THE MAJOR DEEP-SEA EXPEDITIONS AND RESEARCH VESSELS 1873–1960

A CONTRIBUTION TO THE HISTORY OF OCEANOGRAPHY

GEORG WÜST

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GEORG WÜST†

1. INTRODUCTION

From the study of this history of oceanography, written for a broader circle of interested readers, we learn that its progress depends on:

1. The results of the great oceanic expeditions, i.e. on the research work at sea, and the interpretation of data.
2. The improvement of instruments and methods on board ships and in the laboratories, and
3. The development of theory, particularly in dynamical oceanography.

As in all sciences, progress is not continuous. Most of the ideas, instruments and methods influencing research work in the laboratories are conceived in the preparation and in the accomplishment of great expeditions. At the same time new theoretical concepts are also formed. In this paper the progress in oceanography is demonstrated mainly as the results of representative deep-sea expeditions, but it is not exclusively based on these. Other highlights of the development in ocean research are considered whereby European and American efforts are related. In oceanographic history, ships' names have always been better remembered than those of expedition leaders. This may be attributed to the expedition reports which usually take the name of the ships and, more significantly, to the fact that the results represent the work of teams of scientists. The most outstanding deep-sea expeditions that have influenced thought in marine sciences are grouped into four eras (Appendix A).

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2. ERA OF EXPLORATION (1873–1914)

Modern oceanography is considered to have begun with the great British deep-sea expedition on board H.M.S. *Challenger* (Plate I), a spar deck corvette of 2300 tons, which under the scientific leadership of SIR WYVILLE THOMSON crossed the Atlantic, Pacific and Indian Oceans in 1873–1876 along some longitudinal and latitudinal sections (Appendix B, Chart 1). This magnificent expedition provided in fifty folio-volumes (edited by C. WYVILLE THOMSON and JOHN MURRAY) the foundations for our knowledge of the physical–chemical, bathymetric, geological and biological conditions in the open oceans. The first epoch of oceanographic research initiated by the *Challenger* may be termed the "Era of Exploration" (1873–1914). It was characterized by widely-spaced stations along isolated profiles. A combination of the results from several such expeditions produced a first picture of the bathymetry, stratification and circulation of the water masses and the conditions for life in the deep oceans.

The German expeditions, *Gazelle* (Appendix B, Chart 2), *National* under V. HENSEN, and *Valdivia* under C. CHUN (Plate II; Appendix B, Chart 4) during 1874–1899; and *Gauss* under E. VON DRYGALSKI, *Planet* (Appendix B, Chart 5), and *Deutschland* (Appendix B, Chart 6) during 1901–1912* belong to this early era during which meridional sections were preferred. During 1885–1889 the first evidence of the American oceanographic activity, mainly in the western North Atlantic particularly in the Caribbean Sea, was characterized by the expeditions of the U.S.S. *Blake* and U.S.S. *Albatross* under JOHN ELLIOTT PILLSBURY and ALEXANDER AGASSIZ. Under the direction of the latter U.S.S. *Albatross* also worked successfully on biological problems of the eastern and northern Pacific. The current measurements of PILLSBURY during this period at thirty-nine anchor stations of *Blake* at great depths (Fig. 1) in the Gulf Stream system belong to the classical data of physical oceanography "... not so much because they give complete information as to the average currents, but mainly because they made possible" (forty years later) "a convincing demonstration of the correctness of the later methods used for computing [... the so-called geostrophic] currents" (SVERDRUP *et al.*, 1942, p. 673; and WÜST, 1924). From 1886 to 1889 the Russian steamer *Vitiaz* under S. O. MAKAROFF undertook a voyage around the world during which valuable physical observations in the North Pacific were made. In 1889 the great field of the horizontal and vertical distribution of the small drifting organisms, the plankton, was developed with the help of quantitative methods by VICTOR HENSEN, the scientific director of the Plankton Expedition on board the *National*. From 1884 to 1922 PRINCE ALBERT I OF MONACO made systematic biological studies in the depths of the North Atlantic Ocean between the Cape

* Oceanographer of the *Planet* and *Deutschland* expeditions was W. BRENNECKE.

Verde Islands and the coasts of New England, Newfoundland and Spitzbergen aboard his research vessels, the *Hirondelle I* and *II*, and *Princesse Alice I* and *II*. "By enshrining the results" in a large number of folios and "in the monumental buildings at Monaco and Paris he has invested his labours with

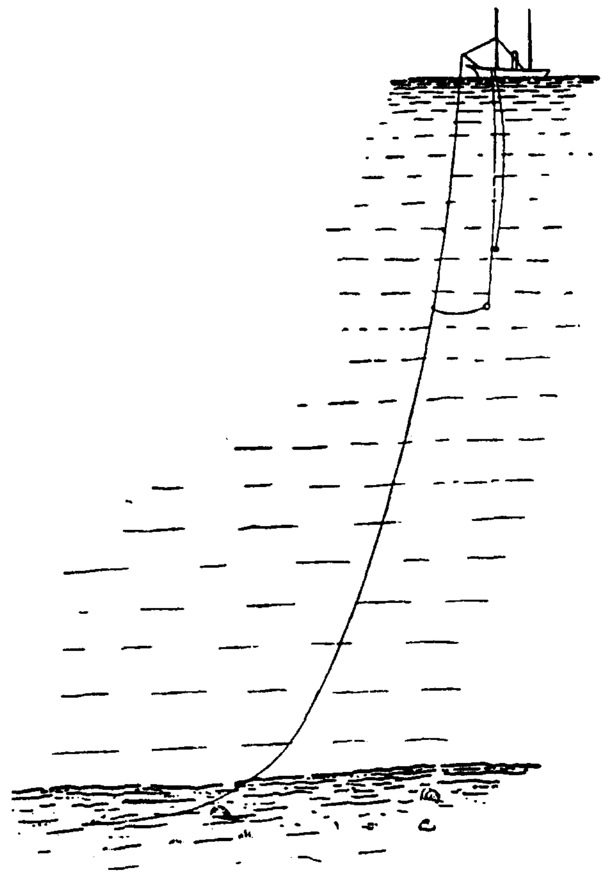

FIG. 1. U.S.S. *Blake* on anchored station in the Florida Stream and the passages of Caribbean Sea during continued current measurements (after J. E. PILLSBURY, 1891).

permanent value for all time" (HERDMAN, 1923, p. 132). About 1900 the Permanent International Council for the Exploration of the Sea was founded by the nations surrounding the North and Baltic Seas especially for a long-range oceanographic program to serve as a scientific basis for a more rational sea fishery.

Concurrently, other important oceanographic discoveries were being made. FRIDTJOF NANSEN on his famous *Fram* expedition (Plate I; Appendix B,

Chart 2) in the Arctic Ocean in 1893–1896 was the first to observe the great depths of the North Polar Basin and the spreading of relatively warm and saline subsurface water from lower latitudes into it. From the ship's ice drift he has shown that the wind-driven currents flow not in the direction of the wind, but at an angle to the right of it (in the northern hemisphere). Stimulated by these observations, V. WALFRID EKMAN (1902; 1905) in 1902 developed his theory of wind-driven currents in which the influences of turbulent friction and the deflecting force of the earth's rotation were for the first time adequately considered. In the same period, FRIDTJOF NANSEN and BJÖRN HELLAND-HANSEN emphasized the importance of greater accuracy in the measurements

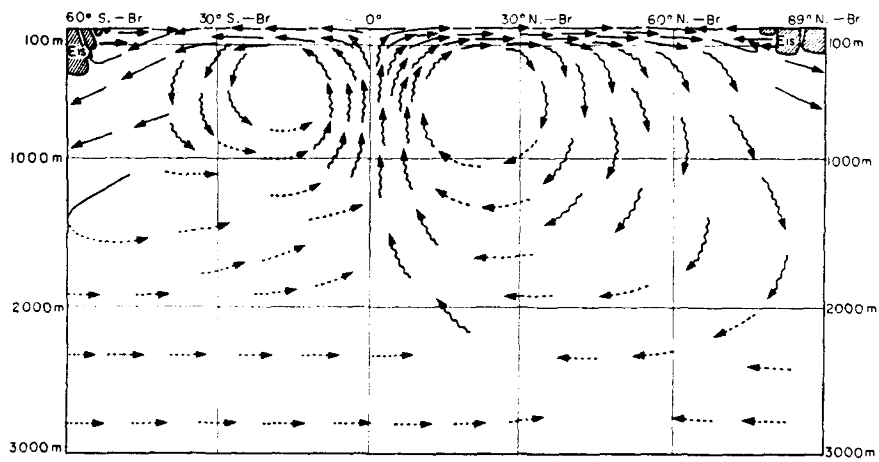

FIG. 2. Schematic diagram of the longitudinal Atlantic deep circulation (after G. SCHOTT in Vol. I of the *Valdivia* Reports, 1902).

of temperature and salinity and made essential contributions to the development of such necessary instruments and methods as the reversing water-samplers (Nansen bottles) and reversing thermometers for serial measurements at oceanographic stations. In 1901 MARTIN KNUDSEN and other members of an international commission established the relationship between chlorinity, salinity and density. They prepared the "Hydrographical Tables" (1901) for the calculation of salinity from chlorinity and for the computation of density at any temperature and salinity. They also improved the accuracy of the measurements by devising special burettes and pipettes and by the preparation of standard tubes containing "normal sea water". But the knowledge of the deep circulation of the oceans remained very schematic. In 1902 the oceanographer of the *Valdivia* Expedition, GERHARD SCHOTT, published the above diagram of the oceanic vertical circulation of the

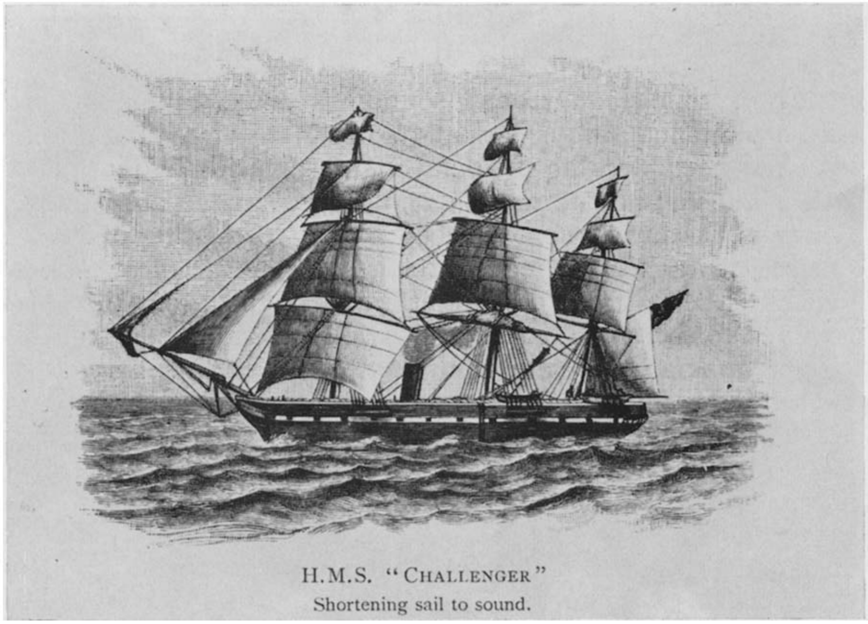

PLATE Ia. H.M.S. *Challenger* (shortening sail to sound).

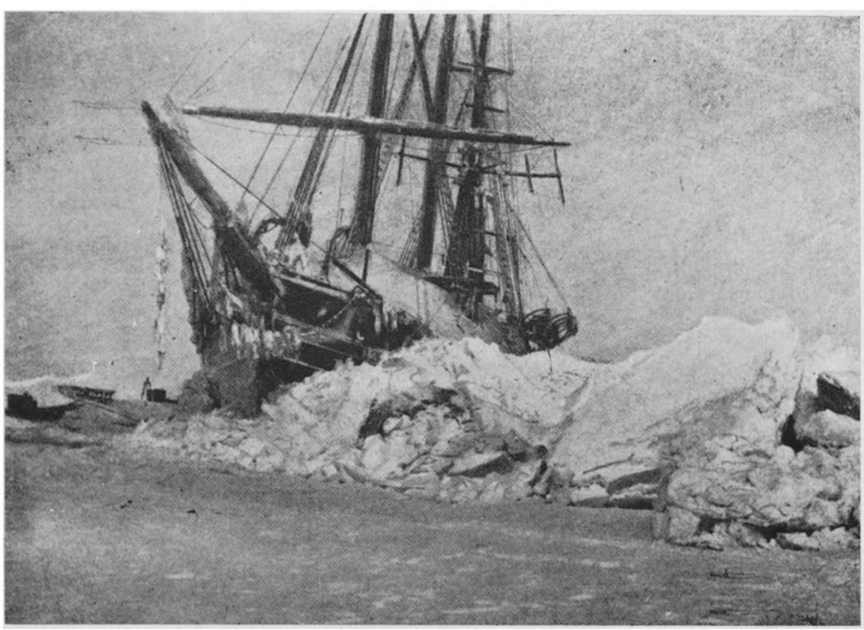

PLATE Ib. *Fram* in the North Polar Basin (after NANSEN, 1900).

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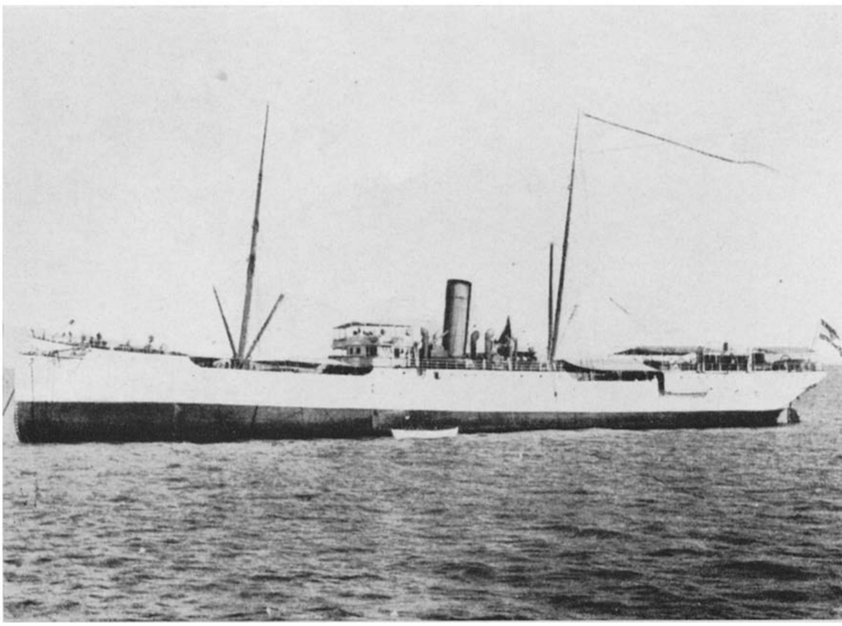

PLATE IIa. Steamer *Valdivia* (after CHUN in *Valdivia* Reports 1902).

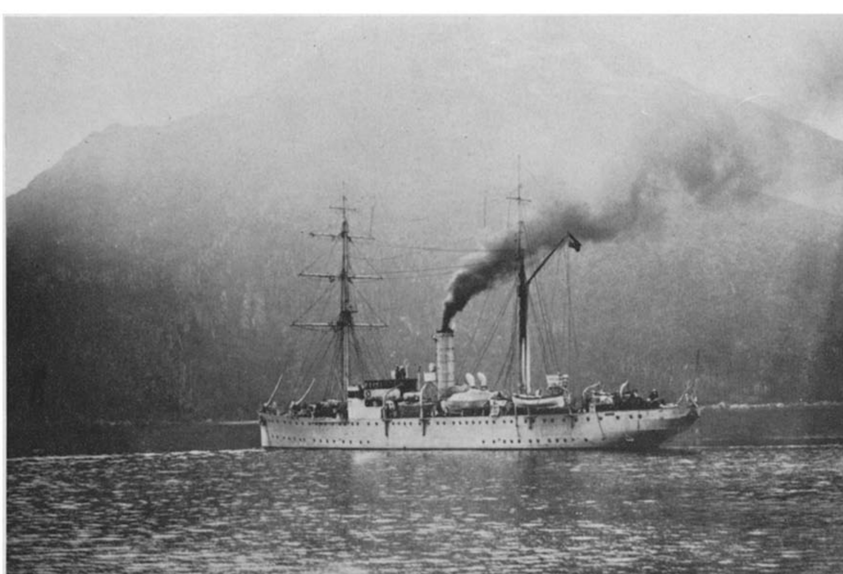

photo Deutsche Atlantische Expedition 1925–1927

PLATE IIb. Research vessel *Meteor* in the Beagle Canal (after *Meteor* Reports).

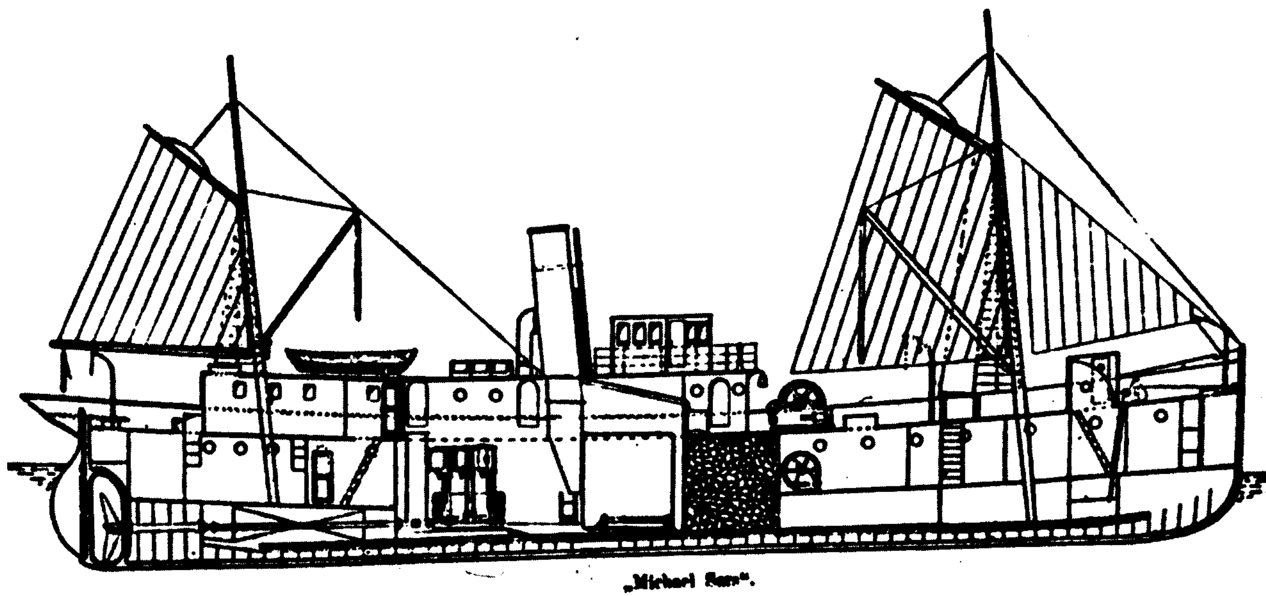

FIG. 3. S.S. *Michael Sars* (after MURRAY-HJORT, 1912).

