DEPARTMENT OF TERRESTRIAL MAGNETISM
J. A. Fleming, Director

Scientific Results of Cruise VII of the CARNEGIE during 1928-1929 under Command of Captain J. P. Ault

OCEANOGRAPHY–IV

THE WORK OF THE CARNEGIE AND SUGGESTIONS FOR FUTURE SCIENTIFIC CRUISES

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PREFACE

The present volume is the thirteenth and last of the series "Scientific results of cruise VII of the Carnegie during 1928-1929 under command of Captain J. P. Ault." The material has been compiled into its present form by O. W. Torreson of the Department of Terrestrial Magnetism. The preparation of this volume, and of ten of the preceding twelve, has been greatly facilitated by the work of Mrs. J. W. Crow, and we take this opportunity to express our appreciation. She has been responsible for transcribing all copy into a form suitable for offset printing, has prepared the layout of each volume, assembled and prepared bibliographical material, and in many other important ways has contributed to the completion of the memoirs of the Carnegie's last cruise.

The purposes of this volume are to present, as a basis for future scientific investigations done aboard ship: (1) Various discussions, differing in point of view, of the equipment and operating program of the Carnegie, and (2) summaries of the results achieved, mentioning not only successful activities, but also the many difficulties encountered and the need for additional work.

Of the 110,000 nautical miles planned for the seventh cruise of the nonmagnetic ship Carnegie of the Carnegie Institution of Washington, nearly one-half had been completed on her arrival at Apia, November 28, 1929. The extensive program of observation in terrestrial magnetism, terrestrial electricity, chemical oceanography, physical oceanography, marine biology, and marine meteorology was being carried out in virtually every detail. Practical techniques and instrumental appliances for oceanographic work on a sailing vessel had been most successfully developed by Captain J. P. Ault, master and chief of the scientific personnel, and his colleagues. The high standards established under the energetic and resourceful leadership of Dr. Louis A. Bauer and his co-workers were maintained, and the achievements which had marked the previous work of the Carnegie extended.

But this cruise was tragically the last of the seven great adventures represented by the world cruises of the vessel. Early in the afternoon of November 29, 1929, while she was in the harbor at Apia completing the storage of 2000 gallons of gasoline, there was an explosion as a result of which Captain Ault and cabin boy Anthony Kolar lost their lives, five officers and seamen were injured, and the vessel with all her equipment was destroyed.

In 376 days at sea nearly 45,000 nautical miles had been covered (see map, p. iv). In addition to the extensive magnetic and atmospheric-electric observations, a great number of data and marine collections had been obtained in the fields of chemistry, physics, and biology, including bottom samples and depth determinations.

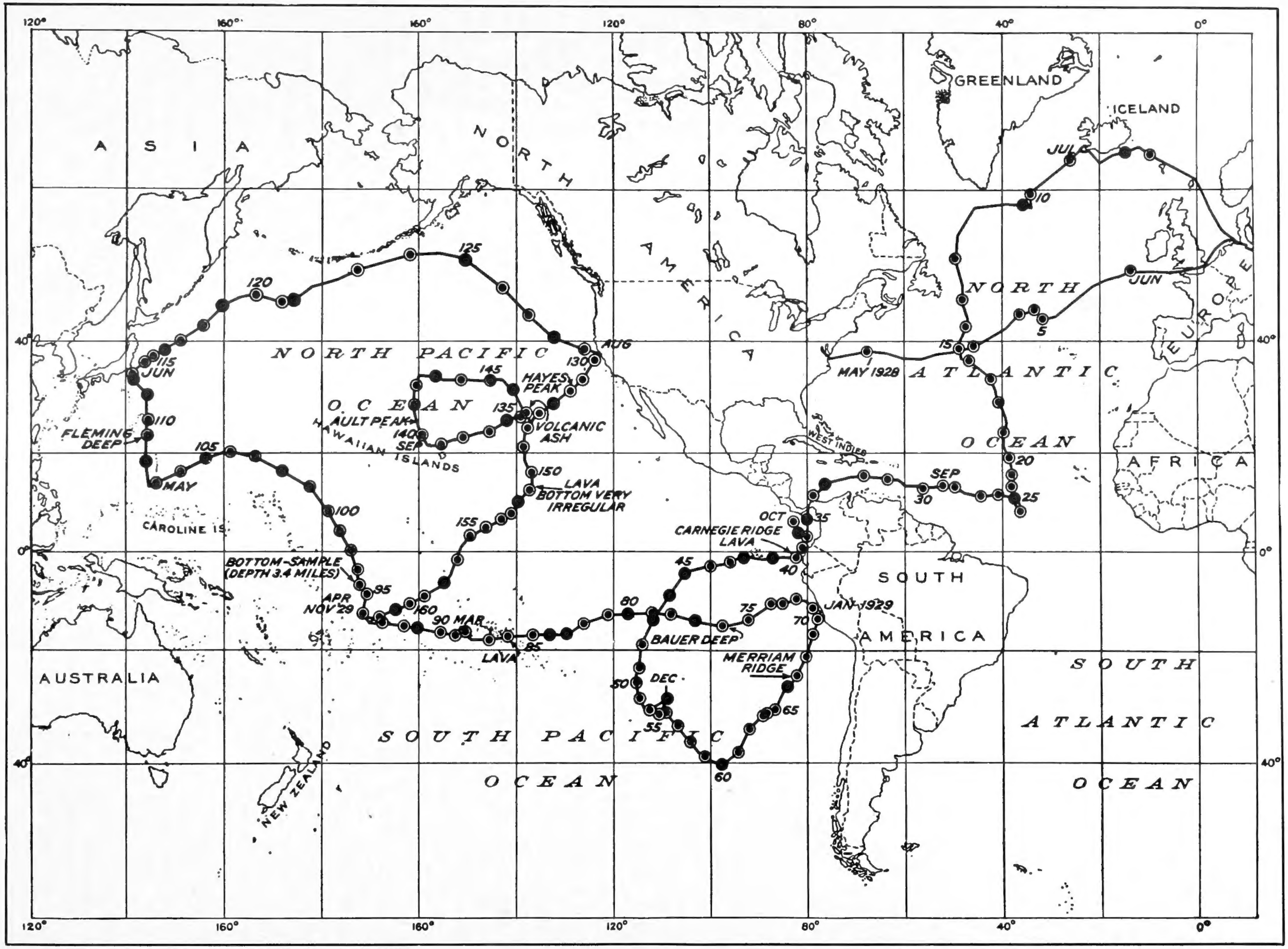
The compilations of, and reports on, the scientific results obtained during this last cruise of the Carnegie have been published under the classifications Physical Oceanography, Chemical Oceanography Meteorology, and Biology, in a series numbered, under each subject, I, II, and III, etc.

