buoys and bottom mounted sensors.
- Monitor the water mass balance of basins such as the Arctic.
- Monitor temperature and the vertical salinity structure of the oceans, in selected regions, by moored buoys and ship observations.
- Monitor the large scale distribution of sea level by the use of an expanded network of tide gages.

In addition to the above programs, the National Ocean Survey is prepared to continue and expand the efforts by its NOAA Data Buoy Office in support of research-oriented experiments related to climate studies such as the Global Atmospheric Research Program (GARP), First GARP Global Experiment (FGGE), Northern Pacific Experiment (NORPAX), Arctic Ice Dynamics Joint Experiment (AIDJEX), etc.

If additional monitoring is needed by research ships to support other platforms and climate field experiments, these vessels can be included in the NOAA Fleet with logistic and data processing support by the Atlantic and Pacific Marine Centers.

Marine Boundaries

One of the most significant and far reaching actions to be taken in the marine field in the next few years will be that of determining marine boundaries and ownership of the oceans. As social, political and economic forces put increasing pressure on international bodies and organizations to reach agreements on base lines and offshore boundaries, the technical and engineering aspects of the complicated problem become more important. Anticipating the need for delimitation, demarcation and recovery of these boundaries with precision and universal acceptance, the National Ocean Survey is prepared to implement a comprehensive program for establishing base lines required for extending offshore boundaries. This program would provide for defining a marine boundary by latitude and longitude, as compared with lines on charts and monuments in the ocean. This procedure anticipates the wide use of high accuracy electronic instruments for positioning and navigation in the near future.

Dynamic Water Column Surveying and Mapping

As the competition increases for use of our coastal waters and their resources, and environmental protection forces additional constraints, the need for understanding the behavior of these waters increases dramatically. The time is not far away when government and industry must know the dynamic behavior of bays, estuaries, inlets, major river outlets, and offshore waters in order to develop pollution control procedures, control ship traffic, plan for coastal land development, allocate resources development, establish maritime regulations, determine marine ecosystem base lines, and conduct outer continental shelf environmental assessments.

With its program of dynamic water column mapping, the Survey is prepared to implement a comprehensive program of water circulation study along the entire coastal area. These surveys will secure needed environmental data, and, if necessary, provide data to mathematically model a given water system in order to reasonably predict its behavior and dynamic characteristics. Present programs are confined to limited geographical areas.

National Wave Climate Program

In addition to understanding and predicting the dynamic behavior of a body of water; it is necessary to understand and predict surface wave action. A comprehensive knowledge of offshore wave conditions is mandatory for the proper design, installation and operation of offshore structures, ports, and power plants. More details on wave action are required for greater safety of merchant ships and recreational boaters. Long-term wave data is necessary for ship design, beach erosion control, coastal construction and developing marine forecasting models.

The Survey is developing a National Wave Climate Program which will include a wave observation network to acquire wave data for incorporation into scientific and engineering projects. The first part of the program is the installation of a network of data buoys to monitor deep water wave spectra plus other oceanographic and meteorological parameters. The second phase involves the selection of near-shore systems, data analysis procedures, and the application of numerical wave refraction models, which can be used where deep water wave conditions are being monitored and detailed bathymetric information is available.

Remote Sensing Surveying

The next generation of instruments to measure and sense marine parameters required for nautical charting, environmental assessment, water dynamics, and other products and services of the Survey are almost certain to operate remotely. Among the instruments now under development is a combined camera and laser instrument carried by helicopter, hydrofoil, air cushion vehicle or low flying aircraft for shallow water bathymetric surveying. The Survey is working with NOAA groups and other Federal agencies in the areas of satellite sensing units for wave height and direction, sea surface temperature, and near-surface meteorological parameters.

To improve the accuracy and speed of in situ ocean sensing, the Survey is now developing: a system which compensates for elevation change in shipboard

bathymetric instruments by correcting for heave, roll and pitch; a side scan sonar system for wide swath bathymetric surveying; a remote, bottom-mounted tide gage; a remote current direction and speed instrument, a new type shipboard current instrument; and an integrated hydrographic survey system.