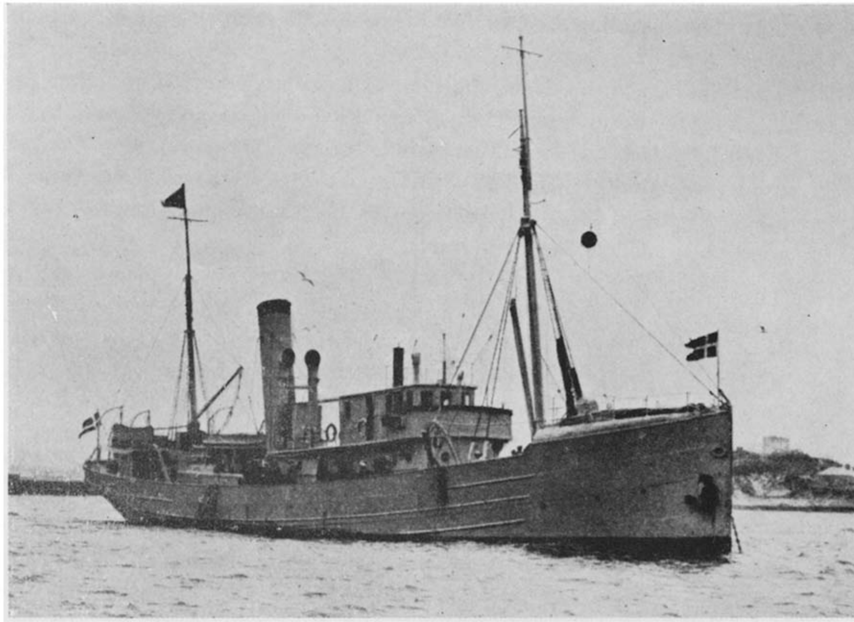

PLATE IIIa. Research vessel *Dana II* (after J. SCHMIDT).

photo Carnegie Institution of Washington

PLATE IIIb. Research vessel *Carnegie*.

Atlantic Ocean (Fig. 2), which shows two more or less closed symmetrical circles for each hemisphere on either side of the equator.

Very soon thereafter, a new start in physical oceanography was made by the Scandinavian school of oceanography. With the small Norwegian research vessel *Michael Sars* (Fig. 3) the first meticulous systematic measurements were made at many stations in the Norwegian Sea. In 1903, in connection with these more accurate observations, J. W. SANDSTRÖM and B. HELLAND-HANSEN (1903) applied the circulation theorem of V. BJERKNES to the ocean in a simplified form. Thus, the permanent deep geostrophic currents could be calculated from a baroclinic field of mass. Bergen in Norway became the mecca of physical oceanographers for the study of such dynamic methods. The Scandinavian scientists also established the style of oceanographic research using very small boats, such as the *Armauer Hansen* of only 53 tons. Oceanography began to grow from a branch of geography which was chiefly descriptive and statistical to a full-fledged branch of geophysics. This period of Norwegian activity (1904–1924) already showed the transition to more systematic research and to a dynamic oceanography.

3. ERA OF NATIONAL SYSTEMATIC AND DYNAMIC OCEAN SURVEYS (1925–1940)

On the basis of this progress and further improvements of instruments and methods, and through the careful planning of ALFRED MERZ (1925), a new era of deep-sea research was initiated in 1925–1927 by the German Atlantic Expedition on the Research Vessel *Meteor* (Plate II) with fourteen latitudinal cross-sections of the Atlantic Ocean between 20°N and 65°S. On these sections (Appendix B, Chart 7) the stations were closely spaced, and subsurface observations were made at standard intervals all the way down to the deep-sea bottom in 4000–6000 meter depths. A huge mass of data on the stratification and circulation of water masses, on bottom sediments, on the distribution of chemicals and of the plankton and on the meteorological conditions were collected. Measurements of the currents were made directly at ten deep anchor stations, and meteorological and aerological observations were made continuously throughout the cruises. The schematic diagram of a *Meteor* deep station shows these so-called "classical methods" (Fig. 4). Reasonable qualitative and quantitative approximations in the study of the central problem of this expedition—the deep circulation and mixing processes in the whole expanse of the Atlantic Ocean—could now be obtained with the help of the core method and dynamic computations. The schematic block diagrams (WÜST, 1950) (Figs. 5 and 6) reveal the unsymmetrical exchange (in reference

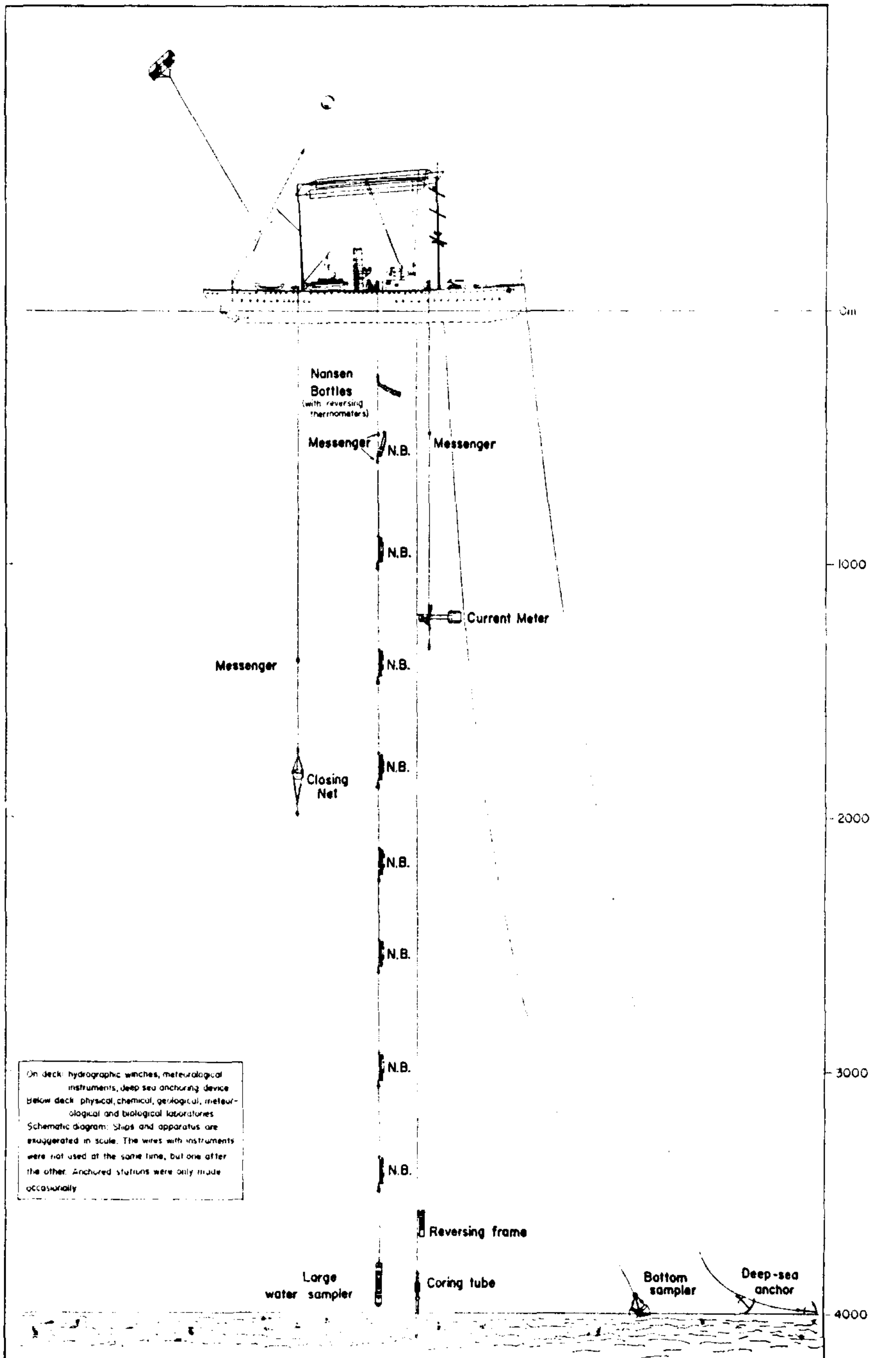

FIG. 4. *Meteor* on a deep-sea station (schematic after *Meteor* Reports, Vol. IV, 1, 1932).

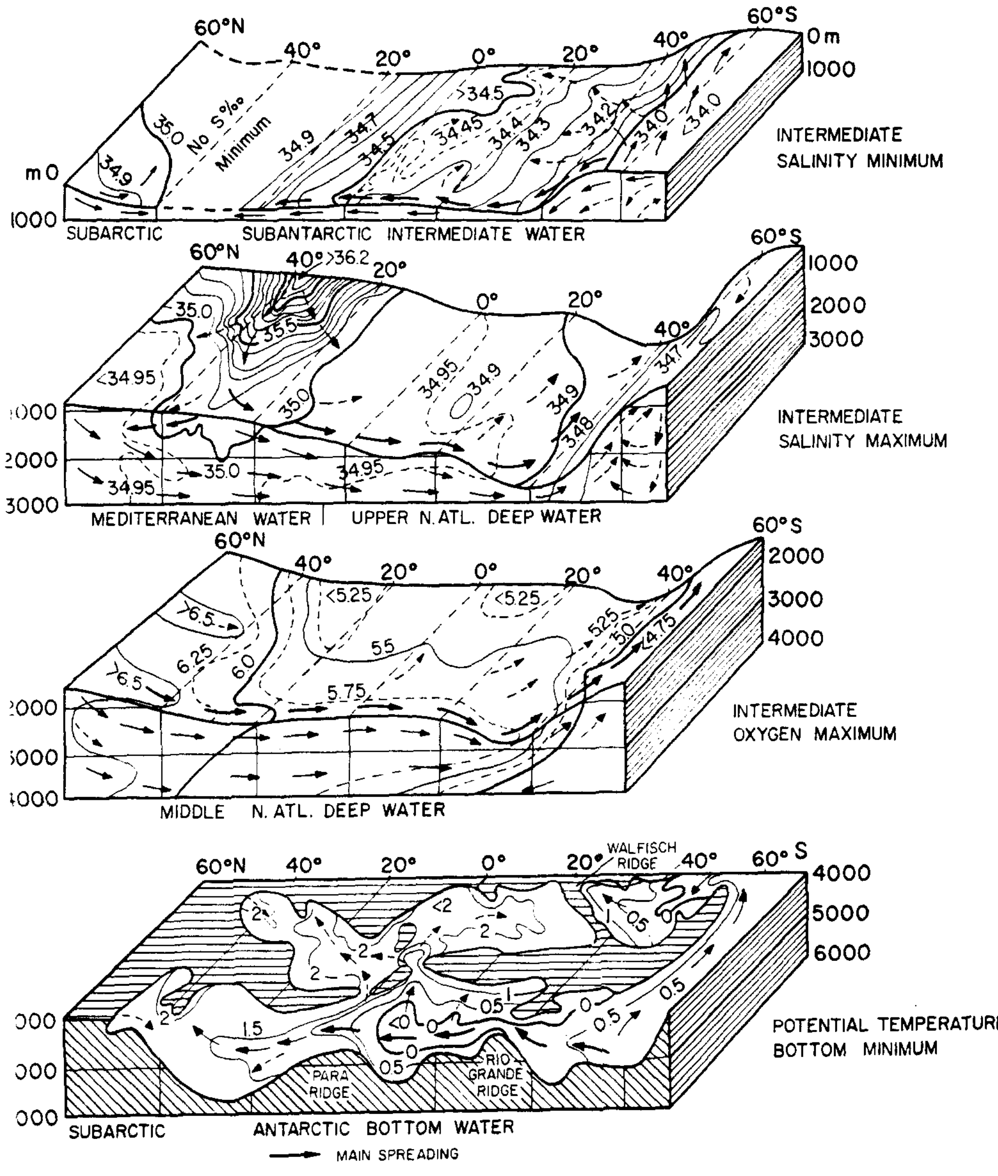

FIG. 5. Schematic block-diagram of the spreading of main water masses of the Atlantic in 4 core layers of the cold water sphere (after WÜST, 1950).

to the equator) of the 5 water types in the Atlantic cold water sphere and an amazing concentration of deep currents of high velocity within a limited western boundary flow. For the first time also a systematic use of the epoch-making invention, the echo sounder, was made. A surprising irregularity of the bottom relief was disclosed in all cross-sections where previously, because of the sparse wire soundings, a great uniformity of the bottom features had been assumed. By the complete analysis of data in the *Meteor* reports, this expedition stimulated other nations to undertake similar deep-sea expeditions such as the Dutch *Willebrord Snellius* Expedition (1929–1930) in the East Indian seas, the British *Discovery* Expeditions (since 1930) mostly in the Antarctic Ocean and the American *Atlantis* Expeditions (since 1931) mainly in the North Atlantic (Appendix B, Chart 11). As an example of the *Discovery* Expeditions we reproduce after G. E. R. DEACON the 19 Antarctic sections of *Discovery II* in 1932–1934 (Plate IV; Appendix B, Chart 10). In 1928–1930 the expedition of *Dana II* around the world (Plate III; Appendix B, Chart 9) became the largest of a series of Danish expeditions, directed by J. SCHMIDT. In 1928 *Carnegie* (Plate III; Appendix B, Chart 8), and since 1937 *Ryofu Maru* and *E. W. Scripps*, started modern research in some regions of the Pacific Ocean which, with the later cooperation of the United States, Canada and Japan, reached its greatest development in the so-called *Norpac* Program within the North Pacific Ocean (Appendix B, Chart 15). In 1938 *Altair* and *Armauer Hansen* made the first attempt of a quasi-synoptic survey in a restricted area of the Gulf Stream northwest of the Azores. Finally in 1937 the drift of the Russian Pole station and in 1938 the ice drift of the Russian icebreaker, *Sedov*, initiated a new era of oceanographic research in the North Polar Sea, which later was continued by numerous Soviet and American ice expeditions. This second era between 1925 and 1940 may be called the "Era of National Systematic and Dynamic Ocean Surveys" and was characterized by a network of measurement points along continuous sections made from one research vessel only.

In this era and the following years, important progress was made mainly in the United States in two fields of physical oceanography:

1. In the dynamics of ocean currents, particularly by C. G. ROSSBY and H. U. SVERDRUP, and
2. By the improvement of instruments, methods and academic education since about 1930, particularly by the newly-founded American oceanographical institutions, of which only the largest are mentioned: Scripps Institution of Oceanography of the University of California at La Jolla, Woods Hole Oceanographic Institution on Cape Cod (Plate IV), and since about 1950, a third, Lamont Geological Observatory of Columbia University in the City of New York. Since 1931 the Woods Hole Oceanographic Institution has made in the depths of the Atlantic

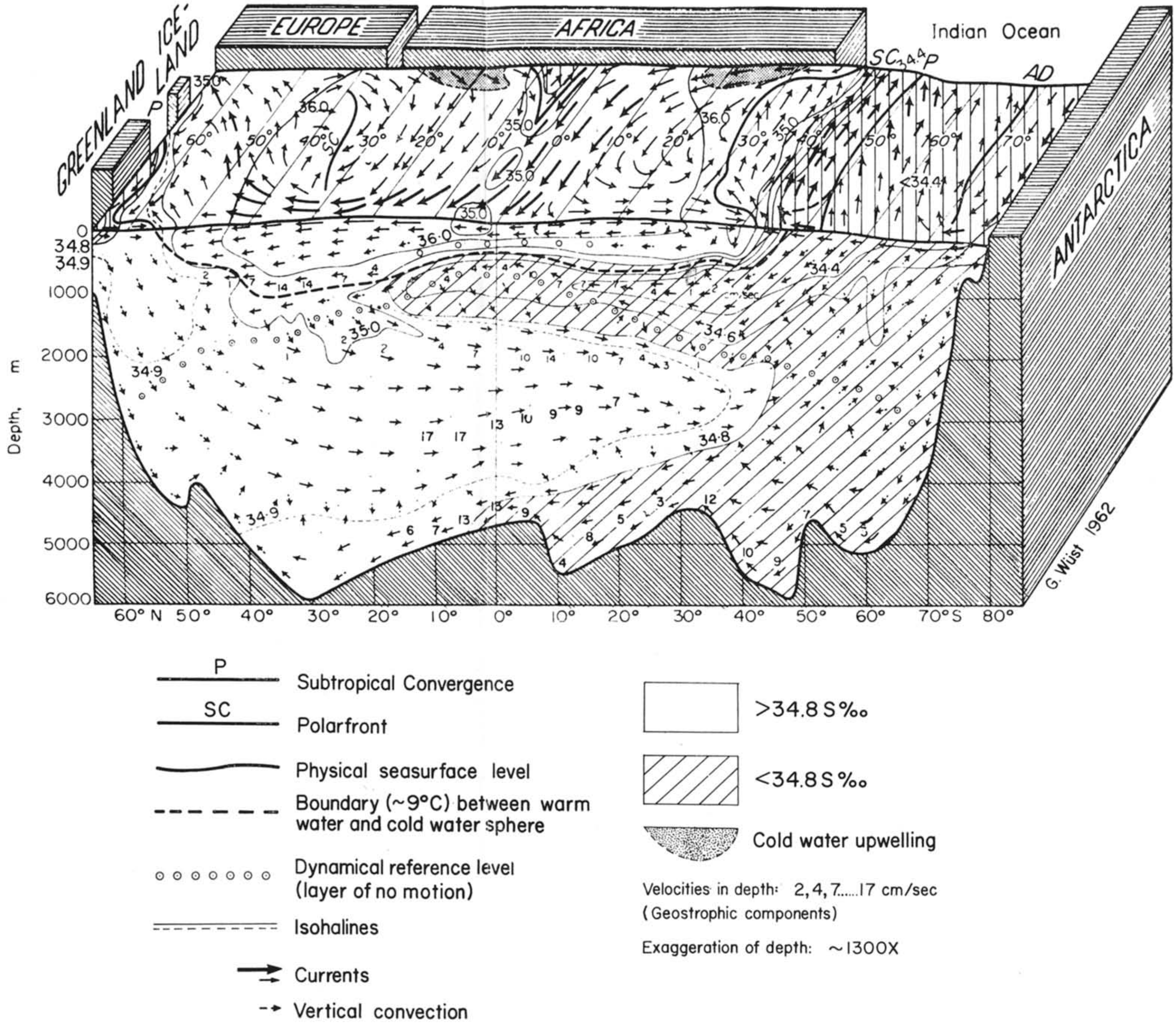

FIG. 6. Schematic block-diagram of the surface currents, of salinity distribution and of deep circulation on the west side of the Atlantic deep sea (after WÜST, 1949, corrected).

the greatest contribution to the source material of serial measurements, not only in quantity but also in quality (Appendix B, Charts 11 and 18).

By an oceanographic triangulation (with the help of a network of 629 stations) A. DEFANT (1941) derived in 1941 in a first approach the absolute topography of the physical sea surface level and of the isobaric surfaces in the depths of the Atlantic Ocean, which made it possible to compute the absolute geostrophic currents and volume transports in the deep sea. In 1942 the modern compendious handbook by SVERDRUP *et al.* (1942) "brought together much of the world's knowledge of the whole science" and "joined the old European and growing American points of view" (VON ARX, 1962, p. 16).

4. PERIOD OF NEW MARINE GEOLOGICAL, GEOPHYSICAL BIOLOGICAL AND PHYSICAL METHODS (1947–1956)

In the decade after World War II new specific methods of marine geology, marine geophysics (seismology, gravimetry and earth magnetism) and marine biology were foremost in the representative great deep-sea expeditions, when the research work at the deep-sea bottom, in the abyssal trenches and in the solid earth crust below the ocean was greatly intensified.* Figure 7 demonstrates the various methods used in such deep-sea research and the greatest depths reached in the ice-cold and dark water masses of the 6½ mile-deep trenches, where the enormous bottom pressure is 1100 atmospheres or 1.1 ton per square centimeter. The classical methods of serial measurements have now been extended down to 10,500 m depths with Nansen water bottles, closing nets and dredges. In 1947–1948 in the calm tropical regions of the world ocean, the Swedish *Albatross* expedition (Plate V; Appendix B, Chart 12) made the first systematic use of BÖRJE KULLENBERG'S (1947) invention of the piston coring tube which made it possible to study undisturbed cores of 20 meter lengths and thus trace the sediments on the deep-sea bottom back to the Tertiary period (Figs. 7 and 9). The oceanographers had long assumed that the layers of water closest to the deep-sea bottom would be inert, i.e., that in the abyssal depths stagnant conditions exist especially in the trenches. It has already been mentioned that in the *Meteor* reports the calculations of the geostrophic deep currents on the western side of the Atlantic have given unexpectedly high velocities. They were in the order of magnitude of 3–13 cm/sec in the Antarctic Bottom Current to the north and of 5–17 cm/sec in the North Atlantic Deep Current to the south (Fig. 6) (WÜST, 1955). Corresponding values were found in 1957 farther north in the North Atlantic Deep Currents, i.e. in the deep counter-current (to the south) under the Gulf Stream off the Blake Plateau by direct current measurements with SWALLOW'S neutrally buoyant floats (Fig. 10) which were in the range of

* See footnote on p. 21.