The preparations for, and the realization of, the program would have been impossible without the generous cooperation, expert advice, and contributions of special equipment and books received on all sides from interested organizations and investigators both in America and in Europe. Among these, the Carnegie Institution of Washington is indebted to the following: the United States Navy Department, including particularly its Hydrographic Office and Naval Research Laboratory; the Signal Corps and the Air Corps of the War Department; the National Museum, the Bureau of Fisheries, the Weather Bureau, the Coast Guard, and the Coast and Geodetic Survey; the Scripps Institution of Oceanography of the University of California; the Museum of Comparative Zoōlogy of Harvard University; the School of Geography of Clark University; the American Radio Relay League; the Geophysical Institute, Bergen, Norway; the Marine Biological Association of the United Kingdom, Plymouth, England; the German Atlantic Expedition of the Meteor, Institut für Meereskunde, Berlin, Germany; the British Admiralty, London, England; the Deutsche Seewarte, Hamburg, Germany; the Carlsberg Laboratorium, Bureau International pour l'Exploration de la Mer, and Laboratoire Hydrographique, Copenhagen, Denmark; the Netherlands Geodetic Commission; the Geodetic Service of Denmark; the Manila Observatory, Nederlandsche Seintoestellen, Fabriek, Hilversum, Holland, and many others. Dr. H. U. Sverdrup, now Director of the Scripps Institution of Oceanography of the University of California, at La Jolla, California, who was then a Research Associate of the Carnegie Institution of Washington at the Geophysical Institute at Bergen, Norway, was consulting oceanographer and physicist.

In summarizing an enterprise such as the magnetic, electric, and oceanographic surveys of the Carnegie and of her predecessor the Galilee, which covered a quarter of a century, and which required cooperative effort and unselfish interest on the part of many skilled scientists, it is impossible to allocate full and appropriate credit. Captain W. J. Peters laid the broad foundation of the work during the early cruises of both vessels, and Captain J. P. Ault, who had had the good fortune to serve under him, continued and developed that which Captain Peters had so well begun. The original plan of the work was envisioned by L. A. Bauer, the first Director of the Department of Terrestrial Magnetism, Carnegie Institution of Washington; the development of suitable methods and apparatus was the result of painstaking efforts of his co-workers at Washington. Truly, as was stated by Captain Ault in an address during the commemorative exercises held on board the Carnegie in San Francisco, August 26, 1929, "The story of individual endeavor and enterprise, of invention and accomplishment, cannot be told."

Captain Ault forwarded a report to the Department at the close of each leg of cruise VII. These reports, prepared by him, start with the initial preparation of the vessel, and are presented here as a complete running account of the cruise, until entrance into the harbor at Pago Pago, Samoa.

A general account of the expedition has been prepared and published by J. Harland Paul, ship's surgeon and observer, under the title The last cruise of the Carnegie, and contains a brief chapter on the previous cruises of the Carnegie, a description of the vessel and her equipment, and a full narrative of the cruise (Baltimore, Williams and Wilkins Company, 1932; xiii + 331 pages, with 198 illustrations). Excerpts from this book are presented in the present volume; the descriptions of the instruments are included because of their presentation from the point of view of the informed layman, and a part of the narrative is given as one of the more interesting



OCEANOGRAPHIC STATIONS, CRUISE VII OF THE CARNEGIE, 1928-29
(At the 35 stations marked ● true sea-water samples were also obtained for salinity calibrations)

descriptions of life and work on board the Carnegie that has been prepared since the cruise ended.

The magnetic program of the Carnegie is summarized in the section "The magnetic work of the Carnegie and the urgency of new ocean magnetic surveys." The need for a magnetic-survey program to be begun as soon as possible is emphasized--even though only a limited program could be carried out initially. The magnetic data of cruise VII are to be included in detail in a coming volume of the series "Researches of the Department of Terrestrial Magnetism" which will cover also observations made at stations on land since 1926.

Dr. E. G. Moberg, of the Scripps Institution of Oceanography, discusses the details of the personnel, equipment, and work of the Carnegie as a guide for planning other scientific cruises of similar character and scope.

A gravity apparatus after the design of Dr. F. A. Vening Meinesz was installed on the Carnegie at San Francisco and for the first time gravity determinations were made aboard a sailing vessel at sea. S. E. Forbush, of the Department's staff, gives an account of the behavior of the apparatus on the Carnegie. Although he was able to get only a few successful results, he found and eliminated some of the difficulties in such investigation.

E. S. Shepherd determined the fluorine content on twenty-one ocean-bottom samples collected by the Carnegie and his results are presented in a short paper. There remains much to be learned about fluorine concentration on the ocean floor.

Following the destruction of the Carnegie in November 1929, and the return to Washington, D. C., of the scientific staff early in 1930, a committee of members of the Department's staff was appointed to consider ways and means of assisting in the development of plans for future magnetic, electric, and oceanographic research over the oceans. The president of the Carnegie Institution of Washington suggested such a committee in order that the experience gained in the operations of the Carnegie might be made available for similar programs in the future. W. J. Peters, F. M. Soule, and O. W. Torreson, who had all taken extensive part in the program at sea, were designated for this duty.

Among the proposals submitted by this committee was one recommending that there be prepared various memoranda relating to the experience acquired on the Galilee and the Carnegie and incorporating suggestions for improvements in instruments, observational procedures, ship's equipment, and comments on any other matters on which constructive suggestions might be of benefit to investigators planning future ocean work.

Nine memoranda were prepared in response to this proposal by members of the committee and members of the scientific staff of the last cruise of the Carnegie. These were prepared in 1930 and given limited circulation at that time. In the present volume the papers are presented essentially as written in 1930, only a few deletions having been made of suggestions and comments no longer applicable, and a few statements corrected on the basis of more up-to-date information. The papers represent an important series of reports on practices and procedures on board the Carnegie, particularly because the seventh and last cruise was the only one on which, in addition to the usual magnetic, electric, and meteorological program, very diversified activities concerned with oceanic measurements were included.

The scope of the researches carried out on the last cruise of the Carnegie may be realized from the complete bibliography compiled by Mrs. Crow, and given in the last section of the book.

The great quantity of results obtained on cruise VII and their excellent quality were due to the executive ability and personal energy of Captain Ault and to the enthusiasm which he aroused in all the ship's personnel. The program was so strenuous, each man had so much to do and worked under so much pressure, that its realization could not have been accomplished without the spirit of complete cooperation and comradeship. Captain Ault possessed forcefulness, resourcefulness, and the ability to make quick decisions. Gifted to an unusual degree with the qualities of leadership he was, withal, sympathetic, kindly, and broadly tolerant. He was a gentleman of the finest type who quickly won the friendship, good will, and cooperation of all. Moreover, he was skilled in navigation, abreast of general scientific thought, and an authority in his own field--there could scarcely have been a combination of qualities more admirably suited to leadership in any oceanographic expedition.