Marine Measurements

Measurements of common physical, chemical, and biological marine parameters (e.g. current speed, salinity, plankton, etc.) have been obtained in the past primarily by individual investigators for specialized scientific research. With the emergence of large scale scientific research within the last decade, encompassing many investigators in a multi-national effort, there is a growing need to assure comparability of measurements, as well as to enable other investigators to utilize with confidence the data that have been stored in data banks.

Furthermore, there has been a recent emergence of state, Federal, and international regulations relating to limits on changes in marine environmental parameters that are permitted. For example, power plants are limited in the maximum temperature rise in the condenser main cooling flow permitted during operation. Similarly, the dumping of waste into some bodies of water is not permitted when the oxygen content is below some specified value. Such statutes, when enforced, become the basis for subsequent judicial action.

The Survey intends to develop the techniques, institutions, and procedures, to assure that all data collected for national or international marine research or monitoring programs shall be capable of being shown to be in agreement with nationally accepted measurement systems to within the accuracy claimed. This is primarily a scientific and engineering question relating to the validity of measurements and involves the establishment of protocols with sufficient ancillary measurements to provide a firm basis for defending measurement data against challenges.

The objective is to have scientifically defensible data on the uncertainty of measurements so that their probity, particularly in matters of litigation, is not open to question. For example, the possession of a "certified" instrument is not in itself enough--it must also be shown to have been used properly. For the rights of all to be properly protected, it must be possible to "cross-examine" the measurement data and thus it is necessary that those involved in enforcement have supporting evidence adequate to withstand such challenges.

Geodynamics Studies

Recognizing the need to develop new approaches and techniques for earth dynamics measurements and the need for refinement of network monitoring systems, the Survey plans to expand its programs in geodynamics. These programs will emphasize systems for time variable changes in geographic positions and gravity, in response to increased demands for this type data.

These new programs in geodynamics should stimulate the undertaking of additional scientific investigations, including the problems associated with mean-sea-level slope, secular variations in the motion of the pole, and plate motions.

Technology Exchange Program

The geodetic survey efforts of states, counties, and other local agencies are shifting dramatically. The introduction of modern, efficient instruments and improved technical ability are completely changing the approach to surveying, and creating a need for information and technical assistance. The Geodetic Advisor Program, the establishment of instrument calibration base lines, and the organization of geodetic workshops have been initiated to assist in meeting these increased requirements. Further effort will be expanded in developing an educational program which will provide consulting, limited computing and other services to the local agencies. Consulting efforts at Survey Headquarters will be initiated so the local agencies can densify existing control and fully utilize the existing national networks.

The Survey has recently initiated a pilot program of three geodetic advisors. Vertical and horizontal control of second-order are being established in Arizona and Louisiana. Training of personnel and recovery of marks are being undertaken in Arizona, Louisiana, and New York.

Releveling Vertical Control Network

Approximately 80 percent of the present vertical geodetic control network is no longer adequate to meet national needs because of crustal movements, low accuracy of early surveys dating back to 1875, and the loss and destruction of many geodetic monuments. The Survey is beginning a 7-year program of releveling approximately 40,800 km of existing level lines, readjustment of the basic framework of the vertical control network, and publication of the results.

Geodetic Field Party Computers

Based on the successful application of a portable computer terminal system with a geodetic field party last year, the Survey is planning to deploy additional units with other field parties as soon as possible. The system allows transmission and processing of geodetic survey data and control station descriptions to a central computer in Bethesda, Maryland, and the receipt of information from headquarters. The advantages are: availability of field data much sooner as compared with conventional data processing procedures; improved efficiency in field surveying; faster computation; and more consistent data.