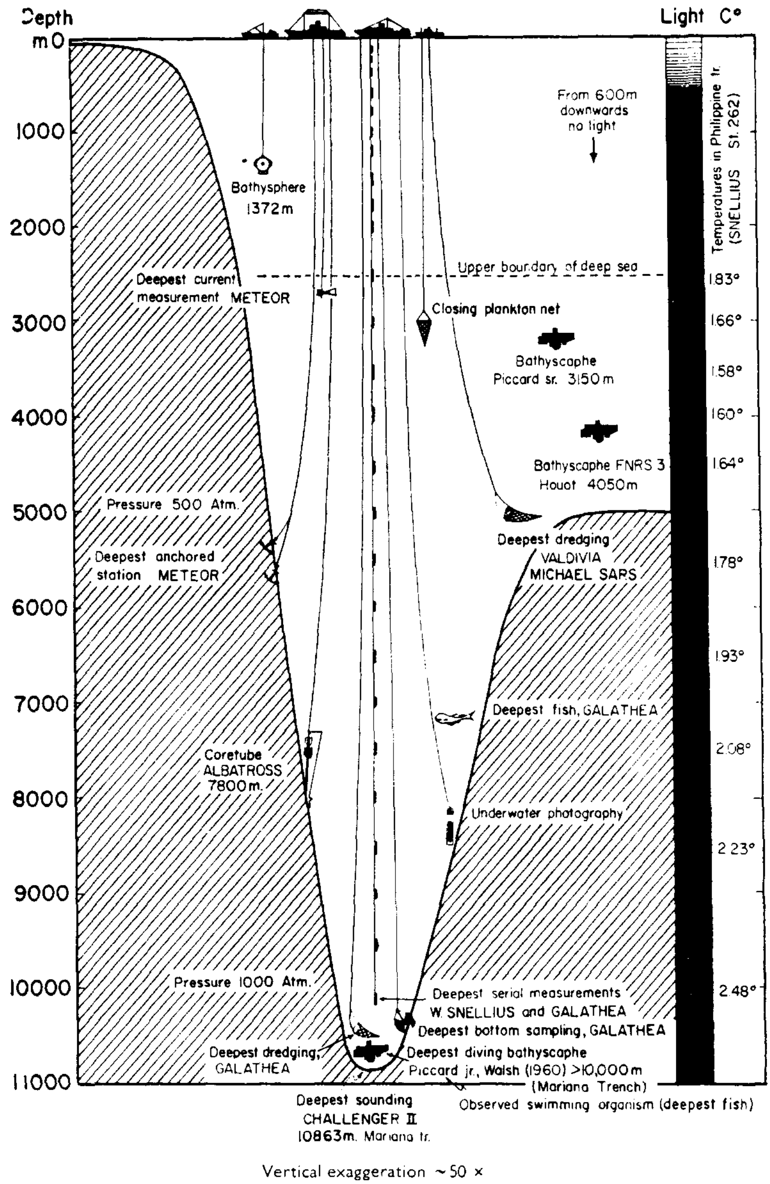

FIG. 7. Schematic diagram of methods in deep-sea research and their maximum depths in abyssal trenches (after WÜST, 1956, corrected).

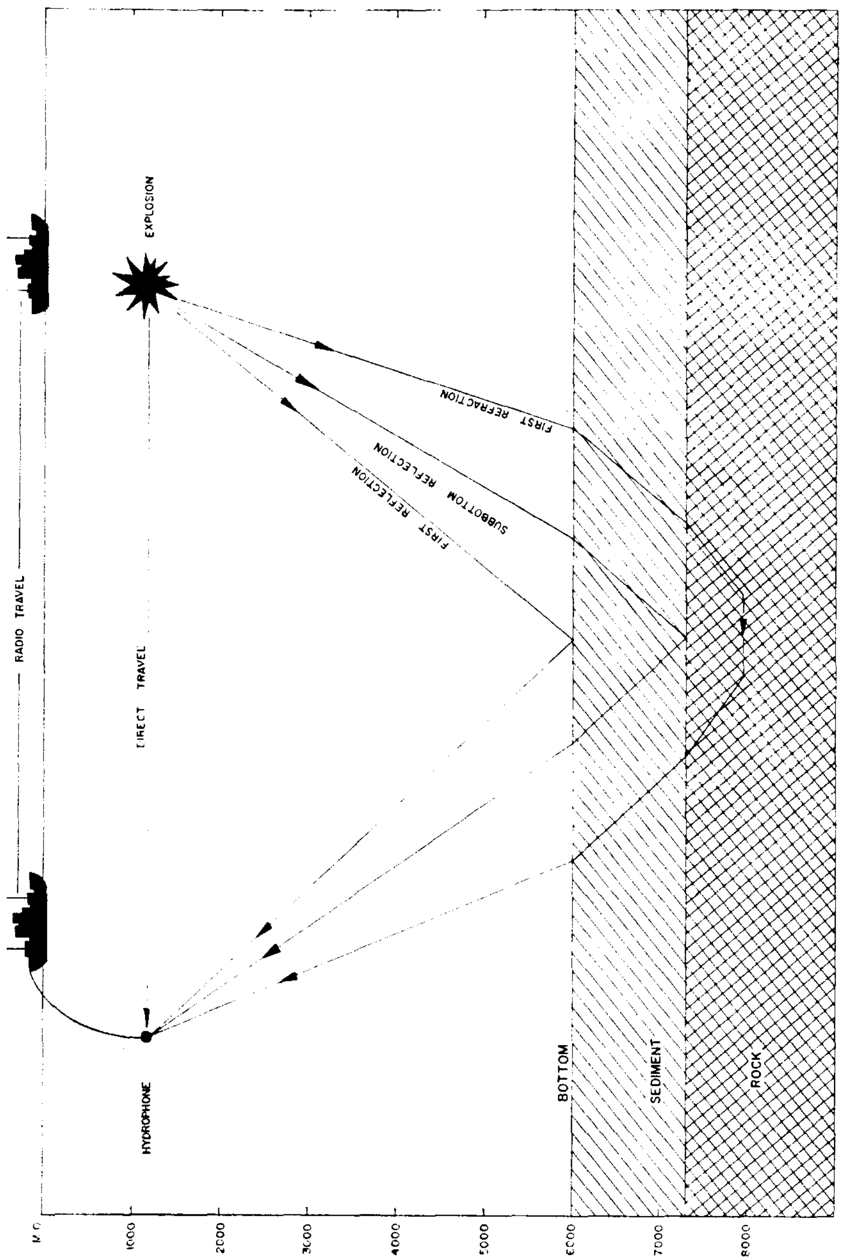

FIG. 8. Refraction shooting by explosive soundwaves (after M. EWING, 1954).

6–18 cm/sec (SWALLOW and WORTHINGTON, 1960). These findings of measurable bottom currents are in agreement with the biological results of the Danish *Galathea* Expedition in 1950–1952 (Plate V; Appendix B, Chart 13), which

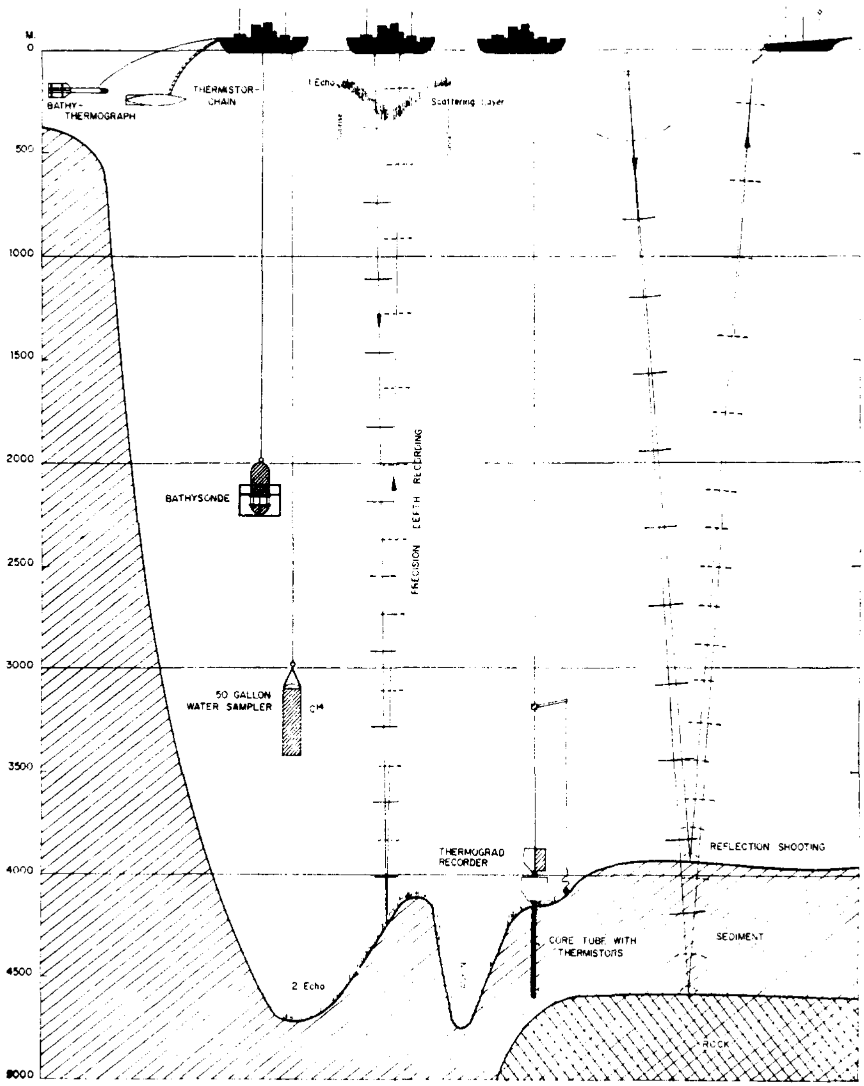

FIG. 9. New electronic methods of continuous recordings of temperature, salinity and depths, reflection shooting for recording the undersea crust, and large water sampler for C^{14} and other isotopes.

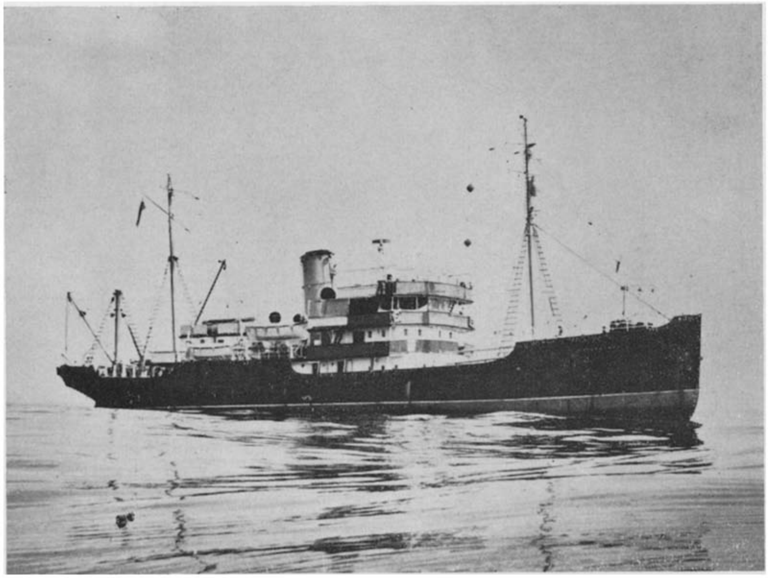

photo National Institute
of Oceanography

PLATE IVa. Research vessel *Discovery II.*

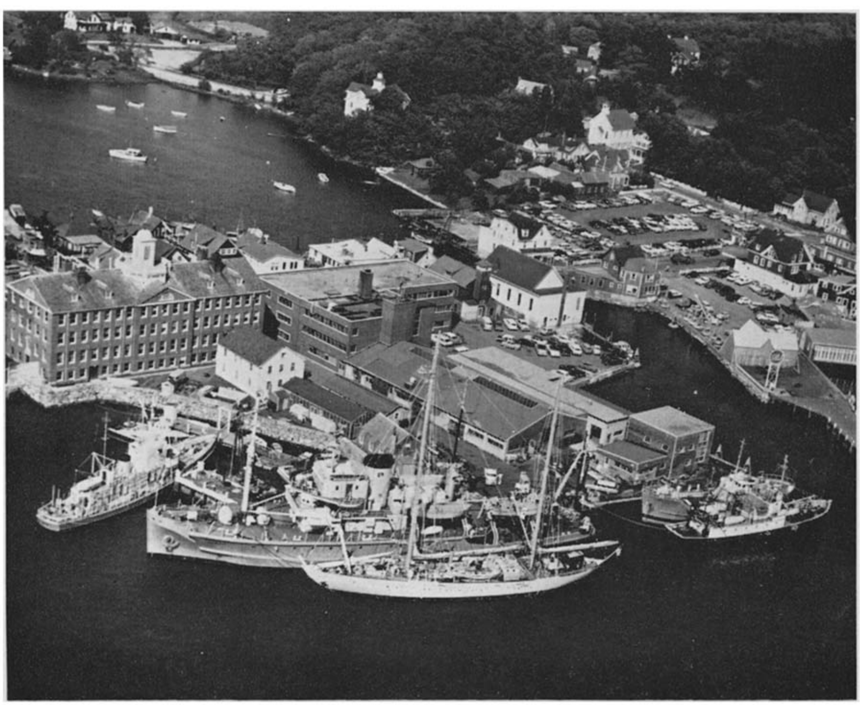

photo C. Spooner

PLATE IVb. Woods Hole Oceanographic Institution and its research vessels.

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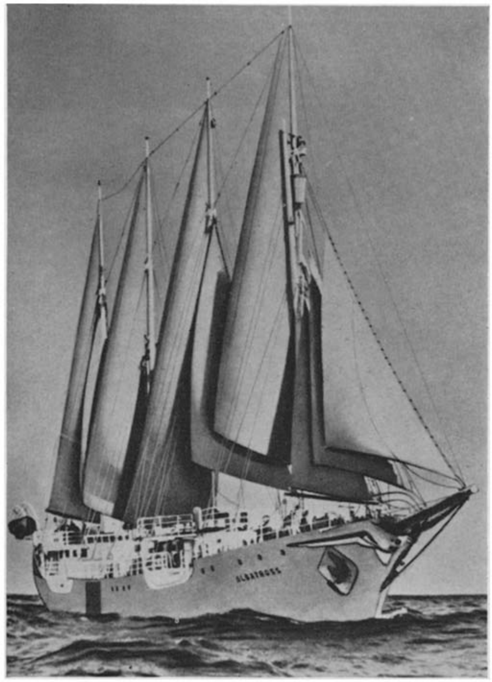


photo Oceanografiska Institutet Göteborg

PLATE Va. Research vessel *Albatross* (Swedish).

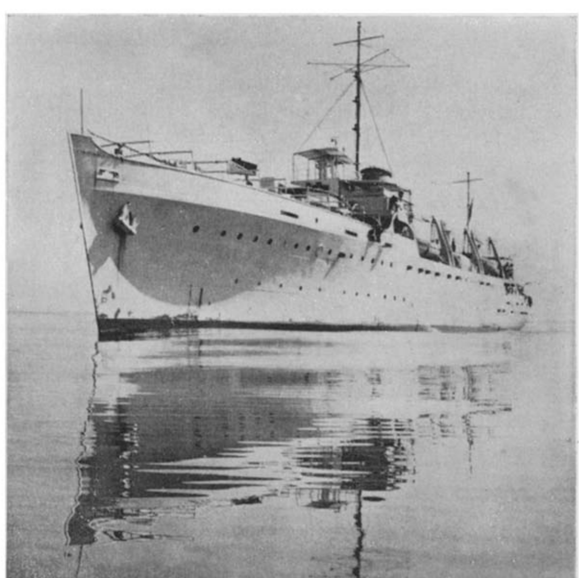


PLATE Vb. Research vessel *Galathea*.

photo Lamont Geological Observatory

PLATE VIa. Research vessel *Vema* leaving New York.

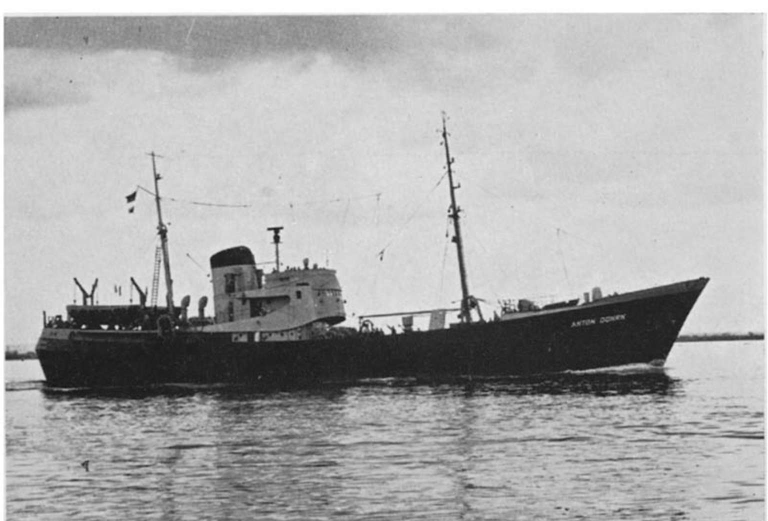


photo F. Krügler

PLATE VIb. Research vessel *Anton Dohrn*.

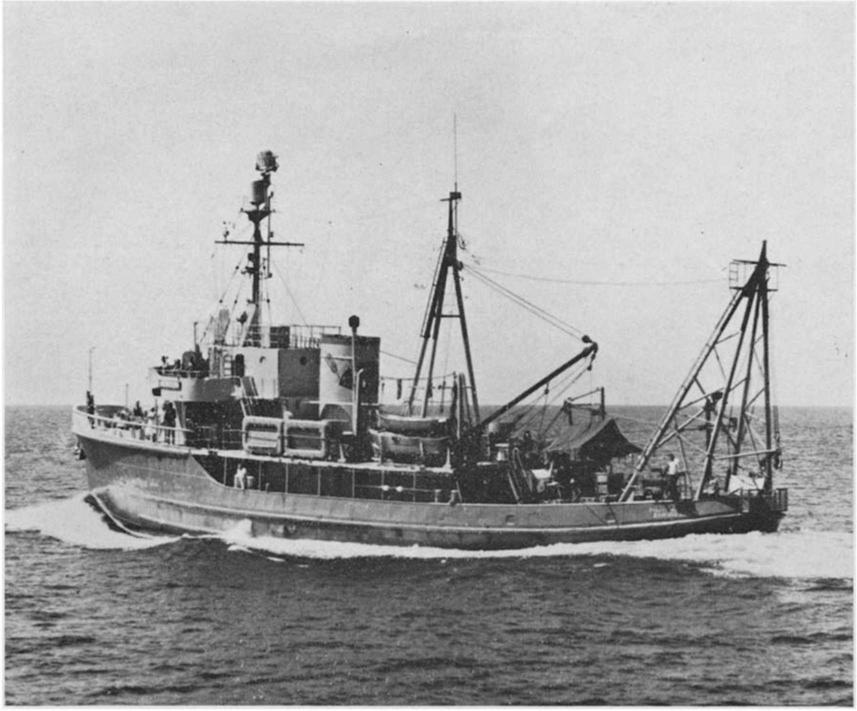


photo Scripps Institution of Oceanography

PLATE VIIa. Research vessel *Horizon*.