As stated above, this is the last volume of the series of "Scientific results of cruise VII." Thirteen volumes have presented in detail the observational data secured, together with the full compilations of the results, and with considerable discussion and interpretation by the many investigators who have given so much time and enthusiastic support in the preparation of the volumes of this series. Naturally there are many possibilities for additional discussions and classifications of data, particularly in the great mass of biological information acquired. It is felt, however, that further researches and compilations and classification of data must be left to specialists in the various lines of endeavor who now have available all the observational material and results with suitable notes regarding details for additional study.

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THE CAPTAIN'S REPORT

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THE CAPTAIN'S REPORT

COMMISSIONING OF THE CARNEGIE, MAY 4, 1927 TO MAY 1, 1928

Until May 4, 1927, the Carnegie lay at the dock of the Washington-Colonial Beach Steamboat Company in Washington, D. C., where she had been berthed, while out of commission, after completion of cruise VI in 1921. She was taken from Washington under tow on May 4 and delivered on May 9 at the yard of the Tietjen and Lang Dry Dock Company, Hoboken, New Jersey, for repairs and overhaul, preparatory to resuming ocean work in terrestrial magnetism and atmospheric electricity, and initiating work in oceanography. Repairs necessitated by dry-rot, and alterations to enable oceanographic work to be undertaken during the forthcoming cruise (VII) were begun May 10. During May and June the repairs made included replacing of rigging, masts and yards, ballast and water tanks, renewal in part of the keelson, reinforcing of the sister-keelsons, rebuilding of bulkheads and berth decks, recalking and resheathing with felt and copper sheathing, and overhauling of running gear, of engine, and of plumbing.

The vessel's hull was found in much better condition than was expected from the examinations made in 1922 and 1925. Thus all frames below water line, where exposed to view, were sound, and borings for bolts to fasten new keelson showed no signs of bad frames; when tanks and ballast were removed, all ceiling in hold was found in good condition; all strakes below the water line proved sound, as did also nearly all above the water line. According to plans, all repairs, alterations, and new installations moved to completion by September 30, 1927.

In the meantime, considerable time has been given to planning the work for cruise VII. Throughout this planning of the program, valuable constructive suggestions have been supplied by various cooperating oceanographers and organizations, both in North America and abroad. A tentative route and schedule were outlined for a cruise of three years in all oceans, inquiries were made regarding oceanographic equipment, and orders for such equipment were placed. A special bronze winch for handling 19,000 feet of aluminum-bronze wire 4 millimeters in diameter was ordered, and a special engine of 30 horsepower to operate the 15-kilowatt generator required for handling the winch. This equipment is intended for securing water samples and water temperatures at various depths for the study of circulation and other oceanic problems. Other special equipment ordered includes water bottles, deep-sea reversing thermometers, aluminum-bronze wire, materials for the construction of a Wenner electric salinity apparatus, distant recording thermograph, evaporation meter, etc. The Navy Department is cooperating with Carnegie Institution through the loan of complete equipment for determining depths by echo methods.

Study was made of the methods for calculating oceanic currents from temperature and salinity data, and special graphs and tables were prepared to expedite calculations. Various other matters incidental and preparatory to the new oceanographic work received attention, including the designing of a new cabin for the biologist and of special biological, chemical, and radio laboratories on deck, and the rearrangement of deck space to permit installation of the new oceanographic equipment.

The repair work was sufficiently completed by October so that the vessel could be towed back to Washington for final outfitting and equipping, arriving October 17. The Department again was indebted to the U. S. Coast Guard for their courtesy and cooperation in towing the Carnegie from New York to the Potomac River. Two days were spent near the mouth of the Potomac trying to recover a bronze anchor lost in May, in testing the new winch and life boats, and in testing the new diving helmet to be used in connection with submarine biological investigations.

During October, November, and December the Carnegie was kept in good condition by Mr. Erickson, first watch officer, assisted by two seamen. Yards and masts were sandpapered and varnished, deck fittings were housed in canvas, three new phosphor-bronze cylinders were installed in the main engine, and plans were made for completion of deck, engine room, cabin, and laboratory fittings and equipment.

Considerable time was spent in planning for the scientific work of cruise VII, which was to start May 1, 1928. Conferences were held with various scientists relating to program and equipment for investigations in physical and biological oceanography, meteorology, solar radiation, aerology, and radio.

During January to April, 1928, active work was carried on in outfitting the new dark room and laboratories, and installing equipment. Special mention should be made of the extra efforts of all members of the ship's crew, of the office and shop force, and of the new ocean party, to complete equipment, tests, and installations in time to sail on the specified date, May 1. The many problems to be solved and the many difficulties which arose can be realized only by those who have gone through similar preparations for a long cruise, during which work in so many new lines of investigation was to be undertaken, with the necessity for designing and constructing new instruments, devising new methods, making tests and standardizations, training new personnel, installing the new equipment on a small vessel, remembering to economize on space, to arrange all in convenient and accessible locations, and to preserve the nonmagnetic feature of the observing domes for the observations in terrestrial magnetism.

The following new instruments, equipment, and fittings were installed or constructed.

1. On the bridge: Sperry searchlight, engine room telegraph, radioactive content collector with compressed air and electric-light connections, and solarimeter gimbal stand.
2. On the quarter-deck: Evaporimeter and gimbal stand (fig. 1); rain gage and gimbal stand; pelorus and stand; control room just abaft radio room for mounting earth-inductor constant-speed control and milliammeter, Sperry gyro roll-and-pitch recorder, Einthoven galvanometer for earth-current observations, recorder for six

electric resistance thermometers (installed at Hamburg in June), and deep-sea reversing thermometers (fig. 2); meteorological shelter (fig. 3) to house wet- and dry-bulb thermometers, Negretti and Zambra recording aspiration psychrometer (installed at Plymouth in June), recording thermograph, one wet and one dry electric-resistance thermometer (installed at Hamburg in June, as also a pair at the top of the mainmast and at the crosstrees); and deck box for housing twenty-five Nansen water bottles and thermometers, bottom samplers (figs. 4 and 5), two Pettersson plankton catchers (fig. 6), and other oceanographic equipment.

3. In the engine room: Various switch boards and control panels; main battery boosting generator; battery charging motor generator for 24-volt battery; 320-ampere-hour battery equipment; air compressor; motor generator for radio; batteries for radio and for resistance-thermometer recorder; Kelvinator refrigerator compressor; complete photographic darkroom equipment and accessories; main sea cock; and lathe.