Geodetic Research

The geodetic research effort is directed toward developing and applying new or improved techniques and instrumentation (1) in support of NOAA and other Federal operational programs which depend on geodetic information, and (2) for extending knowledge of the figure of the earth and its gravity field. Examples in the first category are determination of three-dimensional positions on the lunar surface by photogrammetric analysis of Apollo photography, determination of the sea level surface from satellite altimetry which will serve to delineate tides, currents, and other oceanographic phenomena, and determination of positions to precisions of the order of a few centimeters in order to monitor changes with time. Examples in the second category are the determination of the earth's gravity field from satellite data by improved mathematical techniques, and analysis of the benefits of new data gathering methods such as the satellite-borne gradiometer.

Ultraprecise Numerical Photogrammetry

Field tests over the past few years using precision numerical photogrammetric techniques in coordination with classical ground geodetic surveys have provided evidence of great strides in using this procedure for high accuracy chart and map production and for control surveys at moderate costs.

By improving the hardware, procedures and techniques in aerial photography, photogrammetric processes, and geodetic ground control, the ground accuracies in the final product can be considerably improved as they have been for the last 20 years. Planned tests are expected to produce ground accuracies of first-order (one part in 100,000). Involved in these tests are: a systematic analysis of all possible errors, the use of a special Reseau lens cone, precise determination of monuments in the test area, and data evaluation.

The Survey is prepared to implement a program of using ultraprecise numerical photogrammetry for geodetic control densification and shoreline surveys. The accuracy potential of this procedure permits its use for certain applications in much less time and at relatively low cost, compared with classical geodetic methods.

Automated Charting and Navigation

The shipboard computer-assisted hydrographic data acquisition system is now operational. The computer-assisted nautical charting system is nearing operational status and scheduled for full operational status in the spring of 1980. Recognizing the change in chart user requirements and the potential advantages available with use of state-of-the-art electronics, the Survey is developing plans for the next generation of hardware, software, and procedures.

Future shipboard applications include: a bridge CRT showing a continuously displayed map of the sea floor; solid state memory chips for data acquisition instead of magnetic tape or paper tape; real time telemetry of hydrographic data from a central bank to the survey vessel; and telemetry of acquired data to the central bank; complete integration of ship speed, track, position, course, and depth using satellite and radio telemetry; automatic avoidance systems; and the eventual use of electronic chart displays on command via satellite from a shore-based data bank. In the interim, new chart production processes will include line follower digitizers, laser production of printing plates, and new techniques in multi-color printing.

Aeronautical Chart Automation

As with nautical charting, the Survey has placed high priority on the automation of aeronautical charting by application of the latest advances in computers and electronics. This past year the Survey embarked on an ambitious program to automate the production of aeronautical charts, beginning with the Terminal Area subsystem series which accounts for about 90 percent of the total aeronautical chart production. Elements in this program include: a procedure to validate cartographic data used to prepare charts; building a cartographic data base in digital format for computerized input and output with a variety of uses; and a computerized interface with FAA. To avoid interruption of service during the

transition period from manual to automated production, interim computer services will be developed to assist manual production, particularly in the area of small charts and radar video maps. This project also includes the replacement of manual cartographic procedures and equipment with computerized and computer-assisted systems which will automate the processes of map production.