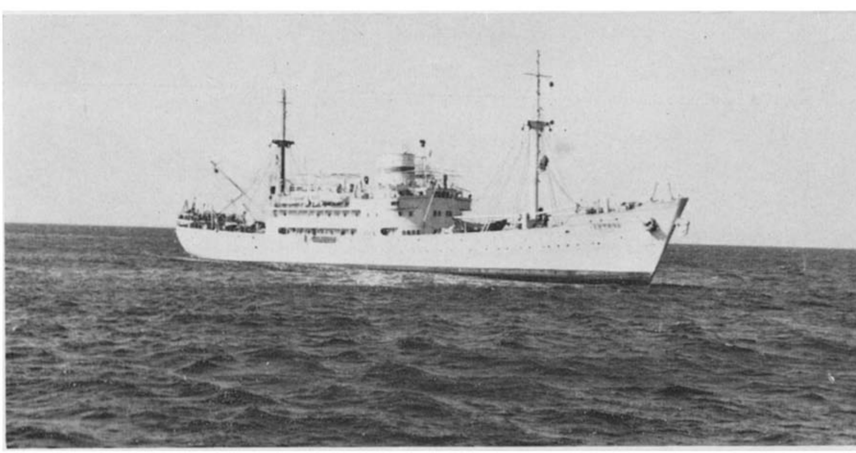


photo N. Zenkevitch

PLATE VIIb. U.S.S.R. research vessel *Vitiaz*.

collected about two hundred species of small living organisms by systematic dredging in the Philippine trench (BRUUN, 1957). In 1960 JACQUES PICCARD and Lieutenant DON WALSH descended in the bathyscaphe *Trieste*, to the bottom of the Mariana trench nearly seven miles deep where they observed flat fishes, jelly fishes and shrimps swimming just above the bottom in these enormous depths. A fish of 4 inches in length seems to be a giant at such depths. When constructing for the first time the schematic diagram in 1956 (Fig. 7) it was not expected that four years later the maximum depth of diving would be increased from 4000 m to more than 10,000 m depths. Similarly, surprising results were obtained on the geophysical features of the oceanic substratum by the expeditions of the American research vessels *Vema* (Plate VI), *Spencer F. Baird*, *Atlantis*, *Chain* (Plate IV), and *Horizon* (Plate VII). In this respect the geophysical activity of the Lamont Geological Observatory under Maurice Ewing must be emphasized. He has organized and partly directed eighteen cruises, each of about ten months' duration, through the deep oceans, partly around the world, including the stormy regions of the higher southern latitudes, with concentration on seismic refraction and reflection shooting and magnetometer, gravimeter and precision depth recordings (Figs. 8 and 9). Here we show only the Atlantic cruises of *Vema* in 1953–1960 (Appendix B, Chart 17). The continuous echograms of the latter have contributed greatly to a modern detailed understanding of submarine morphology, particularly in the deep oceanic basins (with the canyons, ridges, rift valleys, rises, abyssal plains and trenches) and provided BRUCE HEEZEN *et al.* (1957–1961) with the basis for the construction of a new type of physiographic diagram of the Atlantic Ocean. During these cruises *Vema* also collected a remarkable number of large water samples for the determination of the age of the deep water masses by the C^{14} and other isotope methods of geochemistry. Also, important contributions to the geophysics, geochemistry and geology of the deep-sea bottom were accomplished by other American and British oceanographic institutions, particularly by the Scripps Institution of Oceanography which carried out the first heat flow measurements through the floor of the Eastern North Pacific Ocean (REVELLE and MAXWELL, 1952)* and published the first modern geological study of the Pacific Ocean floor (MENARD, 1959).

In this third era, which may be called the "Period of New Geological, Geophysical, Biological and Oceanographical Methods", the Woods Hole Oceanographic Institution continued its remarkable activity in oceanographic field research with numerous cruises of *Atlantis* in the North Atlantic (Plate IV; Appendix B, Chart 11) and started the first systematic, nearly synoptic, studies of the Gulf Stream with *Operation Cabot*, in 1950. By the simultaneous

* This method was introduced by E. C. BULLARD (1949) (see REVELLE and MAXWELL, 1952).

activity of five research vessels and with the help of new recording instruments (bathythermograph, G.E.K., Figs. 9 and 10), this great enterprise discovered the meander-like pattern and the jet stream-like character (sometimes in multiple currents) of the Gulf Stream (FUGLISTER, 1951; FUGLISTER and WORTHINGTON, 1951). In the field of dynamic oceanography, H. M. STOMMEL (1948) gave a physical explanation for the westward intensification of the wind-driven surface circulation. At the same time, W. H. MUNK (1950) of Scripps Institution of Oceanography developed a new theory of wind-driven circulation for ocean basins with a simple shape. In 1954 an amazingly strong and limited equatorial undercurrent in the Pacific was discovered by T. CROMWELL and collaborators (CROMWELL, MONTGOMERY and STROUP, 1954), now called the Cromwell Current.

5. ERA OF INTERNATIONAL RESEARCH COOPERATION SINCE 1957

With all this progress, oceanography once again was approaching a cross-roads. The International Geophysical Year (1957–1959) marks the fourth era of ocean research. In this era, it seems certain that the transition will be accomplished from more or less independent national research work of one ship only to systematic multi-ship enterprises, i.e. to international and more synoptic programs for the physico-chemical and biological conditions in the huge water masses of the ocean basins, as well as for the geological and geophysical features at and beneath the ocean bottom and the meteorological conditions above its surface.

Through cooperation of the research vessels, *Crawford* (only 300 tons), *Atlantis* (Plate IV), *Discovery II* (Plate IV), *Chain* (Plate IV), and the Argentine survey ship, *Capitan Canepa*, about fifteen cross-sections were made in the Atlantic at an interval of 8° latitude between 48°N and 48°S (Appendix B, Chart 18). This Atlantic International Geophysical Year Program was partly a repetition and partly an extension of the *Meteor* Expedition. There were, however, important variations in planning the grid of the stations. To allow more adequate comparison of the profiles, the Atlantic International Geophysical Year profiles north of the equator were also plotted along the parallels of latitude. The number of the stations and the number of the vertical measurement points in the great depths at each station were increased from the so-called standard depths. In addition to this Atlantic International Geophysical Year Program between 48°N and 48°S, the International North Atlantic Polar Front Program (Appendix B, Chart 19a and b) with nine nations cooperating, extended the area of systematic oceanographic cruises farther north with a network of stations along thirty sections, which were partly repeated in the stormy winter months in early 1958. For the first time in the history of deep-sea research, Russia, now possessing an oceanographic fleet of twenty large research vessels and one research submarine, had participated in an international oceanographic research program. The U.S.S.R. commissioned for this cooperation their largest research vessels, *Vitiaz* of 5700 tons (Plate VII), *Mikhail Lomonosov* of 6000 tons (Plate VIII), and *Ob* of 12,600 tons (Plate VIII), the last of which was built as an icebreaker for research in polar seas. In these programs also, systematic studies of nutrients, primary organic production and their relationship to the water types and the bordering convergences and divergences, were included through a close cooperation of physico-chemical oceanographers and planktonologists. West Germany assigned to the Polar Front Program (Appendix B, Chart 19) the research vessels *Anton Dohrn* (Plate VI) and *Gauss* for surveys in both summer and winter. The encouraging experiences of this international teamwork and the initiative of G. DIETRICH (1960) led in 1960 to the International Overflow Program (Appendix B, Chart 20) in the region of the Iceland–Faroe ridge. With the cooperation of six nations aboard nine research vessels, including Russia once more, the closest network of cross-sections ever made in the open ocean was completed. This network was resurveyed twice more and permanent stations were established in the middle of the area, where direct current measurements were also made. This remarkable grid of nearly synoptic stations reveals what we may anticipate in the fifth era just begun, the "Era of Synoptic Oceanography".

During the International Geophysical Year the international oceanographic cooperation reached its peak in the Atlantic Ocean. In the North Pacific and in the Indian Ocean a similar task was fulfilled on a smaller scale by the continuation of the already mentioned *Norpac* Program (Appendix B, Chart 15), the so-called Intertropical Pacific Program, and in 1955–1959 the Russian cruises of *Vitiaz* (Plate VII) and *Ob* (Plate VIII) in both areas (Chart 16). In summary, we can say that, as a result of the International Geophysical Year programs, the quantity and also the quality of the basic data, especially in physical oceanography, marine geophysics and marine geology, were "increased and improved by a whole order of magnitude". An important international agreement was attained by the creation of the World Data Centers where all observations of the International Geophysical Year are collected and available for all scientists of the world.* Remarkable contributions to this progress have been made since 1955 by the application of new recording, partly electronic, measuring apparatus invented mainly in American, British, Australian, Canadian and German laboratories. As examples, the following are some of the important new devices: the salinometer

* Since 1961 a U.S. National Oceanographic Data Center in Washington became more and more helpful to the American oceanographers by sending them photocopies of its huge collection of serial measurements, etc.

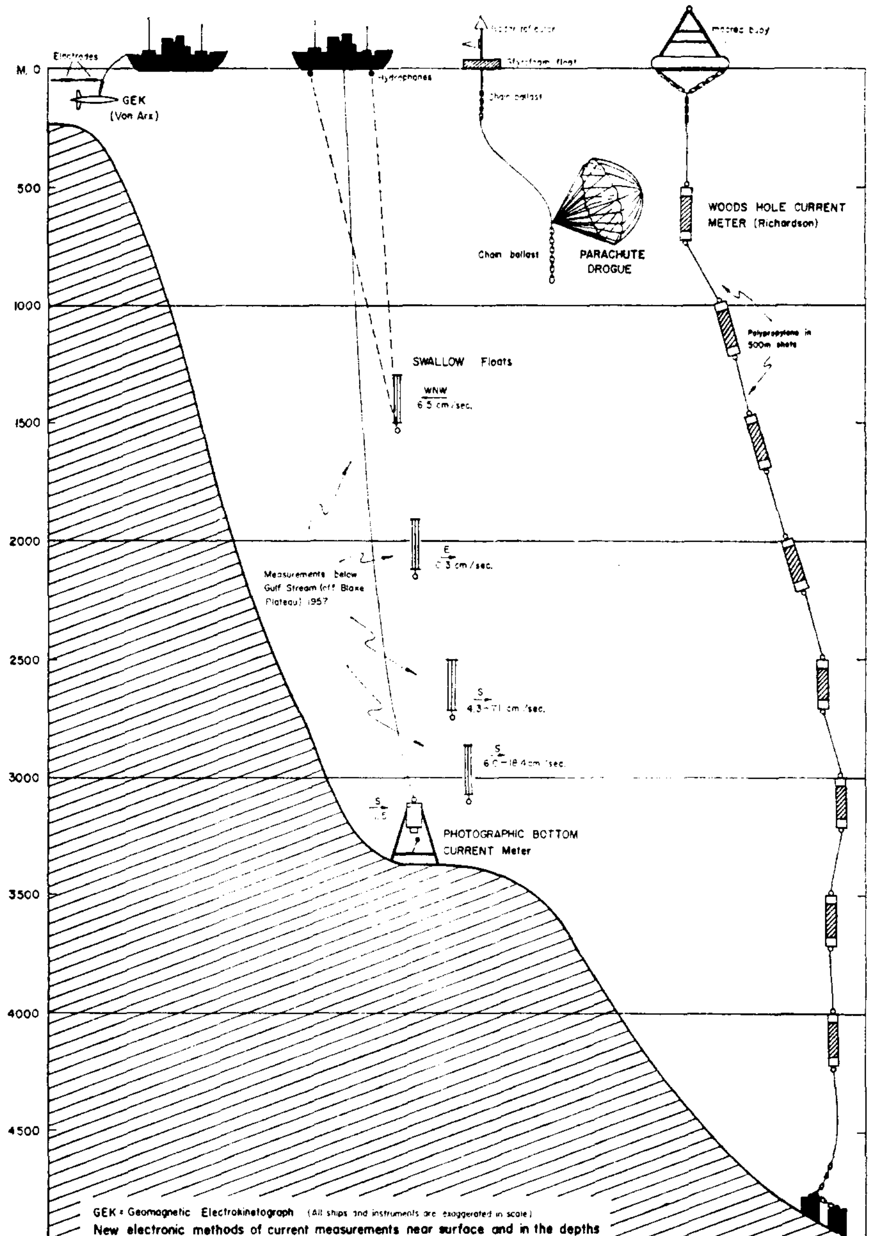


FIG. 10. New electronic methods of current measurements near surface and in the depths.

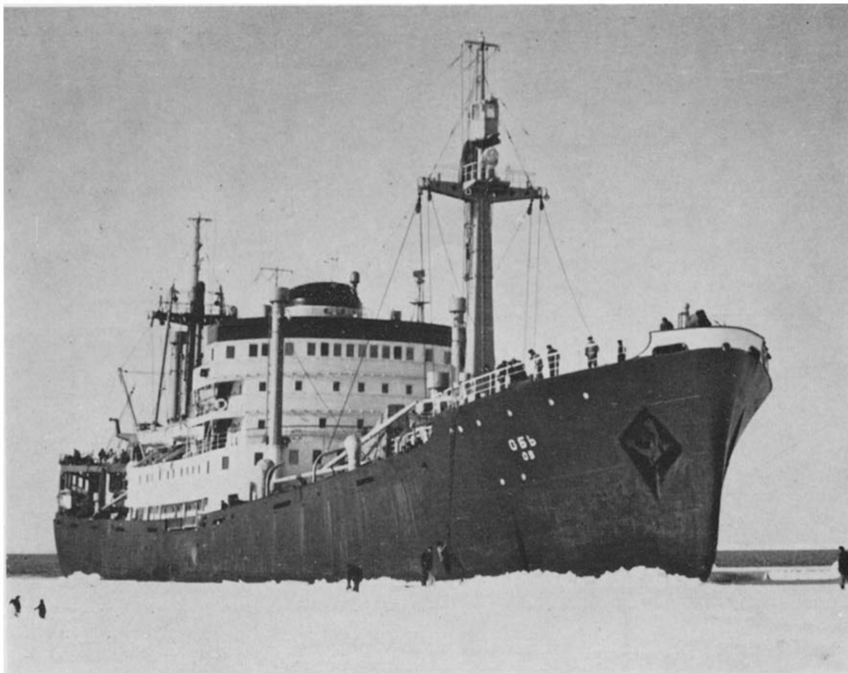


photo A. N. Bogoyavlensky

PLATE VIIIa. U.S.S.R. research vessel *Ob*.

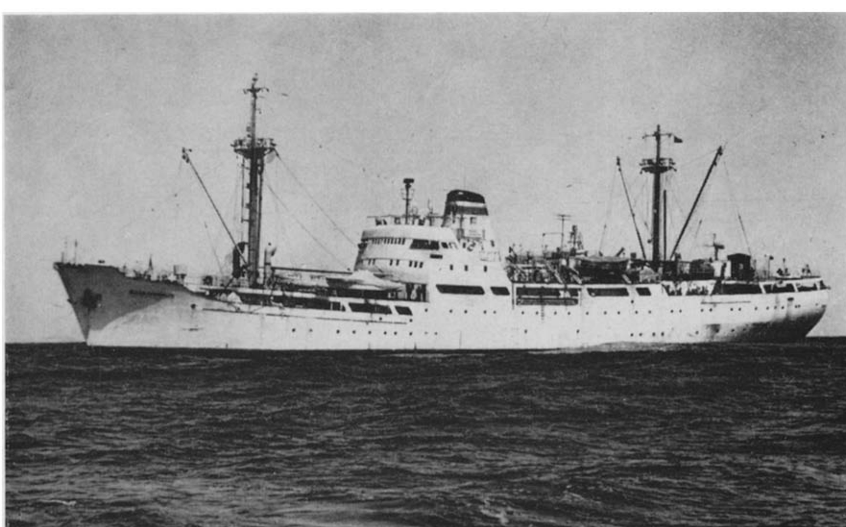


photo L. Zenkevitch

PLATE VIIIb. U.S.S.R. research vessel *Mikhail Lomonosov*.

Facing page 18

photo F. Krügler

PLATE IXa. The international oceanographic fleet for the "Overflow Program" in the Faroe Islands 1960.

photo Lamont Geological Observatory.

PLATE IXb. *Vema* rounding Cape Horn April 1960.

(for the rapid and exact electronic determination of salinity), the bathythermograph and the thermistor chain (for continuous recordings of temperature in near surface layers), the thermograd recorder (for heat flux recordings in the sediments and near bottom waters), and the bathysonde (for temperature, salinity and pressure recordings to 3000 m depths after KROEBEL, 1961, and HINKELMAN, 1956). Figure 9 shows schematically these new electronic methods of continuous recording of temperature, salinity and depths, reflection shootings for recording the undersea crust and large water sampler for geochemistry. At present the most promising new electronic methods of direct current measurements near the surface and in the depths are the G.E.K. (after VON ARX, 1950), SWALLOW (1955) neutral-buoyancy floats, photographic bottom current meter, parachute drogue and Woods Hole current meters (after RICHARDSON *et al.*, 1963); they are schematically represented in Fig. 10. The larger American research vessels, such as *Chain*, *Horizon* (Plate VII), *Vema* and *Argo*, are already today floating oceanographic and electronic laboratories. In the next ten years there will be about fifty new research vessels of various kinds and sizes in the United States. In most nations with large oceanographic institutions, plans for the construction of new types of research vessels have been drawn up and we may generally expect a greater willingness of governments and science foundations to finance and sponsor an increased number for further basic research in the deep oceans on a much expanded scale.

This report on the fourth era of oceanic research would be incomplete without reference to the more recent development of the theory of ocean currents and many other problems in oceanography. Inspired by the surprising observational results of the jetstream character and meander-like pattern of the Gulf Stream, numerous models have been constructed. In 1958, H. M. STOMMEL (1958a) published an important monograph on this subject. Also, the findings of the unexpected strong volume transports at great depths on the western side of the oceanic basins have given rise in the United States to some theoretical models of the oceanic deep circulation patterns (STOMMEL, 1958b; STOMMEL and ARONS, 1960). But here, as in all other fields of oceanography, the recent developments, especially in American laboratories, progress so fast that each report for the past year is out of date as it is issued.

In many parts of the world ocean, particularly in the Indian Ocean and the South Pacific Ocean, oceanography has not advanced beyond the second and third stages of research. In 1959 during the New York meeting of the Special Committee on Oceanic Research (SCOR), a plan for an International Indian Ocean Expedition during the nineteen-sixties was proposed. Although it was possible to make one survey with a number of ships to cover most of the Atlantic, the work at tropical stations in the Indian Ocean (between 20°S and 24°N) must be repeated during each monsoon because of the complete reversal of the wind and current systems. Because of the stronger zonal components in the Indian Ocean, this work will be done not only by equidistant latitudinal sections but also by longitudinal ones. In any case the Indian Ocean will be the next field of systematic international cooperation on a large scale.