4. Ocean laboratory: Electric salinity bridge (fig. 7) and accessories; chemical equipment for determining salinity, oxygen, and phosphate content of sea water; hydrogen-ion concentration apparatus; and various instruments and accessories for marine biological investigations.

5. Radio room: Short wave receiver (fig. 8) and transmitter; sonic depth finder; and quarters for observer and radio operator.

6. Atmospheric-electric house: New mountings and connections for all instruments and batteries; motor, fan, and ventilating shaft for conductivity apparatus (fig. 9).

7. Cabin and wardroom: Kelvinator electric refrigerator; constant-speed motor and operating shaft for earth inductor in forward dome; and new lighting circuits and connections.

All arrangements and installations were sufficiently well advanced by May 1 so that the Carnegie sailed at 09h 00m under tow for St. Mary's River, near the mouth of the Potomac.

The scientific staff (fig. 10), their titles, and their special fields, were as follows.

Captain J. P. Ault, commander of the expedition, master of the vessel, and chief of scientific staff.

W. C. Parkinson, senior scientific officer, atmospheric electricity and photography.

O. W. Torreson, navigator and executive officer, magnetism, navigation, and meteorology.

F. M. Soule, observer and electrical engineer, magnetism and physical oceanography.

H. R. Seiwell, chemist and biologist, oceanography.

J. H. Paul, surgeon and observer, medical work, meteorology, and oceanography.

W. E. Scott, observer, magnetism, navigation, and commissary.

L. A. Jones, radio operator and observer, radio conditions and communication, magnetism.

The sailing staff (figs. 11 and 12) included: A. Erickson, first watch officer, C. E. Leyer, engineer, and F. Lyngdorf, steward, all of whom had been on board during the entire two years of the sixth cruise; E. Unander, second watch officer; H. Jentoft, third watch officer; O. Backgren, cook; W. H. Taylor, mechanic; eight seamen, and two messboys.

In addition to the above, the following members of the office staff accompanied the vessel to complete tests and installations and to assist with the observations during swinging ship operations, and in the ship and shore observations of the electric potential gradient at St. Mary's River: W. J. Peters, O. H. Gish, J. W. Green, G. R. Wait, C. Huff, W. F. Steiner, and A. Smith. J. A. Huff of Baltimore also accompanied the vessel in order to complete electric installations.

WASHINGTON, D. C. TO NEWPORT NEWS, VIRGINIA, MAY 1 TO 10, 1928

Shortly after midnight on May 2, the Carnegie came to anchor at the mouth of the St. Mary's River to await sunrise before beginning the program of swinging the ship to determine deviations of the magnetic instruments. The day broke fair and six swings under her own engine were made to detect any deviations in declination or horizontal intensity. Simultaneous observations were made ashore by the Department's field parties which had established numerous magnetic stations on both the Maryland and Virginia sides of the Potomac River around the position previously selected for the swings. The vessel returned to its previous anchorage on the evening of May 2, and remained there during May 3 and 4 while potential gradient comparisons were being made with the shore station. Experiments were made also to test the marine earth inductor and the radio installation. On May 5 the Carnegie was swung again under her own engine in the morning to detect any deviations in dip and intensity, and then returned to anchorage to complete potential gradient comparisons. Simultaneous shore observations were made during all swings and comparisons. At 20h 30m anchor was weighed and the Carnegie proceeded to Newport News where she arrived at 8h May 6 for docking and adjusting the oscillator of the deep-sea sonic depth finder.

During May 7 to 10 a new diaphragm was installed on the oscillator (fig. 13) of the sonic depth finder, new radio equipment was secured from the Norfolk Navy Yard, new main sea cock was installed, and some small repairs were made on the vessel. P. T. Russel of the Washington Navy Yard assisted with the repairs to the oscillator, and T. A. Marshall of the Naval Research Laboratory assisted with the new radio equipment. Mr. J. A. Fleming, Assistant Director of the Department, and Mr. W. M. Gilbert, Executive Secretary of the Carnegie Institution of Washington, arrived from Washington for final conference and inspection. On May 10 the Carnegie was towed out to Hampton Roads, some moving pictures were taken of the vessel making sail (fig. 14), and at 16h departure was taken from Cape Henry--cruise VII had commenced at last.

NEWPORT NEWS, VIRGINIA TO PLYMOUTH, ENGLAND, MAY 10 TO JUNE 7, 1928

Weather conditions were rather unfavorable throughout the entire time--strong winds, heavy seas, and cold and rainy weather. The course as planned was followed fairly well for the first two weeks, but during the last two weeks head winds and baffling winds were experienced. The vessel was held off the entrance to the English Channel for ten days by easterly and southeasterly winds and gales.

In spite of bad weather, declination (D) observations with marine collimating compass (fig. 15) were made at twenty-nine stations, and horizontal intensity (H) with deflector (fig. 16) and inclination (I) with earth inductor at twelve stations. All magnetic instruments worked well. The maximum range in the inclination for a single station did not exceed 30′ as determined with earth inductor 7 using improved gimbal mounting (not gyro) and microammeter without amplification. At all but three stations experimental determinations of H were made with the same method; vertical intensity (Z) was determined also at a number of stations.

The atmospheric-electric program has been carried out as completely as was possible. The radioactive content apparatus has not yet been put in operation. The masthead mounting for the photographic potential gradient electrograph has not been found practicable because of the great play of the masthead in moderate and rough weather. Experiments are being conducted to determine if this equipment may be used at the stern near the eye-reading potential gradient apparatus.

Six ocean stations for securing temperature and water-sample series were occupied, conditions of sea and weather not being favorable for stopping the vessel on other days. All the equipment, winch, water bottles (fig. 17), and deep-sea reversing thermometers, both protected and unprotected, work excellently. The open glass protecting tubes on four of the unprotected thermometers were broken, owing to the thermometer frames being too small. These tubes will be replaced in Hamburg; the thermometers themselves were uninjured. The three water bottles on the bottom end of the wire on one series were not reversed, owing to the messenger being obstructed by some fibrous organism which had become entangled with the wire. Some animal of the deep had fouled the wire. The unprotected thermometer, calibrated for pressure, gave excellent control of the actual depths reached. Usually, due to a stiff breeze, the wire angle at the surface was very large, so that some control of the depth was necessary.

The townets (fig. 18) were operated at eight complete stations, and surface tows were made at fifty stations. Whenever the vessel was hove to or under slow headway, advantage was taken of the opportunity to secure surface tows and dip-up specimens with dip nets. Many collections were made at night, using the underwater light. The large meter nets were not used except on one or two occasions, awaiting the devising and construction of heavier releasing devices.