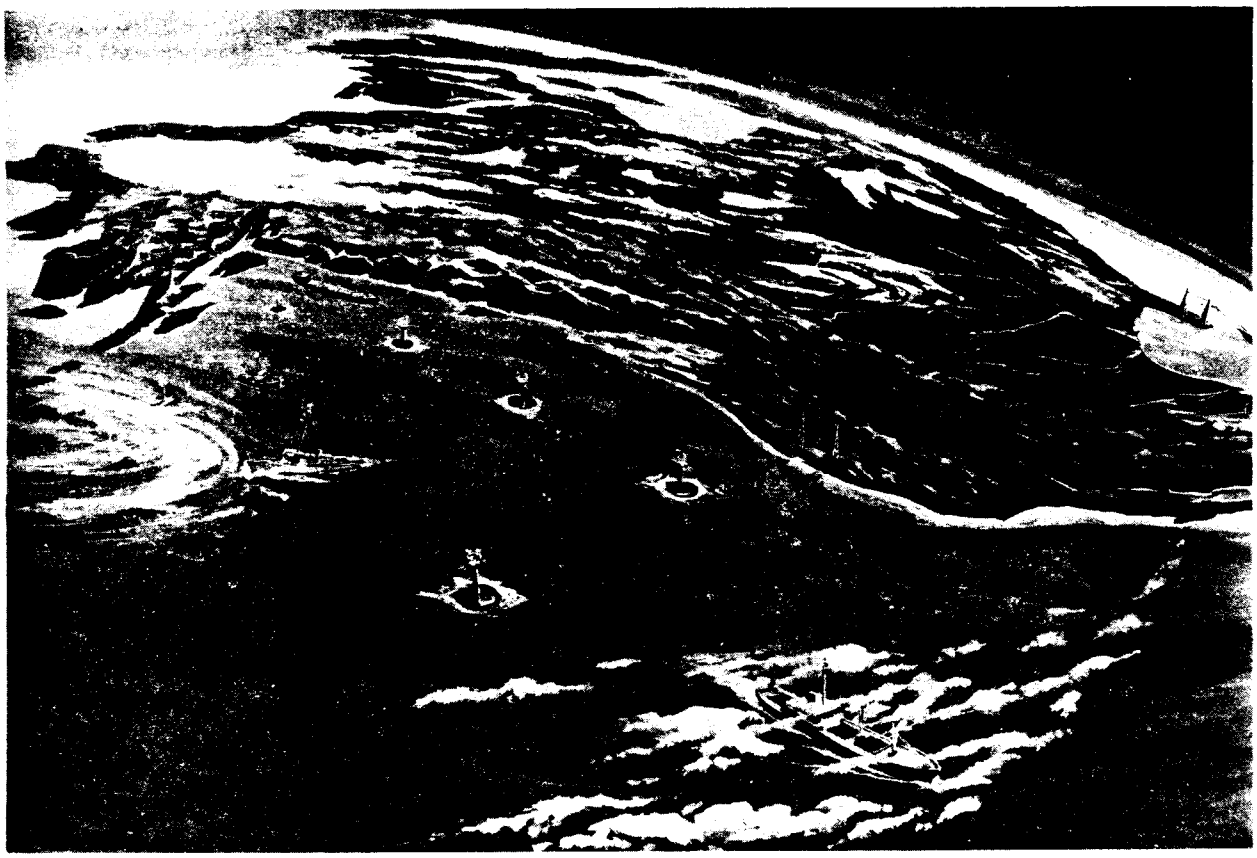
In addition to the automation of cartographic data processing and map production, aeronautical charting future plans include the development of techniques and hardware to provide cartographic data in new formats in response to sophisticated electronic air traffic control systems and computerized navigation systems. This includes direct data input via solid state memory units, real-time transmission of data from a central data bank, and systems which provide greater interaction in real-time between aircraft, ground controllers and a central cartographic data bank.

Coastal Zone Mapping

The Survey has a program to accelerate the production and revision of standard map products in the coastal zone, and to make a new series of maps which are needed to meet expanding mapping requirements generated by the economic development of the Outer Continental Shelf such as offshore drilling, deepwater ports, offshore nuclear powerplants, ocean dumping, and compliance with environmental requirements. These maps will also serve as primary tools for state, county, local, and Federal agencies to better plan for optimum utilization, conservation and management of the coastal zone area being impacted by OCS development as well as urban sprawl, and private use for tidal property. Plans call for production as a cooperative effort jointly funded and supported by the Survey and the U.S. Geological Survey.

The revision program will upgrade an existing series of maps with a scale of 1:24,000 using Geological Survey data for the land portion and Survey data for the water portion. Survey bathymetric data will be shown in metric units, and Geological Survey hypsographic data will be shown in English units. The program will involve approximately 1,600 maps.

The new map program will be an entirely new family of maps at a scale of 1:100,000 to fit within the National Mapping Program, and to serve as a basic map series for coastal zone planning and studies. The new series, to be produced in all-metric format, will total about 300 different maps.



Artist's concept of deployed environmental buoys