6. CONCLUDING REMARKS

The first step of oceanographic activity must be the observational work at sea with all the pleasures of exploration, oceanographical measurements and visits to strange coasts. However, the conditions are not always as pleasant as in the laboratories on land (Plate IX). The second step is the numerical evaluation of the data which must increasingly be done with the help of electronic computers because of the enormous increment in the numbers of observations being made. But in the further development of oceanography, the expensive collection of the mass of data cannot be regarded as the main task of expeditions. Complete analysis of the data must not be pushed farther and farther into the background. The third step, the complete interpretation of data which will provide the new results anticipated for the central problems of the expeditions, is the most tedious of all, but it brings the greatest progress and satisfaction. It is the duty of able oceanographers to complete the analysis and interpretation of the tremendous amount of new data and to set high standards for the publication of the results, as was done by the great expeditions in the past. Such tasks are time-consuming and also expensive. However, the scientific value of an expedition or of the teamwork on an international expedition program depends on the quality and the completeness of the results published in extensive expedition reports. The classical methods could start with the assumption that in the greater depths we have stationary conditions. This means that the processes of circulation or advection which tend to modify the distribution of properties are balanced by other agencies, such as the effects of the turbulent vertical and lateral mixing processes. The deeper layer of the stratified ocean may be said to approximate a state of thermohaline equilibrium. Therefore, for the deduction of the permanent geostrophic currents, the *mean* steady state may be used. To have an over-all picture of the mean steady state of stratification and permanent circulation in all oceans and seas is, in any case, an indispensable presupposition for any special study of the variations. Now with the new continuous and synoptic recordings of temperature, salinity and currents, it becomes more and more possible to analyze in space and time the *true* dynamic processes of circulation, turbulent diffusion, internal waves and tidal currents in the depths, and to deduce in better approximations the interaction between ocean and atmosphere, between ocean and sediment and between water masses, plankton, nutrients, primary production and other biological-chemical phenomena of the environment.*

ACKNOWLEDGMENTS

The author wishes to thank Dr. MARY SEARS for her help in making the English text more idiomatic and to the following institutions and scientists for providing him with photos of research vessels and other information: Carnegie Institution of Washington, Institut für Meereskunde der Universität Kiel, Lamont Geological Observatory (Palisades, New York), Dr. J. LYMAN (National Science Foundation, Washington), National Data Center (Washington), National Institute of Oceanography (Wormley), Navy Electronics Laboratory (San Diego), Oceanografiska Institutet (Göteborg), Scripps Institution of Oceanography (La Jolla), Woods Hole Oceanographic Institution (Woods Hole), Zoologiske Museum (Copenhagen), and Prof. L. ZENKEVITCH (Moscow). The author was given technical help by BARRY BURCAW (Lamont Observatory) who made the final drawings of the figures and the charts, and technical help by Mr. D. J. RAYMOND (Vice President of Pergamon Press, New York).

* This summary is incomplete, and the last part is already out of date because of the thriving enterprises at sea and of the increasing results in the oceanographic laboratories of the world since the International Geophysical Year. This historical report which concerns only the major deep-sea expeditions of the period 1873–1960 is seen with the eyes of an European physical oceanographer and marine meteorologist. However, he has had the privilege of working, since 1919, in these fields at sea and in the Oceanographic Institutions in Berlin, Kiel, and (as a guest) since 1960 at Palisades, New York, and of being in contact with the other disciplines of oceanography, such as marine geology, geophysics, chemistry and biology. It was not the task of this report to include the numerous successful shorter cruises in marginal or smaller areas of the deep oceans and of the enclosed seas (like Mediterranean, etc.). Likewise the cruises undertaken mainly for applied oceanography such as fishery biology and hydrographic surveys, are not taken into consideration, in spite of the fact that they have made important contributions to our knowledge of the physical-chemical properties of the environment, of the bathymetry and of other features in the deep oceans.

In Europe and throughout the world, a number of large institutions for most branches of oceanography (including marine biology, geology and geophysics) are under development. The largest, until 1960, were the National Institute of Oceanography in Great Britain (Wormley) and numerous others in the U.S.S.R. and Japan. Smaller ones in Scandinavia (Bergen, Copenhagen, Helsinki, Göteborg), in France (Paris), in West Germany (Kiel, Hamburg) and in other countries must be mentioned because of their significant contributions to oceanography since about 1900. A complete list of such eminent institutions cannot be given here.

APPENDIX A

REPRESENTATIVE VESSELS IN OCEANOGRAPHIC DEEP-SEA RESEARCH (1873–1960)

Name of Vessel	Nationality	Commissioned	Tonnage	Ocean	Main Studies
		Ia. Era of Exploration (1873–1914)			
*Challenger**	British	1873–1876	2306	Atlantic, Indian, Pacific	Biology, Physics, Sediments
*Gazelle**	German	1874–1876	1900	Atlantic, Indian, Pacific	Physics
*Blake**	U.S.A.	1877–1886	400	Atlantic (Gulf Stream system)	Physics, Currents
Albatross	U.S.A.	1887–1888		North Atlantic	Biology, Physics
*National**	German	1889	854 (gross)	North Atlantic	Plankton
*Fram**	Norwegian	1893–1896	530	North Polar Sea	Physics
*Valdivia**	German	1898–1899	2176 (gross)	Atlantic, Indian	Biology of great depths
Princesse Alice I and *II**, *Hirondelle I* and *II**	Monaco	1888–1922	—	North Atlantic	Biology
*Gauss**	German	1901–1903	1332	Atlantic, Indian, Antarctic	Physics, Geography
*Planet**	German	1906–1907	650	Atlantic, Indian, West Pacific	Physics
*Deutschland**	German	1911–1912	598 (gross)	Atlantic, Antarctic	Physics

* Complete analysis of data published in extensive expedition reports.—(see Appendix CI)

REPRESENTATIVE VESSELS IN OCEANOGRAPHIC DEEP-SEA RESEARCH (1873–1960) (cont'd)

Name of Vessel	Nationality	Commissioned	Tonnage	Ocean	Main Studies
Ib. Transition to systematic research (1904–1924)					
*Michael Sars**	Norwegian	1904–1913	226	Norwegian Sea, North Atlantic	Physics
*Armauer Hansen**	Norwegian	Since 1913	53	Norwegian Sea, North Atlantic	Physics
II. Era of National Systematic Surveys (1925–1940)					
*Meteor**	German	1925–1927	1178	German Atlantic Exp. 65°S–20°N	Physics, Chemistry Meteorology, Geology, and Biology
Meteor	German	1929–1938	1178	Iceland–Greenland waters, some N. Atl. cruises	Physics, Chemistry, Biology
*Dana I** and *II**	Denmark	1921–1935	*Dana II* 360 (gross)	Atlantic, Indian, Pacific	Biology
*Carnegie**	U.S.A.	1928–1929	568	Pacific	Physics, Biology, Sediments
*Willebrord Snellus**	Dutch	1929–1930	1055	Indonesian Seas	Physics, Sediments
*Discovery** and *Discovery II**	British	1930 ff	(*Discovery II*) 2100	Antarctic	Physics, Biology
Atlantis	U.S.A.	1931 ff	460 (gross)	North Atlantic	Physics, Chemistry

*Complete analysis of data published in extensive expedition reports.—(see Appendix CI)

REPRESENTATIVE VESSELS IN OCEANOGRAPHIC DEEP-SEA RESEARCH (1873–1960) (cont'd)

Name of Vessel	Nationality	Commissioned	Tonnage	Ocean	Main Studies
Ryofu Maru	Japanese	1937 ff	1206	Pacific	Physics
E. W. Scripps	U.S.A.	1938 ff	140	Pacific	Physics, Chemistry, Sediments
Altair	German	1938	4000 (gross)	Gulf Stream Exped. N. Atlantic	Physics, Currents
Sedov	Russian	1938–1939	1538	North Polar Sea	Physics
IIIa. Period of New Geological, Geophysical, Biological and Oceanographical Methods (1947–1956)					
*Albatross**	Sweden	1947–1948	1450	Atlantic, Indian	Sediments, Physics
*Galathea**	Denmark	1950–1952	1600	Pacific	Biology of abyssal depths
*Atlantis**	U.S.A.	1947 ff	460	Atlantic	Physics, Geophysics
Vema	U.S.A.	1953 ff	734	Atlantic, Indian, Pacific	Geophysics, Geology
Anton Dohrn	German	1955–1956	999	North Atlantic	Biology, Physics
Spencer F. Baird	U.S.A.	1956	143 ft	Pacific (operation Chinook)	Geophysics, Physics
IIIb. Transition to synoptic research in smaller areas (1950)					
Atlantis and other vessels	U.S.A.	1950, (1956)	—	Gulf Stream	Physics, Dynamics (Operation Cabot and second survey)
IV. Era of International Research Cooperation since 1957					
Crawford	U.S.A.	1957–1959	350	Atlantic IGY Program	Physics, Chemistry

*Complete analysis of data published in extensive expedition reports.—(see Appendix CI)

REPRESENTATIVE VESSELS IN OCEANOGRAPHIC DEEP-SEA RESEARCH (1873–1960) (cont'd)

Name of Vessel	Nationality	Commissioned	Tonnage	Ocean	Main Studies
Atlantis	U.S.A.	1957–1959	460	Atlantic IGY Program	Physics, Chemistry
Discovery II	British	1957–1959	2100	Atlantic IGY Program	Physics, Chemistry
Capitan Canepa	Argentina	1957–1960	1000	Atlantic IGY Program	Physics
Gauss	W. Germany	1957–1960	800	North Atlantic Polar Front and Overflow Program	Physics
Anton Dohrn	W. Germany	1957–1960	1000	N. Atlantic Polar Front and Overflow Programs	Biology, Physics
Explorer and other vessels	Scottish	1957–1960	(*Explorer*) 200 ft	N. Atlantic Polar Front and Overflow Programs	Biology, Physics
Vitiaz	U.S.S.R.	1957–1960	5700	All Seas (IGY Program)	Physics, Chemistry, Biology, and Geology Trenches
Numerous research vessels*	Japan, U.S.A. Canada	1955–1960	—	Pacific (Norpac Program)	Physics, Biology

* In Chart 15 the names of U.S. and Japanese vessels taking part in the 1955 Norpac Program are given as an example of this international research cooperation.

REPRESENTATIVE VESSELS IN OCEANOGRAPHIC DEEP-SEA RESEARCH (1873–1960) (cont'd)

Name of Vessel	Nationality	Commissioned	Tonnage	Ocean	Main Studies
Mikhail Lomonosov	U.S.S.R.	1957–1960	6000	All Seas (IGY Program)	Physics, Chemistry, Biology
Ob	U.S.S.R.	1957–1960	12,600 (gross)	Southern Seas (IGY Program)	Physics, Chemistry, Biology
Horizon	U.S.A.	1957–1960	900	Pacific	Geophysics, Physics
Chain	U.S.A.	1958–1960	2100	Atlantic, Indian	Geophysics, Physics
Argo	U.S.A.	1959–1960	2079	Pacific, Indian	Geophysics, Physics
Shokalski	U.S.S.R.	1960	3600	All Seas	Physics, Meteorology
Woeikof	U.S.S.R.	1959	3600	All Seas	Physics, Meteorology
Pole	U.S.S.R.	1959	5000	—	Physics etc.
Lena	U.S.S.R.	1958	12,600	Polar Seas	Physics, Meteorology
Severyanka	U.S.S.R.	1958	1050	All Seas	Submarine for oceanographic research
Numerous research vessels*	International	Since 1958	—	Indian Ocean Expedition Program	Physics, Geophysics, Biology, Chemistry, Geology, Meteorology

* Countries, ships and cruises participating 1958–1962 in this Indian Ocean Program are published in a chart (H.O. No. 17138B) by the U.S. Navy Hydrographic Office (Sept. 1962). The International Indian Ocean Program actually started in 1958 with the cruise of *Vema*, and in 1959 and 1960 with cruises of *Diamantina* (Australia), *Commandant Robert Giraud* (France), *Vitiaz* (U.S.S.R.), *Argo* (U.S.A.), *Requisite* (U.S.A.), and *Umitaka-Maru* (Japan).