The salinity bridge has been in successful operation from the first and salinities usually are available on the day following the occupation of an ocean station.

The depth finder has been used at fifty-seven stations. Unfortunately it was not possible to check its accuracy with wire soundings, but in shallow water the results agreed to within one fathom of the chart values.

Daylight contact with radio station NKF (U. S. Naval Research Laboratory at Anacostia, D. C.) failed early in the trip. It is hoped that a more extensive schedule, including one at night, may be arranged later. Good contact has been maintained with station W1MK at Hartford, Connecticut, U. S. A., throughout the trip, with one or two exceptions.

The ship has been kept up in as good condition as was possible, in view of the almost continuous bad weather. The small engine and generator worked well and frequent use was made of the main engine during calms and to get eastward against the head winds. The new arrangements for lifeboats and new laboratories were found to cause too heavy strain on the chartroom owing to lateral thrusts from lifeboat platforms, with consequent flooding of the cabin and staterooms. The accumulation of water on the main deck naturally is troublesome. While in Plymouth harbor, supports will be installed under the inboard ends of the crossbeams which bear the boat platforms, to take the weight off the chartroom and other laboratories. The heavy weather also caused the copper sheathing to peel off in many places along the water line. The vessel will have to be dry-docked in Hamburg to complete the necessary repairs.

In general, the vessel labors and works less than heretofore, in spite of being very heavy and low in the water aft. The quarter-deck has been awash many times during the trip across, something which has happened very rarely in past cruises. The rigging has kept fairly taut and in good condition. One of the large bronze bolts holding the topgallant mast in place on the top of the foremast carried away early in the trip.

After the ten-days' delay with head winds, the vessel was within a few hours' sail of picking up the first landfall at Bishop Rock, Scilly Islands. Then it began to rain, fog and mist closed in, and it was necessary to stand off to sea again. After several hours, it cleared up enough to head for the light, which was picked up at midnight. A fine fair wind took the vessel to within ten miles of Plymouth by afternoon of the following day, when it began to rain, mist and fog set in, and the wind hauled ahead. We were on the point of heading back to sea again, when the headland was sighted two miles west of Plymouth harbor. We then took in square sails, started the engine, and beat our way to port against a rising gale, with only one hour of daylight remaining. The pilot was found awaiting inside the harbor when the vessel had already gained a safe position near the breakwater. In letting go the port anchor, the new cable was so stiff and hard and wet from continual bad weather that it kinked and could not be let out rapidly enough to fetch the vessel up against the gale. The starboard anchor was let go just in time to avoid danger, and the vessel remained at anchor until taken to the well-sheltered inner harbor the next morning. For the next thirty-six hours a terrific gale blew from southeast to southwest which would have sent us hurrying back to sea again for another week, had we first been lucky enough to weather the confines of the channel.

PLYMOUTH, ENGLAND TO HAMBURG, GERMANY, JUNE 18 TO 22, 1928

The Carnegie left Plymouth at 16h 30m, June 18, being towed fifteen miles offshore until sails were set, and with a fair wind proceeded up the channel all night. The engine was operated the next day because of light winds and calm. During the night of June 19, the Carnegie passed through Dover Strait with favorable wind and tide; fortunately there was no fog, and conditions were excellent. Soon after leaving the Strait, however, the wind hauled ahead, and it was necessary to operate the engine almost continuously through the North Sea.

After making successful landfalls along the Dutch and German coasts approaching the Elbe River, and when within three hours' sail of the mouth of the river, fog, mist, and rain set in, making it impossible to sight the two lightships which point the way to the mouth of the Elbe. By keeping on and watching for the traffic route as indicated by glimpses of steamers passing to southward in the mist, the ship gradually headed up against the strong flood tide and finally made out the pilot vessel during a temporary lifting of the fog. The engine again proved its value, taking the vessel up the river against head winds and calms, until we met the tugboat (ordered from Hamburg the previous night) while passing Borkum Riff lightship.

Dr. H. U. Sverdrup of the Geophysical Institute in Bergen, Norway, and Research Associate of the Department, was on the dock to meet the party, and it was a welcome sight to see the face of an old friend in a strange country. The Carnegie reached dock at Hamburg on June 22 at 19h 30m, a little over four days out of Plymouth.

Surface tows were made and samples taken at thirty-three stations in the English Channel, Dover Straits, and the southern North Sea to the mouth of the Elbe River, and analyzed for phosphates, H-ion concentration, and salinity (fig. 19). Two surface tows also were made as the vessel proceeded up the Elbe River to Hamburg. Magnetic declination, inclination, and horizontal intensity were determined at two sea stations between Plymouth and the mouth of the Elbe River.

We received a very enthusiastic welcome at both Hamburg and Berlin. Much interest was manifested in the program and equipment of the expedition by the officials and scientists of the Deutsche Seewarte in Hamburg and of the Institut für Meereskunde and other organizations in Berlin and Potsdam. Every effort was made to assist us with suggestions and advice and to complete our equipment. To expedite matters, some equipment was turned over to us at once from the supply on hand at the Deutsche Seewarte and at the Institut für Meereskunde, a cooperation and assistance which was greatly appreciated.

During a brief visit to Berlin, the results and equipment of the "Meteor" expedition were inspected, visits were made to the various scientific organizations, and an illustrated lecture was delivered before the assembled scientists of Berlin and Potsdam. The magnetic observatory at Potsdam was inspected during a brief visit.

Many visitors inspected the Carnegie and her equipment during our stay in Hamburg, and we are much indebted to Vice-Admiral Dominik, President of the Deutsche Seewarte, and to Dr. K. Burath, in charge of magnetic work in the Deutsche Seewarte, for their kindness and courteous assistance. Dr. H. U. Sverdrup, was of chief assistance in completing our instrumental equipment and in arranging our program, having come from Bergen, Norway, especially to meet us. Drs. Defant and Wüst, of the Institut für Meereskunde, were especially active on our behalf during our visit to Berlin.

Some ship and engine room repairs were made, the vessel was dry-docked for repairs to sheathing, and the winch was modified to hold 10,000 meters of piano wire for securing bottom samples. The firm of Hartmann and Braun installed six resistance thermometers, three dry and three wet, two each at the top of the mainmast, at the crosstrees, and in the shelter house on the main deck, and mounted the recorder in the control room.

Our stay in Germany was unusually profitable and inspiring. To meet and consult with so many who were enthusiastic about our program and prospects, and helpful with suggestions, and who indicated so strongly the importance of the data we are securing, and who were so keenly interested in the many problems we hoped to investigate, gave us a better view of the task before us, and we came away with renewed enthusiasm.