APPENDIX B

CHARTS OF TRACKS OF 20 MAJOR DEEP-SEA EXPEDITIONS

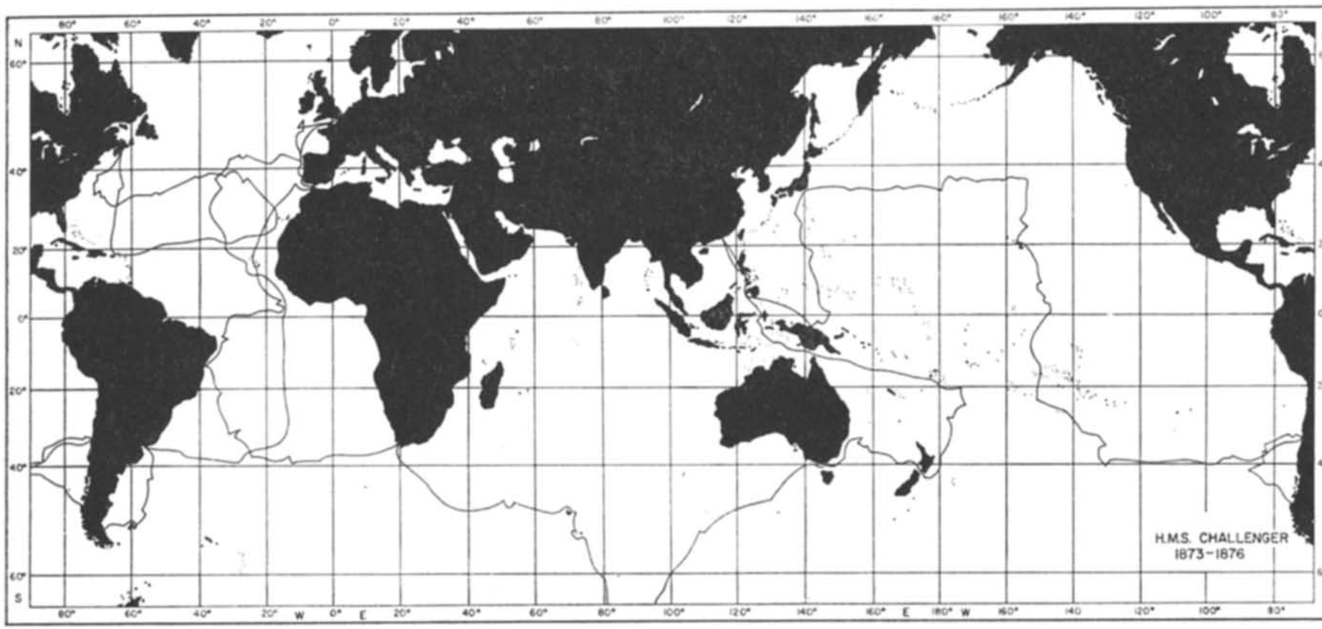


Chart 1. Track of H.M.S. *Challenger* 1873–1876

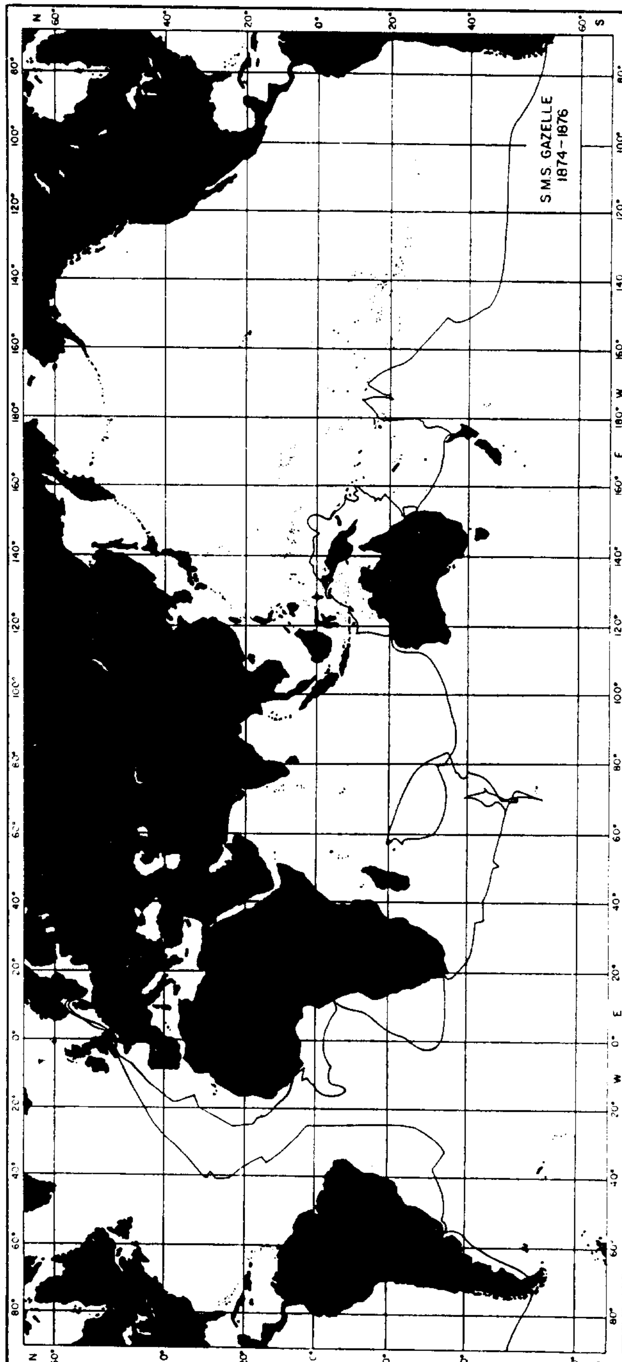


Chart 2. Track of S.M.S. *Gazelle* 1874–1876

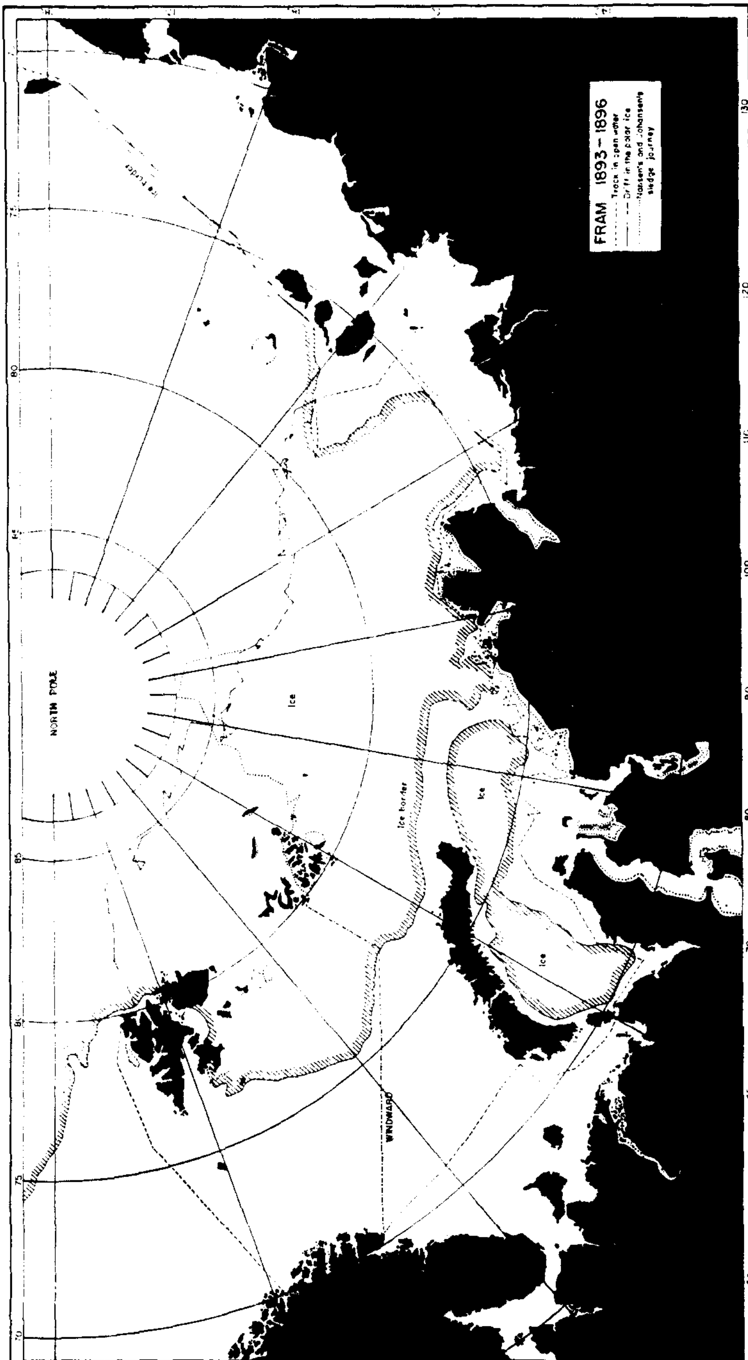


Chart 3. Track of *Fram* 1893–1896

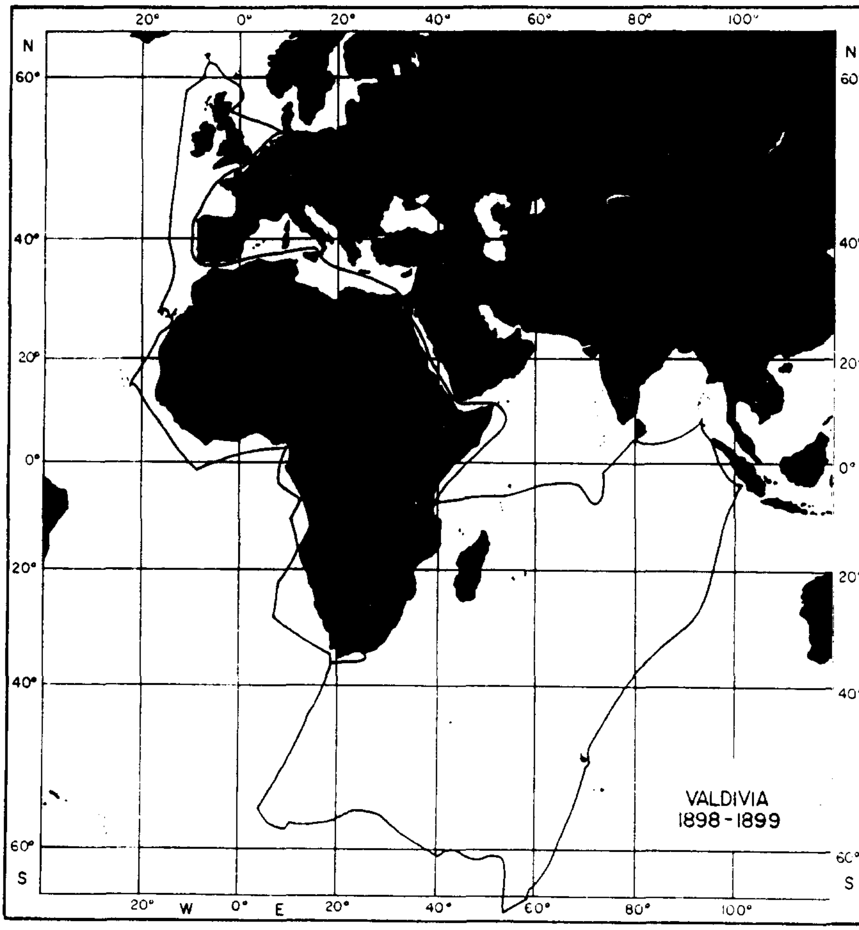


Chart 4. Track of *Valdivia* 1898–1899

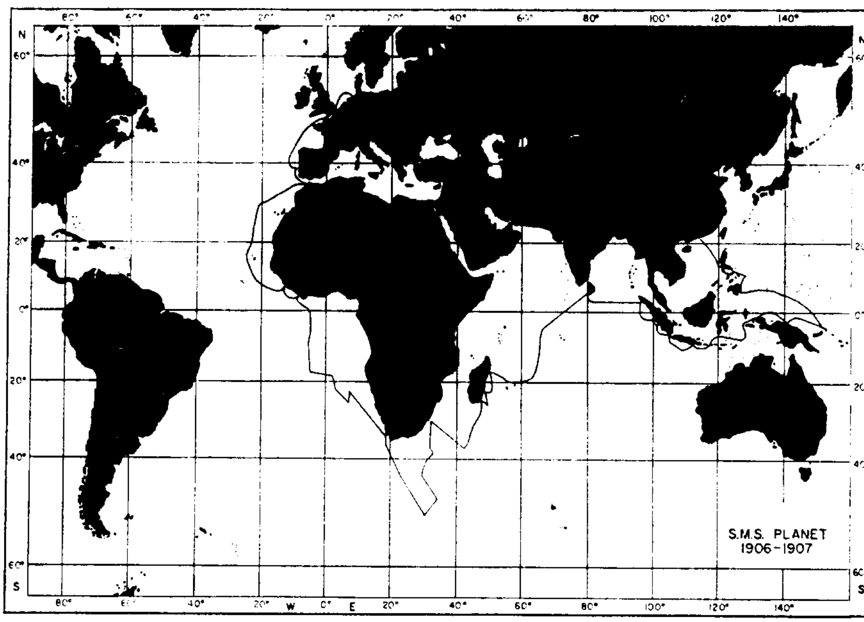


Chart 5. Track of S.M.S. *Planet* 1906–1907

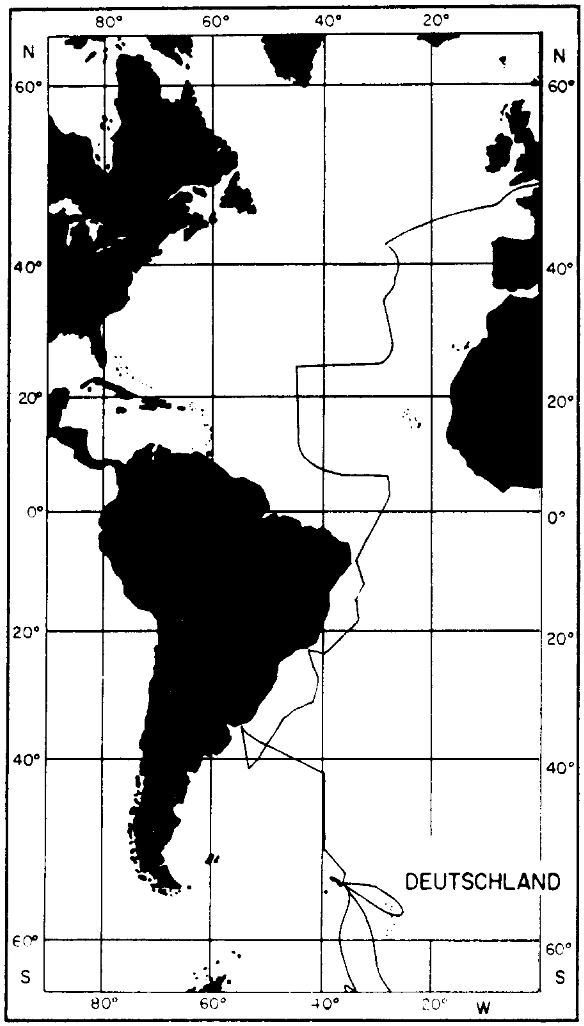


Chart 6. Track of *Deutschland* 1911–1912

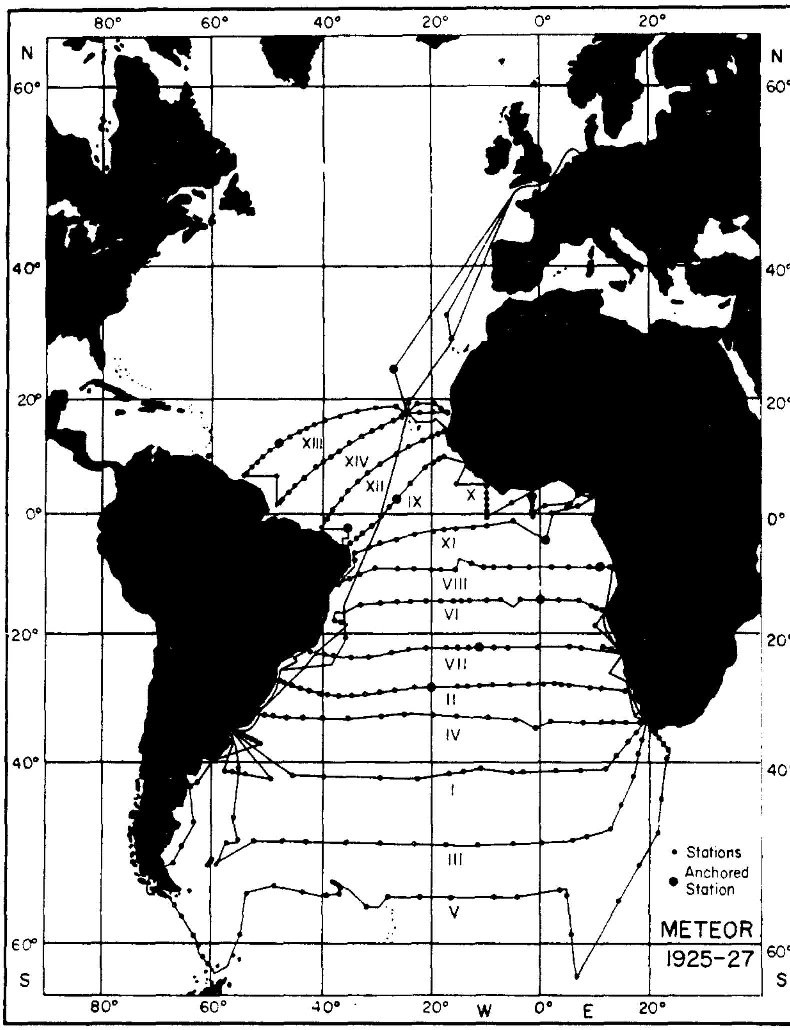


Chart 7. Cross-sections and stations of *Meteor* 1925–1927

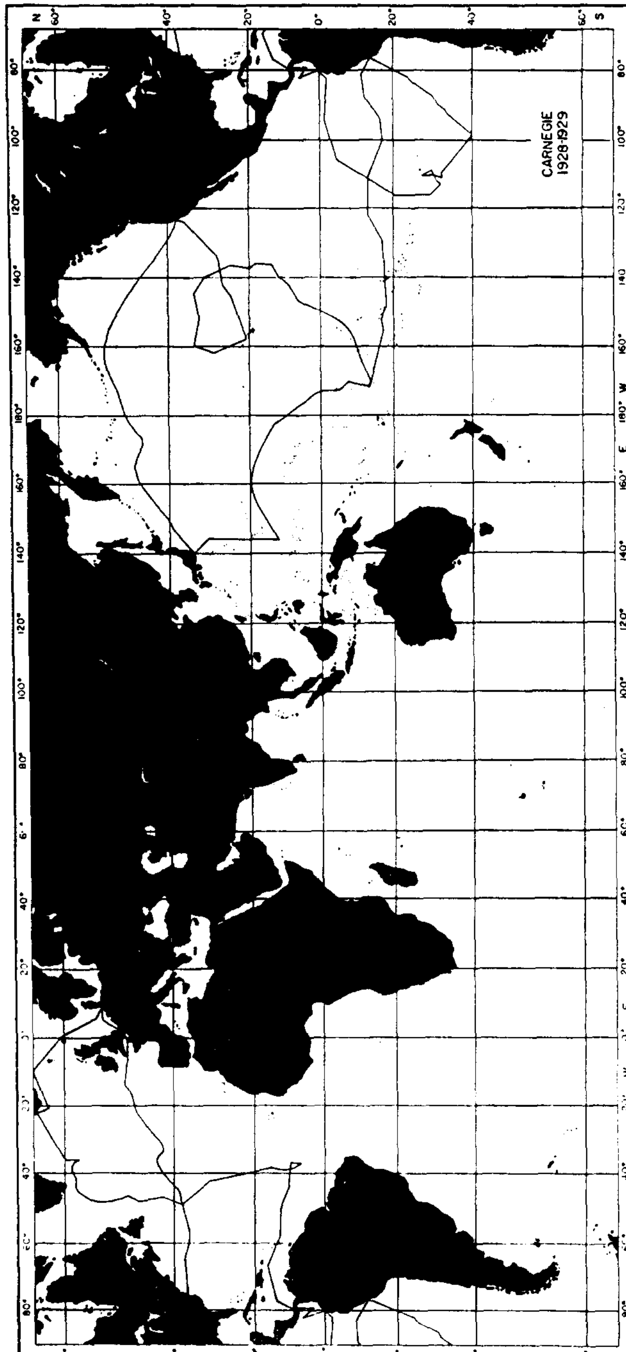


Chart 8. Track of *Carnegie* 1928–1929

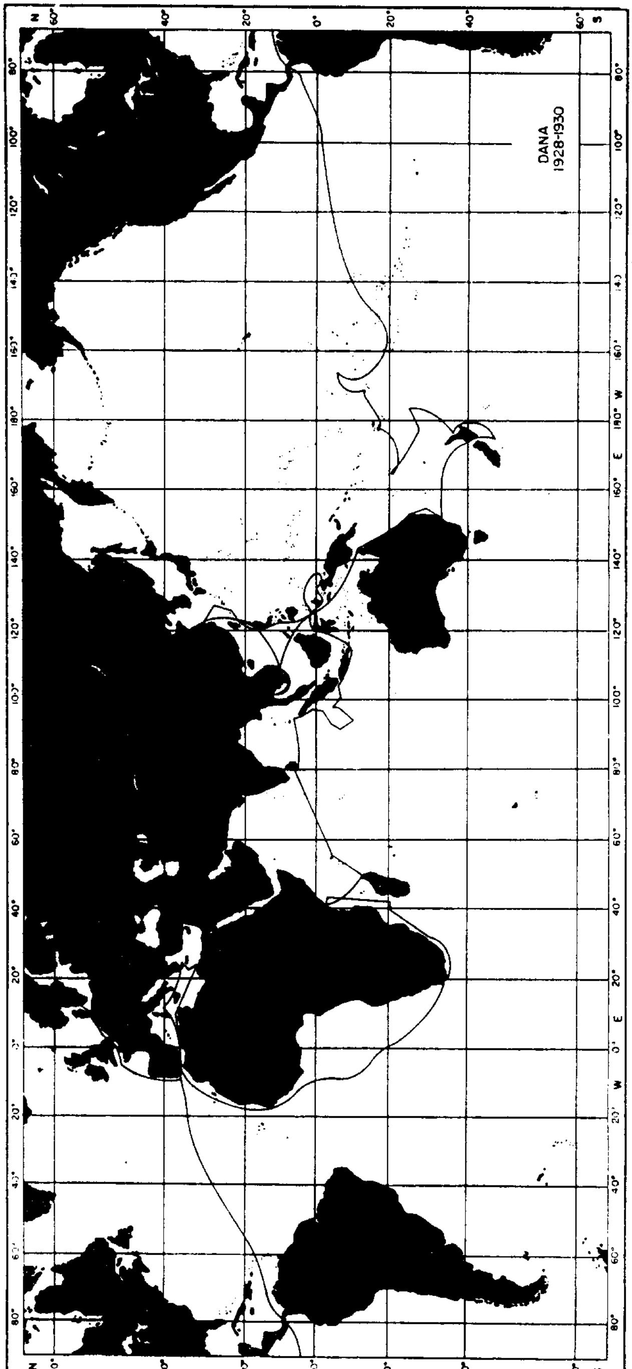


Chart 9. Track of *Dana II* 1928–1930

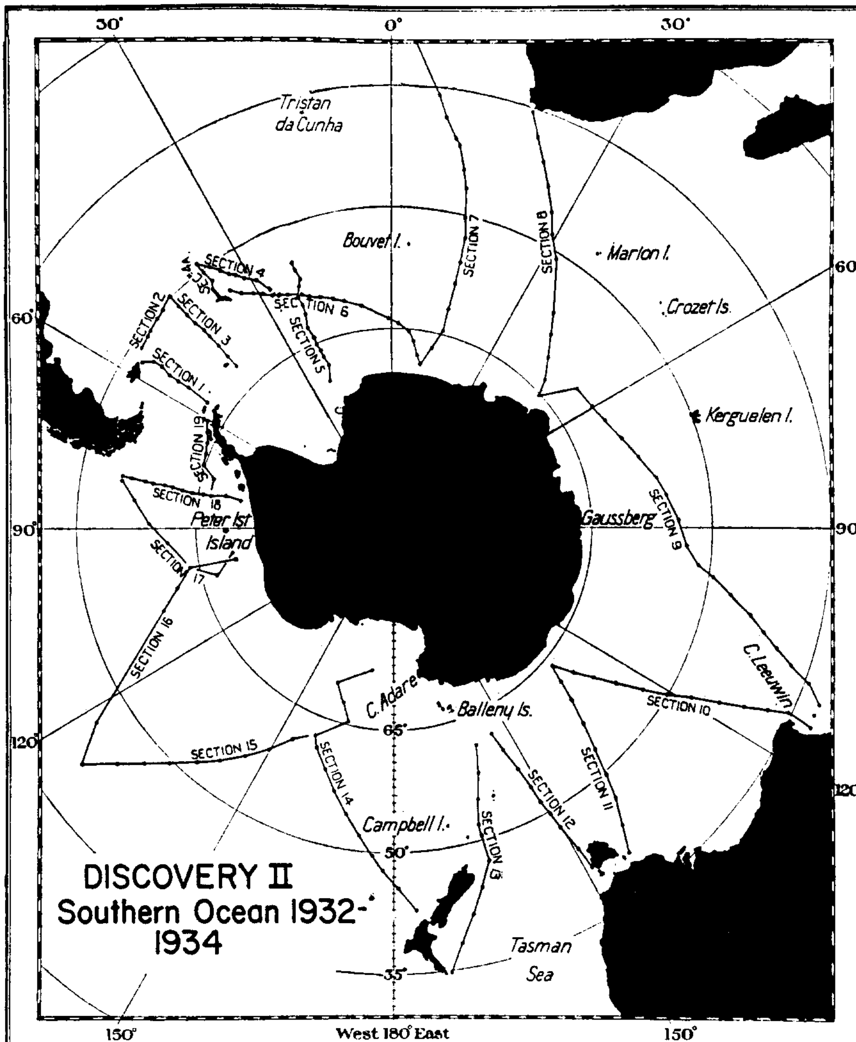


Chart 10. Sections and stations of *Discovery II* 1932–1934
(after DEACON in *Discovery Reports* Vol. 15)

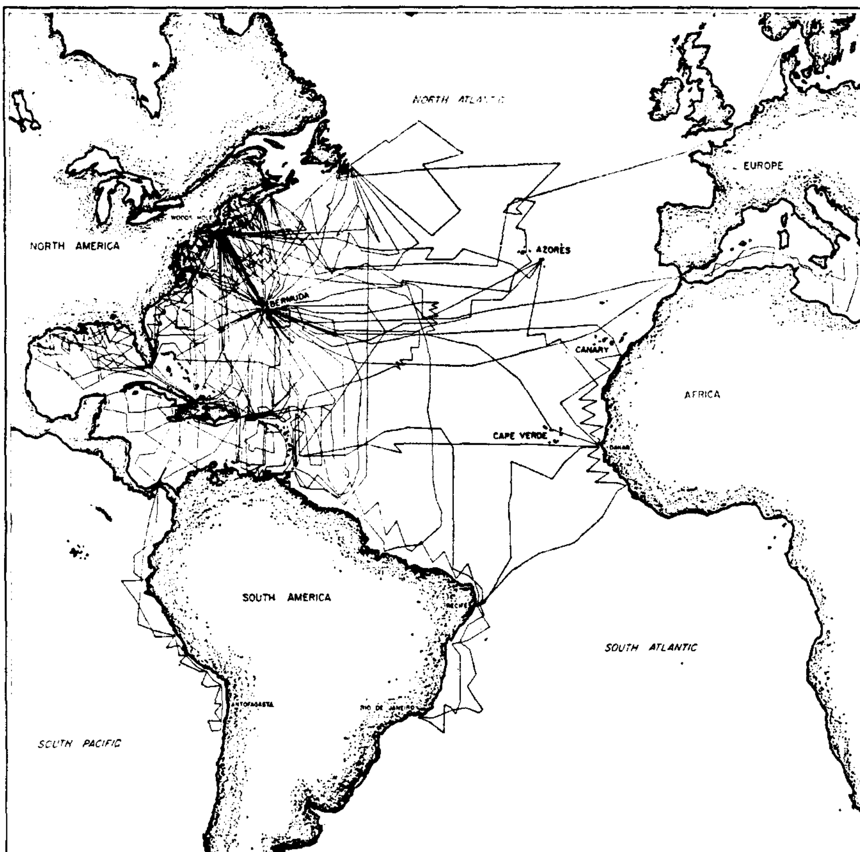


Chart 11. Principal cruises of *Atlantis* 1931–1957

Chart 12. Track of Swedish *Albatross* 1947–1948

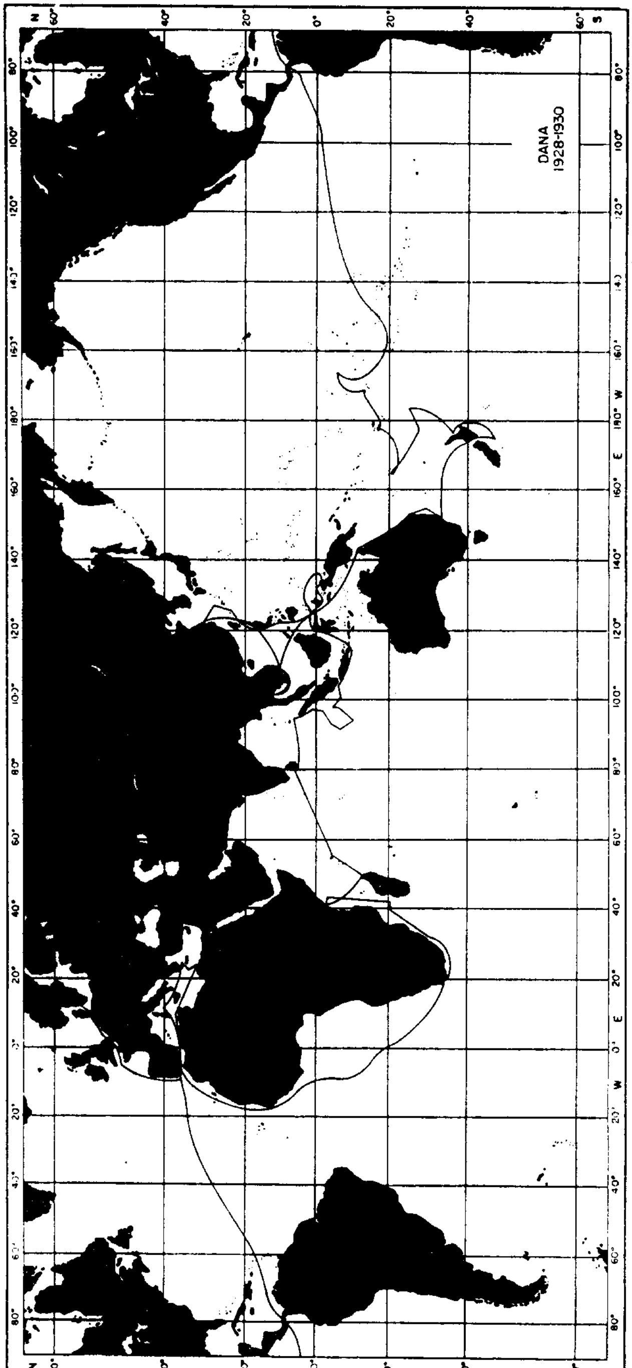


Chart 9. Track of *Dana II* 1928–1930

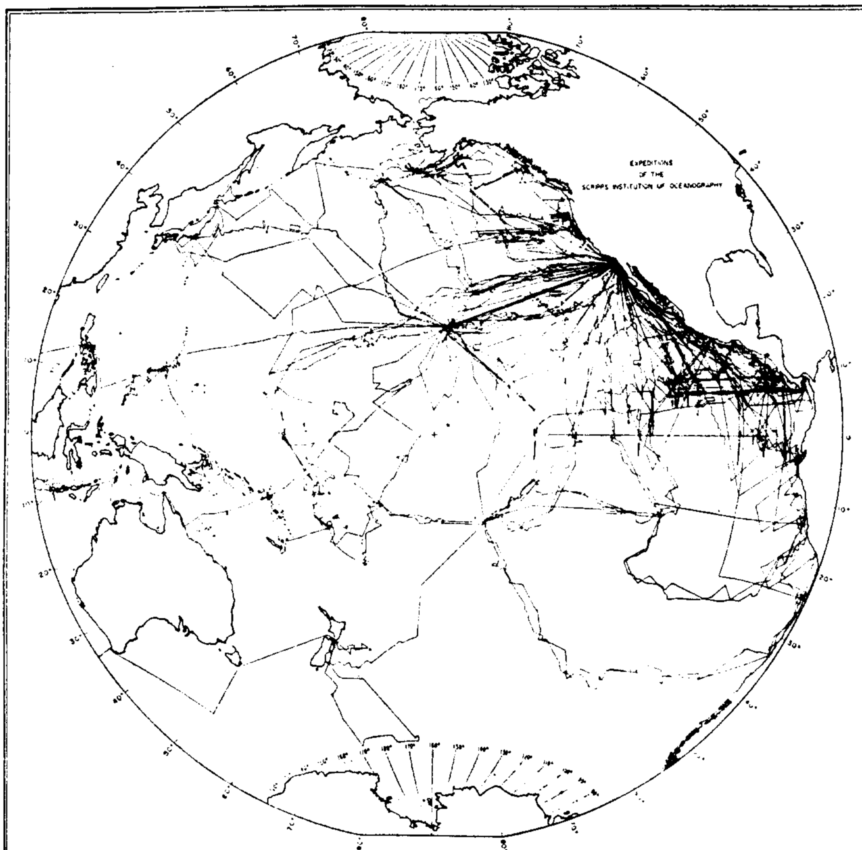
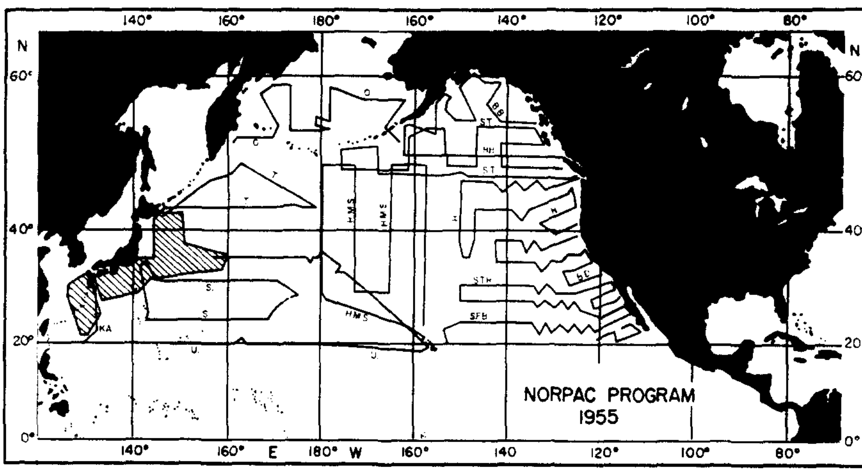


Chart 14. Cruises of research vessels of Scripps Institution and Navy Electronic Laboratory 1950–1960



United States ships: H.M.S. HUGH M. SMITH, B.B. BROWN BEAR, S.T. STE. THERESE, H. HORIZON, B.D. BLACK DOUGLAS, STR. STRANGER, S.F.B. SPENCER F. BAIRD.
Japanese ships: O. OSHORO MARU, T. TENYO MARU, KA. KAGOSHIMA MARU, S. SATSUMA, U. UMITAKA MARU.