HAMBURG, GERMANY TO REYKJAVIK, ICELAND, JULY 7 TO 20, 1928

The Carnegie left her berth at Hamburg, Germany, about noon on July 7 under tow. When the mouth of the Elbe River was reached, a strong head wind was blowing so it was necessary to retain the tugboat for a tow of twenty miles to sea to insure getting offshore safely. At 8h 30m, July 8, the engine was started and the towline was cast off. By midnight it was possible to set the square sails, so the engine was stopped and the vessel proceeded on course through the North Sea, making good progress on July 9, 10, and 11. The Shetland Islands were sighted on the afternoon of July 11 and the Faroes on the afternoon of July 12, both groups being passed to the northward.

Prevailing southwest winds prevented making the southward loop between Iceland and the Faroes, as planned, and the Carnegie stood off to the northwest to cross the track of 1914 near the southeast corner of Iceland. This track was reached July 14 and then for six days head winds were met as the vessel fought her way westward along the south coast of Iceland. The engine again proved its value and was operated with the fore-and-aft sails as often as conditions were favorable, for a total of seventy-six hours during six days. Without the engine it would not have been possible to make Reykjavik and at one time serious consideration was given to proceeding to St. Johns, Newfoundland and omitting Iceland. As the wind shifted only between northwest and southwest, it was necessary to tack or wear ship eleven times. Usually when trying to make a headland or to pass a definite and necessary point, the weather was bad and visibility was obscured by mist and rain, making navigation difficult and exacting, and entailing some risk. The anchorage at Reykjavik was reached at 8h 30m on July 20, the harbor being entered in the midst of rain squalls and low hanging mist and fog.

The magnetic work was carried out between Hamburg and Reykjavik, as planned, entirely clear weather being present to secure good series of declination observations at eleven stations and horizontal-intensity and inclination observations at six stations. Only two oceanographic stations were occupied, owing to strong winds and time required in tacking against head winds.

Surface tows were made and samples obtained at five stations. The depth finder was used at forty stations.

Observations of all the atmospheric-electric elements, with the exception of radioactive content, were made whenever conditions permitted. Lack of time and adverse weather prevented getting the radioactive content apparatus into working order. At Hamburg a stage was built on the stern rail to starboard of potential gradient apparatus no. 2 and the photographic potential gradient recorder was mounted thereon (fig. 20); the collector rod of the latter was remodeled so as to project from the stern and to place the collector-discs out over the water. Some very good results were obtained with this arrangement. On account of head winds, which required frequent running of the main engine, some of the potential gradient records do not represent normal air conditions, but it is felt that the present location of the instrument is the most feasible one on the ship and it is anticipated that reliable diurnal-variation data may now be obtained regularly. Eye-reading apparatus no. 2 gave trouble during the damp weather after leaving Hamburg because of breakdown of the sulphur bearing-insulators; these were recast at Reykjavik.

In Hamburg Dr. Kolhörster delivered to us the penetrating radiation instrument of his own design (Günther and Tegetmeyer No. 5503), and daily intercomparisons between this instrument and penetrating radiation apparatus no. 1 were made. There are some difficulties in using an instrument such as this, rigidly attached to a rolling ship, and having coarse fibers widely separated and in constant and irregular motion.

REYKJAVIK, ICELAND TO BARBADOS, WEST INDIES, JULY 27 TO SEPTEMBER 16, 1928

The Carnegie left Reykjavik at noon on July 27, 1928, going out under her own power against a head wind. By 14h the entrance point of the bay was cleared. Heading down toward Cape Farewell, good progress was made for the first four days. On July 31 the winds became unfavorable and on the next day they went calm and it was necessary to operate the engine. By August 3 the wind had sprung up from the northeast and was blowing a strong breeze. When opposite Cape Farewell, course was set toward Newfoundland, omitting the proposed loop toward Baffin Bay in order to gain on the schedule.

Auroral displays were seen during the nights of August 3, 4, 5, and 6. High arches went completely across the sky, with some streamers but very little color. On August 5 an iceberg was sighted at a distance of ten miles and course was changed to pass near; it measured four hundred feet long and ninety-five feet high. After crossing the Great Bank of Newfoundland on August 6, an ocean station on the edge of the Bank with 130 meters of water was occupied August 7. The temperature of the water at a depth of 52 meters was -1°6 C, being 11°4 C at the surface.

For over two weeks the vessel made her way southward (averaging about one hundred and forty miles per day and heaving to for an ocean station three times per week [figs. 21, 22, 23, and 24]), and entered the Gulf Stream on August 8, to be greeted with much warmer weather. On August 10 a gale blew from the southwest for a few hours, otherwise this period up to August 23 was marked by fine weather and moderate breezes.

On August 23 the region of light winds and calms, at latitude 16° north, was entered. For twelve days the average run was only sixty-five miles daily, with ninety-seven miles as a maximum. During this time the new boom walk (fig. 25) was tried out and dip nets and silk townets were used from it to good advantage. Various bottom samplers were tried out under favorable conditions; two samplers were lost because of a faulty wire.

On August 31 in 8° north latitude, because of delay through calms, it was decided to change course for Barbados. Light air and calms continued until September 10, when a moderate gale blew from the southwest, the wind having changed from northeast to northwest back to north-by-east, then back again through northwest to southwest. This was undoubtedly the effect of the hurricane which three days later was centered over the Mona Island passage which wrought such serious damage throughout the West Indies.

The island of Barbados was sighted late in the afternoon of September 16. After remaining hove to off the south point of the island nearly all night, anchorage was made in Carlisle Bay at 8h 30m on the morning of September 17, only three days behind the scheduled date of arrival.

The results obtained between Reykjavik and Barbados include 77 declination measurements, 25 values of both inclination and horizontal intensity, 22 ocean stations occupied, 205 sonic depth determinations, and 6 complete and 3 incomplete potential gradient diurnal-variation series. Evaporation observations were made on three days. Thus excellent series of observations were made in all the various subjects. Especially valuable will be the oceanographic results which will provide a cross section practically through the center of the North Atlantic, between latitudes 46° and 8° north. Temperature, salinity, density, specific volume, hydrogen-ion concentration, and phosphate-content variations from the surface down to a minimum of 2000 meters and a maximum of 5500 meters were determined. Plankton tows were made at the surface, 60, and 120 meters with silk townets, and the Pettersson plankton pump was operated at the same depths at all ocean stations.

Thus the first long passage of the cruise was completed in a satisfactory manner. The members of the party stood up well under the trying and strenuous conditions attending such a period. The equipment stood up well, with the few exceptions noted separately.

BARBADOS, WEST INDIES TO BALBOA, CANAL ZONE, OCTOBER 1 TO 11, 1928

Leaving the Bridgetown mooring buoy at 11h 30m, October 1, 1928, under her own power, the Carnegie headed up northwest to sight Martinique for a fine view of this mountainous island the next day, Mount Pelée showing up clearly except for a cloud bank at the top. For one brief moment the mist lifted enough to see the jagged peaks at the top of the cone against the white cloud background. After squaring away for Colon at noon October 2, fine weather, broken by occasional squalls with heavy rain, lightning, and thunder, prevailed to within twenty-four hours' sail of Colon. One squall took the vessel at 11 knots for two hours.

At the first ocean station after leaving Barbados, a good bottom sample was secured on the long water-sample series, using the Vaughan sampler. At the next station, after hauling in seven hundred meters of the first series, the first bottles jammed against the davit block and before the winch could be stopped, the wire parted. Four thousand meters of wire, eleven Nansen bottles, five unprotected and seventeen protected Richter deep-sea reversing thermometers, and the second Vaughan snapper-type sampler, were lost. During work at an ocean station two half-meter nets are put out and towed from the after davit on the port side, one one-meter net is towed from the starboard side at the stern, the plankton pump is operated from one side platform using the port reel of heavy wire, and the two thermometers and water-bottle series are operated from the other platform. At times the pump is being lowered while the first bottle series is being brought up, or vice versa. The townets are being hauled in with the wire around the gypsy head, and the wire reeled up by hand, while the second bottle series is being brought up, the water samples drawn off, and the thermometers taken off the bottles and carried to the control room to be read later. Thus the fraction of a second lost in signaling to shut off the current when a bottle came to the surface caused the loss. A thimble was clamped on the broken end of the cable and some bottles were sent down to 1650 meters--all the wire left on the drum. The next day seven hundred meters of the 6-millimeter wire were spliced on the end of the 1650-meter length, using one bottle at the end, and the next bottle above the splice, with the messenger and chain long enough to reach below the splice. The reel of spare wire will be wound on the winch at Balboa.

Totals of four ocean stations, fifteen declination measurements, five inclination and horizontal-intensity measurements, and twenty-nine sonic depth stations were occupied. No atmospheric-electric series was made because of rainy weather and poor insulation on the ion counter. Radio contact with station W1MK was maintained as usual, and station NKF was overheard on several nights working the Byrd expedition vessels. The biological and chemical work was carried on successfully.

BALBOA, CANAL ZONE TO EASTER ISLAND TO CALLAO, PERU, OCTOBER 25, 1928 TO JANUARY 14, 1929

Anchorage was made in Limon Bay, Atlantic entrance to the Panama Canal, at 4h, October 11, after having used the engine for twenty-four hours because of calms or head winds. There surely is a thrill in coming into this harbor at night, steering by chart courses, picking out the lighthouses on the ends of the two breakwaters which protect the bay and form a narrow entrance which must not be missed or shipwreck will follow, then coming into the bay, following the course as indicated by the excellent range lights back along the canal, one fixed and the other flashing, and feeling our way to an anchorage clear of the other vessels and of the buoys marking the shoals.

By 11h the same morning we had arranged for a tow through the canal, had cashed a check at the bank to pay canal tolls, had completed all arrangements for clearance, pilot, etc., had hoisted the anchor and were on our way to our fourth passage through the canal with the Carnegie. By 19h we were alongside the dock at Balboa, everything having proceeded with its usual clockwork precision. Our mail was delivered to us at Miraflores during the afternoon, a courtesy on the part of the canal officials which was very much appreciated.

A busy two weeks followed. Records must be completed, abstracted, and mailed. Reports must be prepared. Biological specimens, bottom samples, and apparatus in need of repair, must be packed and forwarded to the office. New equipment must be brought aboard, unpacked, and installed. Vessel repairs and dry-docking must be supervised. Discontented members of the crew must be brought before the U. S. Shipping Commissioner; some paid off, others sent to the hospital, and some persuaded to remain. New men must be secured and signed on.

Leaving Balboa at noon October 25, the Carnegie had over twenty-four hours of fair wind before facing two weeks of head winds, heavy rains, squally weather, tacking back and forth, and running the engine in an attempt to get away from the Gulf of Panama. We stood southward for five days, then northwest for three days, with no change of wind. This made it apparent that we should have to use the engine and fore-and-aft sails on a long tack to the south in an effort to win past the coast of Ecuador, south of the equator, into the region of the southeast trade winds before we could make our way westward. So the route was changed to go south of the Galapagos Islands instead of north. Malpelo Island was sighted on our tack to the north and again was passed near by on the long tack to the southward. This island is an isolated, barren rock, one mile long and 846 feet high. There was more rain during these first two weeks than during all the preceding five months of cruise VII. The engine operated well except for two days' delay due to a burnt-out bearing in one connecting rod. Before clearing the coast and getting a favorable change of wind for sailing, the gasoline supply became very low, account being taken of requirements for the three months before a new supply could be obtained.

The delay in the Gulf of Panama gave splendid opportunity for securing a number of ocean stations in this interesting region. Salinities of surface water were low, owing to the enormous supply of fresh water poured out by the rivers emptying into the Gulf and from the heavy rainfalls. With the shift of wind November 8 from southwest to south, the engine could be shut down, the vessel proceeding westward under sail.

While occupying the ocean station on November 3, the oscillator used with the sonic depth finder to measure the ocean depth failed to operate, owing to some short circuit in the coils. This was a great handicap, since now it became necessary to determine the ocean depth by sending the bottom sampler down on the piano wire before lowering the water bottles and thermometers. On November 8, at station 40, about one hundred miles west of the Ecuadorean coast at latitude 1° 32′ south and longitude 82° 16′ west, it was not planned to secure a bottom sample but to send the water bottles and thermometers down to 3000 meters as the chart gave the depth at about 3300 meters. After 1600 meters of wire had been let out and another water bottle was being attached, the chief engineer, at the winch controls, stated that he believed the wire had touched bottom since the reel had slowed down very definitely. On hauling the wire and bottles up, ten meters of wire were found to be tangled around the bottom bottle and the lead weights. From this result it was concluded, after making allowances for various factors, that the depth was approximately 1515 meters. A bottom sampler sent down at once on the piano wire reached bottom at 1454 meters and brought up a small sample of black rock fragments with some globigerina ooze. The new mountain ridge thus indicated was named "Carnegie Ridge." It rises about 1800 meters above the general level of the ocean floor in its vicinity.