Various other Japanese ships

Chart 15. Cruises of NORPAC–Program 1955

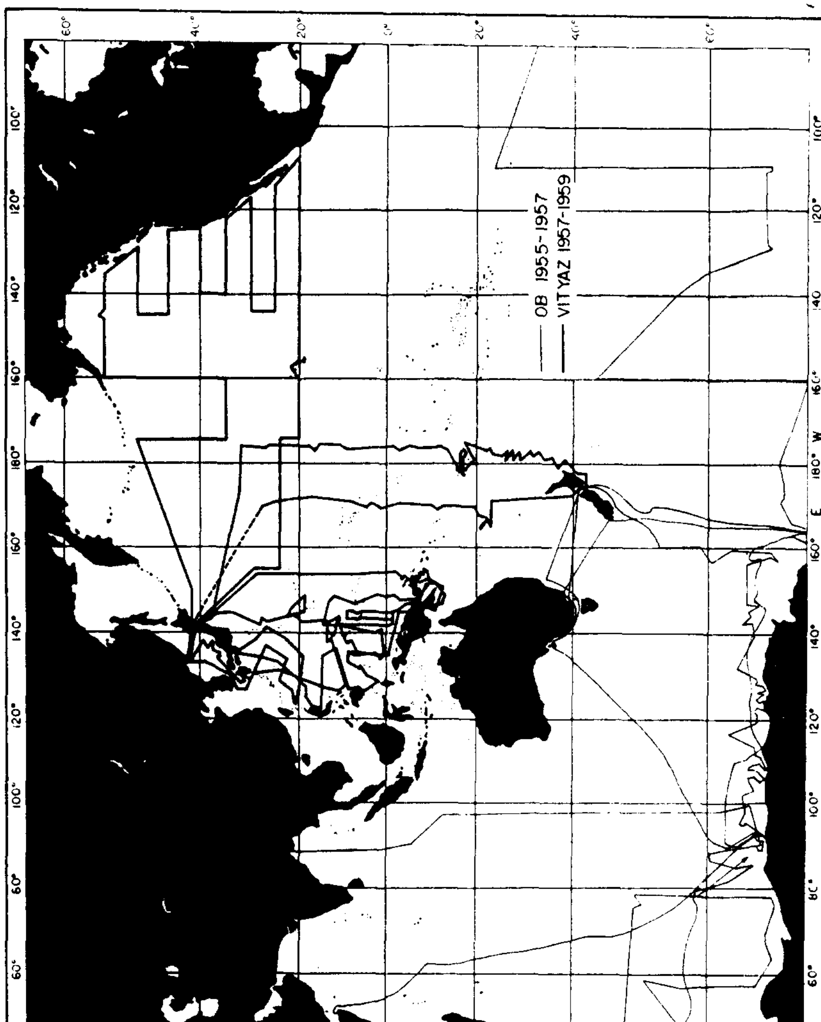


Chart 16. Tracks of *Ob* and *Vitiaz* 1955–1959

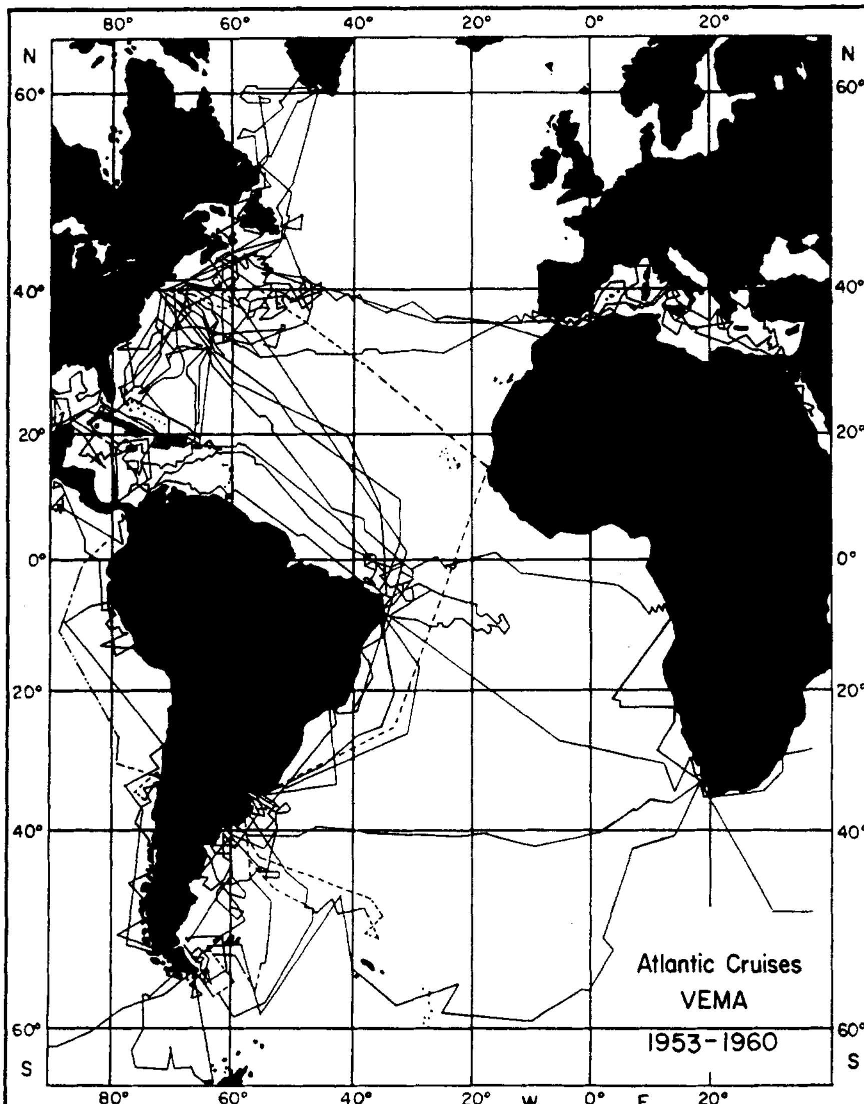


Chart 17. Atlantic cruises of *Vema* 1953–1960

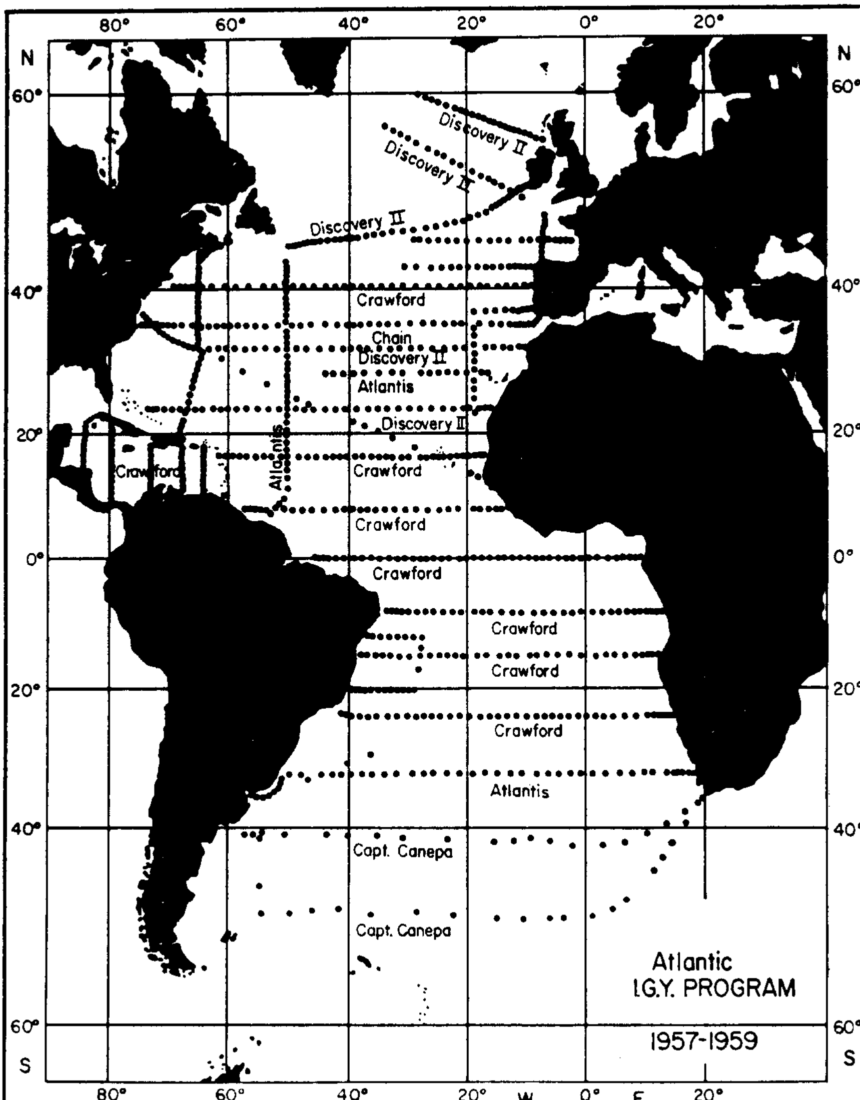


Chart 18. Sections and stations of the Atlantic IGY Program 1957-1959

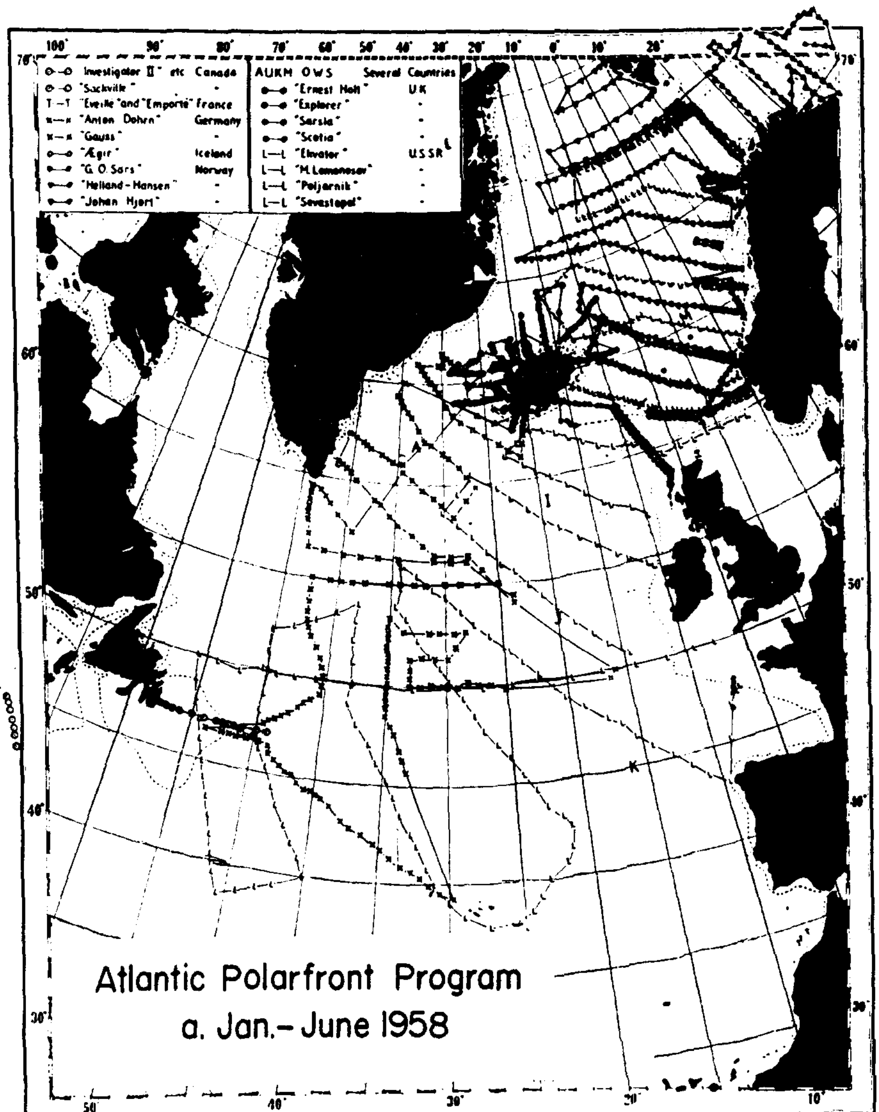


Chart 19a. Cruises of the Atlantic Polar Front Program, January–June, 1958

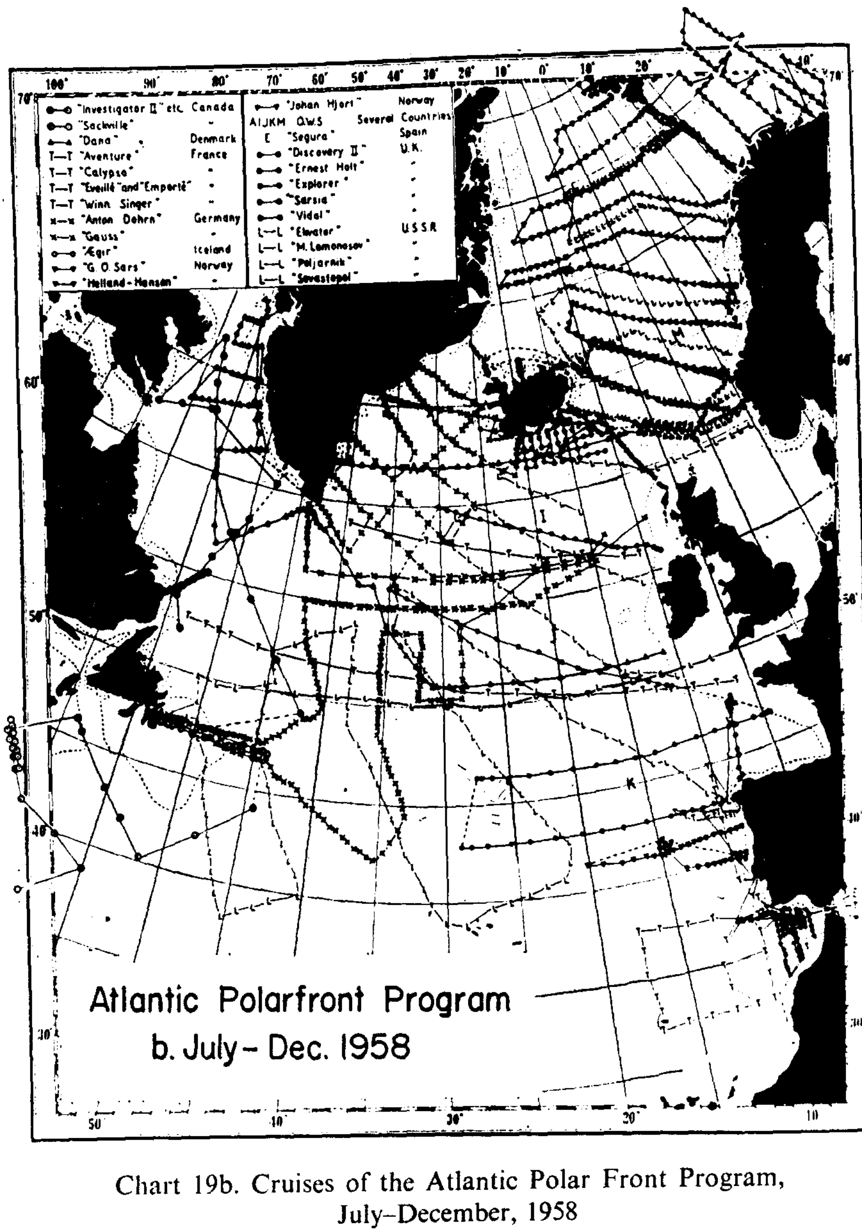


Chart 19b. Cruises of the Atlantic Polar Front Program, July–December, 1958

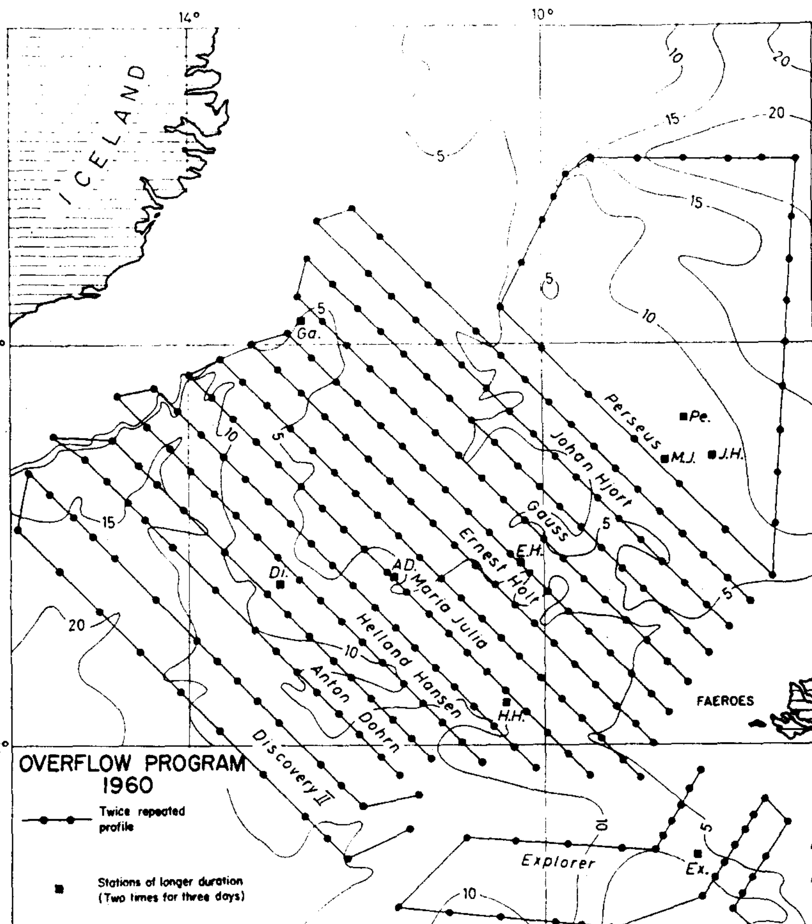


Chart 20. Sections and stations of the International Overflow Program, 1960

APPENDIX C

LITERATURE ON DEEP-SEA RESEARCH AND ITS HISTORY
(in Chronological Order)

I. The great Deep-Sea Expedition Reports.

Reports on the Scientific Results of the Voyage of H.M.S. *Challenger* during the years 1873–1876. Edited by C. WYVILLE THOMSON and JOHN MURRAY. About 50 volumes, London, 1884–1895.

Die Forschungsreise S.M.S. *Gazelle* in den Jahren 1874 bis 1876—herausgegeben vom Hydrographischen Amt des Reichs-Marine-Amts 5 Bände, Berlin, 1888–1890.

Ergebnisse der in dem Atlantischen Ozean vom Mitte Juli bis Anfang November 1889 ausgeführten Plankton-Expedition 1889 der Humboldt-Stiftung auf Grund von gemeinschaftlichen Untersuchungen einer Reihe von Fach-Forschern, herausgegeben von Victor Hensen. 5 Bände (in etwa 30 Teilbänden), Kiel und Leipzig, 1892–1912.

The North Polar Expedition 1893–1896. Scientific Results (on board *Fram*). Edited by F. NANSEN. Numerous volumes, Christiana, 1900 ff.

Wissenschaftliche Ergebnisse der Deutschen Tiefsee-Expedition auf dem Dampfer *Valdivia* 1898–1899, im Auftrage des Reichsamtes des Innern herausgegeben von Carl Chun, 25 Bände, Jena 1902, ff.

Résultats des Campagnes Scientifiques accompliés sur son Yacht par Albert Ier, Prince Souverain de Monaco, 110 fascicules, 1889–1950. (Fasc. 89 published in 1934, contains a list of all stations).

Ergebnisse der Deutschen Südpolar Expedition 1901–1903, im Auftrage des Reichsamtes des Innern herausgegeben von E. von Drygalski, 20 Bände, Berlin, bis 1952.

Forschungreise S.M.S. *Planet* 1906–1907. 5 Bände, Berlin 1909.

Report on the Scientific Results of the *Michael Sars* North Atlantic Deep-Sea Expedition 1910, carried out under the auspices of the Norwegian Government and the superintendence of SIR JOHN MURRAY, K.C.B. and Dr. JOHAN HJORT. Vol. I–V. Univ. Bergen 1930–1956.

Wissenschaftliche Ergebnisse der Deutschen Atlantischen Expedition auf dem Forschung- und Vermessungschiff *Meteor* 1925–1927, herausgegeben von ALBERT DEFANT, 16 Bände in 30 Teilbänden, Berlin, 1932–1960.

The Danish *Dana* Expeditions 1920–22, in the North Atlantic and the Gulf of Panama, Oceanographical Reports edited by the *Dana* Committee, Copenhagen, London, 1929.

The Carlsberg Foundation's Oceanographical Expedition round the World, 1928–30 and previous *Dana*-Expeditions, under the leadership of the late Prof. JOHANNES SCHMIDT, Nos. 1–58, Copenhagen, 1932–1962.

Scientific Results of Cruise VII of the *Carnegie* during 1928–1929 under the command of Captain J. P. AULT. Carnegie Institution of Washington Publications, 12 Vol., Washington 1942–1945.

Scientific Results of the *Snellius*-Expedition in the Eastern Part of the Netherlands East-Indies 1929–1930 under the leadership of P. M. VAN RIEL—Vol. I–VI, Leiden 1936–1957.

Discovery Reports, issued by the Discovery Committee (later, the National Institute of Oceanography, Great Britain), numerous partial volumes in Vol. I–XXXIII, London, 1929–1963.

Reports of the Swedish Deep-Sea Expedition 1947–1948, edited by HANS PETTERSSON, Vol. I–X. Göteborg, 1957–1959.

Galathea Reports, Scientific Results of the Danish Deep-Sea Expedition Round the World 1950–1952, Vols. 1–6, edited by A. FR. BRUNN, SV. GREVE and R. SPÄRCK, Copenhagen 1957–1962.

II. *Monographs and Shorter Contributions on Expedition Results. Publications of Data.*

AGASSIZ, A. (1888) Three cruises of United States Coast and Geodetic Survey Steamer *Blake* in the Gulf of Mexico, in the Caribbean Sea, and along the Atlantic coast of the United States from 1877 to 1880. 2 Vols. *Bull. Mus. Comp. Zool., Harvard Coll.* **15**, 220 pp; **14**, 314 pp. (Also: Houghton, Mifflin and Company, the Riverside Press).

PILLSBURY, J. E. (1891) The Gulf Stream—a description of the methods employed in the investigation and the results of the research. Appendix 10 in: *Report of the Superintendent, U.S. Coast and Geodetic Survey for the year ending June* 1890, 459–620.

MAKAROV, S. O. (1894) *Vitiaz and the Pacific Ocean.* (In Russian) St. Petersburg, 2 Vols.

HELLAND-HANSEN, B. and NANSEN, F. (1909) The Norwegian Sea: Its physical oceanography based upon the Norwegian research 1900–1904. *Rept. on Norwegian Fishery and Marine Investigations, Bergen*, **2** (2), 390 pp., 25 pls.

MURRAY, J., and HJORT, J. (1912) The Depths of the Ocean: A general account of the modern science of oceanography based largely on the scientific research of the Norwegian Steamer *Michael Sars* in the North Atlantic. MacMillan, London, 821 pp. (Chapter 1 contains an historic review of oceanographic investigations.)

BRENNECKE, W. (1921) Die ozeanographischen Arbeiten der Deutschen Antarktischen Expedition 1911–1912. (Forschungsschiff-*Deutschland*). *Archiv. Deutsch. Seewarte*, 39, (1), 1–216, Tafel 1–15.

HELLAND-HANSEN, B., and NANSEN, F. (1926) The Eastern North Atlantic. The cruises of the *Armauer Hansen*, No. 1. *Geofys. Publ., Oslo*, **4** (2), 1–76, 71 pls.

ISELIN, C. O'D. (1936) A study of the circulation of the western North Atlantic. *Papers in Phys. Oceanogr. and Meteorol.*, **4** (4), 1–101.

DEACON, G. E. R. (1937) The hydrology of the Southern Ocean. *Discovery Reports*, **15**, 1–123, 44 pls.

DEFANT, A., NEUMANN, G., SCHRÖDER, B., and WÜST, G. (1940–1941) Aus den wissenschaftlichen Ergebnissen der Internationalen Golfstrom-Unternehmung 1938. In: 5 Beiheften der *Annalen der Hydrographie und Maritimen Meteorologie*, Hamburg. (Contains mainly the results of the German research vessel *Altair*.)

FUGLISTER, F. C., Edit. (1960) Atlantic Ocean Atlas of Temperature and Salinity Profiles and Data from the International Geophysical Year of 1957–1958. *Atlas Ser., Woods Hole Oceanographic Institution*, Vol. 1, 209 pp.

BÖHNECKE, G., and BÜCKMANN, A., Editors (1959–1962) Die Expeditionen von F.F.S. *Anton Dohrn* und V.F.S. *Gauss* im Internationalen Geophysikalischen Jahr, 1957/1958. *Deutsche Hydrogr. Zeitschr., Ergänzungsheft*, Reihe B (4°), Nos. 3–6.

Results of some of the Russian investigations in the Indian and Pacific Oceans, 1956–1959 were translated into English by Scripta Technica, Inc., for the American Geophysical Union:

Trudy, Morsk, Gidrofiz. Inst., Akad. Nauk. SSSR, 22.

Doklady, Akad. Nauk, SSSR, Oceanology, Vols. 136–141.

III. *General sources reporting results of oceanographic research.*

A. Other shorter contributions on results of deep-sea research are published in numerous journals and periodicals: *Deep-Sea Research, Journal of Marine Research, Journal of Geophysical Research* (formerly the *Transactions of the Geophysical Union*), *Deutsche Hydrographische Zeitschrift* (formerly *Annalen der Hydrographie und Maritimen Meteorologie*), *Ergänzungshefte zur Deutschen Hydrographishen Zeitschrift, Berichte und Ergänzungshefte der Deutschen Wissenshaftlichen Kommission für Meeresforschung, Rapports et*

Procès-Verbaux, Cons. Perm. Int. Expl. Mer, Journal du Conseil, Cons. Perm. Int. Expl. Mer, and in many other American, Canadian, British, Australian, German, French, Japanese and Russian periodicals.

B. Certain oceanographic institutions distribute their own contributions (originally published in the regular scientific periodicals). Among the most important for the period under discussion are:

Collected Reprints, National Institute of Oceanography, Vol. 1-9, Wormley, 1953-1961.
Contributions, Scripps Institution of Oceanography, University of California, 1954-1961.
Collected Reprints, Woods Hole Oceanographic Institution, 1933-1960 (distributed 1934-1961).
Collected Reprints of Lamont Geological Observatory, 1949-1960 (restricted distribution).

C. Data other than those printed in various expedition series, are printed extensively in the following publications (among others) or by the following agencies:

Bulletin Hydrographique, 1934-1955 *Conseil Permanent International pour l'Exploration de la Mer* (for the North Atlantic Ocean).
University of California, Scripps Institution of Oceanography. Oceanic Observations of the Pacific Pre-1949-1955, Berkeley, 1957-1961 (for the Pacific Ocean.)
U.S. Fish and Wildlife Service, Special Scientific Reports, Fisheries.
Australia, Commonwealth Scientific and Industrial Organization, Division of Fisheries and Oceanography, Oceanographic Station Lists, since 1952.
Cahiers Océanographiques, Comité Central d'Océanographie et d'Étude des Côtes (formerly *Bulletin d'Information*).
Canada, Fisheries Research Board of Canada, Manuscript Report Series (Oceanography and Limnology).
France, Institut Francais d'Océanie, Noumea, New Caledonia, Rapports Scientifiques.
Japan, Central Meteorological Observatory, Results of Marine Meteorological and Oceanographic Observations (later Japan Meteorological Agency).
Japan, Hokkaido University, Faculty of Fisheries, Data Record of Oceanographic Observations and Exploratory Fishing.
Japan Hydrographic Office, *Maritime Safety Board, Publ.* 981, *Hydrographic Bulletin.*
Japan, Tokyo University of Fisheries.
Boletin del Instituto Español de Oceanografia.
The U.S. National Oceanographic Data Center has issued in its Catalogue Series a provisional "Reference Sources for Oceanographic Station Data", Publication C-1 ($2.00) which lists sources of oceanographic data generally.

IV. *Selected Contributions to the History and Status of Deep-Sea Research (published since* 1923).

HERDMAN, W. A. (1923) *Founders of oceanography and their work.* Edward Arnold, London, 340 pp.
BIGELOW, HENRY B. (1931) *Oceanography: its scope, problems and economic importance.* Houghton, Mifflin, Boston and New York, 263 pp.
STAHLBERG, W. (1934) Ch. 1. Deutschlands Anteil an der Erforschung der Tiefsee, 1-26 In: *Das Meer in volkstümlichen Darstellungen,* Dritter Band, *Tiefseebuch,* G. Wüst, Schriftleitung, E. S. Mittler, Berlin, 144 pp.
SCHOTT, G. (1935) *Geographie des Indischen und Stillen Ozeans.* Kapitel II: Die Erforschung der Indischen und Pazifischen Gewässer, 16-31 (mit Literaturverzeichnis und Karten der Reisewege). C. Boysen, Hamburg, 413 pp.
VAUGHAN, T. W., and others (1937) International aspects of oceanography. Oceanographic Data and Provisions for Oceanographic Research. National Academy of Sciences, Washington, 225 pp.
SCHOTT, G. (1942) *Geographie des Atlantischen Ozeans.* Kapitel II: Enforschungsgeschichte des Atlantischen Ozeans, 22-41 (mit Literaturverzeichnis und Karten der Reisewege). C. Boysen, Hamburg, 438 pp.

SVERDRUP, H. U., JOHNSON, M. W., and FLEMING, R. H. (1942) *The Oceans: their physics, chemistry and general biology.* Prentice-Hall, Englewood Cliffs, New Jersey, 1087 pp.

COKER, R.E. (1947) *This great and wide sea. An introduction to oceanography and marine biology.* Chapter 3: Pioneers in Oceanography. Chapter 4: Oceanography in America. (Both seen through the eyes of a marine biologist.) Univ. North Carolina Press, 325 pp.

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DIETRICH, G. (1957) *Algemeine Meereskunde: Eine Einfuhrung in die Ozeanographie*, Kapitel III, Ozeanographische Instrumente und Messmethoden, 80–124, Gebrüder Borntraeger, Berlin-Nikolassee, 492 pp. (English edition 1963).

ROMANOVSKY, V., FRANCIS-BOEUF, C., and BOURCART, JACQUES (1953) *La Mer.* Chapter II: Histoire de l'Océanographie. Librairie Larousse, Paris 503 pp., 870 fine text figs., 16 color pls.

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National Academy of Sciences–National Research Council, Committee on Oceanography (1962). Oceanography 1960 to 1970, Section 11. History of Oceanography. (A brief account of the development of oceanography in the United States.)

BÖHNECKE, G. and MEYL, A., Edits. (1962) Denkschrift zur Lage der Meeresforschung. Im: Auftrage der Deutschen Forschungsgemeinschaft und in Zusammenarbeit mit zahlreichen Fachgelehrten. Wiesbaden.

VON ARX, WILLIAM S. (1962) *An Introduction to Physical Oceanography.* Ch. 1. Early explorations and ideas, 3–18; Appendix A. Some events that have influenced thought in the marine sciences since 600 B.C., 351–396. Addison-Wesley, Reading, Massachusetts, U.S.A., 422 pp.

DEACON, G. E. R. (1962) The development and present status of oceanography as a scientific discipline. *ICSU Review*, **4**(2), 82–91.

DEACON, G. E. R., Edit. (1962) *Sea, Maps and Men. An Atlas-History of man's explorations of the oceans.* Doubleday, Garden City, New York, 297 pp. (A popular scientific book, extremely well illustrated and with the various chapters written by scientific experts.)

DEACON, G. E. R., Edit., DIETRICH, G., German editor (1963) *Die Meere der Welt: Ihre Eroberung und Ihre Geheimnisse.* (This is the German edition of the previous reference.)

WÜST, G. (1963) Repräsentative Tiefsee Expeditionen und Forschungschiffe 1873–1960, Aus Denkschrift der Deutschen Forschungsgemeinschaft. Naturwissenschaftl. Rundschau, Stuttgart.

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