With the change of wind on November 8, we were at last on our way westward and on November 11 we sighted the first of the Galapagos Islands. Much to our regret we did not have time to stop. These islands appear rather barren from the south. Isabella Island has a beautiful, though small, lava cone, where lava has boiled up out of the side of the mountain. At one point lava has overflowed and broken down the side of the cone toward the sea.

On November 13, while occupying an ocean station, the bottom snapper failed to close. Owing to unusual currents, the 4-mm water bottle wire on the port side tangled with the 6-mm plankton pump wire on the starboard side and, before anything could be done, the strain on them, because of the pull against the keel of the vessel, parted the smaller wire, and four water bottles--with eight thermometers, lead weights, and messengers --disappeared out of sight. Later, when we hauled up on the other wire on the starboard side, to our amazement, there came into view all our bottles, etc., tangled up with the plankton pump. By careful work everything was secured and hauled up without loss or damage, except for 300 meters of the smaller wire which was kinked and useless. During an oceanographic station, the 0.9-mm piano wire with bottom sampler (usually the "snapper" type) is used on the davit aft; the 4-mm aluminum-bronze wire, with about ten water bottles and twenty thermometers, is operated on the port davit, if the ship is hove to on the port tack; the plankton pump is lowered on the 6-mm aluminum-bronze wire on the starboard davit; and the silk townets are operated from the forecastle head forward, so that four activities are under way at the same time. Formerly the silk nets were towed from the quarter-deck also, but Mr. Erickson rigged up blocks and lines so they could be towed from the forecastle head, thus avoiding the refuse of the ship and reducing the danger of so many lines aft fouling each other.

Since the receiving microphones of the sonic depth apparatus were still in good order, some means was sought to make a noise in the water which might serve to return an echo from the bottom, the time interval to be measured by a stop watch. After considering several expedients (for example, making up a few small bombs with some powder carried for use in the life line gun) it was suggested to the chief engineer that he devise a shotgun method of firing shells under water out of a 20-foot length of brass pipe. Thus use might be made of the large stock of shotgun shells supplied by Dr. Wetmore of the Smithsonian Institution for securing specimens of land birds from isolated islands. Within a short time the pipe was fitted with a shell holder at one end just long enough to cover the shell and a firing pin was constructed to be operated by hand at the other end. With this device the operator stands on the main deck, starboard side, opposite the microphones, leaning over the rail and holding the long pipe, the shotgun shell being in its holder at the lower end, about two feet under water. When the observer at the microphones blows the whistle, the operator releases the firing pin and it slides down the tube, striking and exploding the shell. This operation is repeated once and at times twice. Very often the observer hears and records the second echo of an explosion. The accuracy of this method is rated as ±200 meters, and by comparison with seven depths as determined with unprotected thermometers calibrated for pressure, the shotgun method gave depths about 200 meters too shallow. On occasions the agreement was remarkable. With this device soundings were obtained twice or more daily during the remainder of the cruise from November 15 to January 14, the date of arrival at Callao. When sounding in such shallow water as 300 meters near the coast, seven echoes were heard, and the interval between the shot and the fifth echo was measured.

Although now in the region of the equator with fairly steady southeast trade wind, the temperature of the air was anything but tropical, ranging from 20° to 24° C. The following two months were characterized by excellent weather, light winds, cool temperature, very little rain or fog, and one gale which continued for only six hours. The temperature never exceeded 24° C and was as low as 15° for one or two days while the vessel was in the region of 40° south latitude.

Although the Carnegie passed close to the south side of the various islands in the Galapagos group, no stop was made because of the delay in leaving the Gulf of Panama. In order to make up for some of this delay, the loop to Easter Island was shortened by about ten days, with no appreciable loss in the scientific data secured since we were able to follow previous tracks on the revised loop.

During this cruise we used, for the first time, a theodolite (fig. 26) loaned by the U. S. Navy Department for observing balloon flights at sea. This instrument is constructed with special tripod and gimbal so that it can be kept fairly level as the ship rolls and pitches, and the changing azimuth or direction and the changing altitude of the balloon can be measured as the balloon steadily rises at its average rate of about 180 meters per minute. Forty-four flights were observed. The balloon is filled with hydrogen gas until it reaches a diameter of about three feet (fig. 27), and is then released to go wherever the direction and velocity of the wind at various heights may take it (fig. 28). During the first ten minutes, readings are made every thirty seconds, then every minute until the balloon disappears. Torreson operated the theodolite, Scott called out time and recorded, and Ault usually followed the balloon with a sextant, to measure the altitude. The use of both theodolite and sextant saved the flight from failure many times. When the vessel would roll heavily and the balloon was changing its direction rapidly, it was difficult to follow and was lost frequently. By having the altitude from sextant readings it could be picked up again. On one occasion the balloon was followed for sixty-four minutes, but the average time was twenty to thirty minutes. With a strong trade wind it usually disappeared in fifteen minutes. Thus we secured excellent determinations of the direction and velocity of the wind at different levels from the surface up to heights of from two to six miles.

The magnetic and electric program was carried out regularly, the good weather and moderate sea giving excellent results.

The securing of bottom samples now was being made a regular part of the oceanographic program. Several types of bottom samplers were tried. None worked perfectly, but the snapper type, as improved by Dr. Vaughan, which he had ordered made for our use, proved to be the most satisfactory. Letting it go down, with jaws open, as rapidly as its 50-pound weight would take it, on striking the bottom the wires would go slack, the weight would release the catches which hold the jaws open and the jaws would close, snapping up about a pint of bottom mud or ooze, a spring then keeping them closed. At times the snapper did not close, but even then enough mud stuck to the inner walls of the irregularly shaped jaws to give a good sample. On one occasion the heavier Meteor sampling tube was sent down and it was forced into the bottom for a distance of two feet, bringing up an excellent sample. The second time it was used, it stuck too tightly in the mud, so that the wire broke and the sampler was lost.

Sending a sampler to the bottom has its difficulties. A small steel wire, 0.9 mm in diameter, is used because of its light weight and because it offers very little resistance in passing through the water. By watching it pay out with the 50-pound snapper on the end, one can tell rather easily when the snapper strikes bottom and the strain is released. Automatic devices have been provided for this purpose also, but with the vessel rolling and pitching it seems better to keep a strain on the wire through a rod held in the hand. Sometimes the vessel drifts so rapidly that the wire stretches out to windward at so large an angle that there is not wire enough to reach bottom.

On December 6 the ship arrived at Easter Island and six days were spent at anchor in the open roadstead of Cook Bay. We were welcomed and guided to the anchorage by the entire male population, or all who could get into the few boats, and all seemed delighted to see some new faces. The Governor came out with the Chilean flag flying. It had been six months since the last visitor. We then lowered our dinghy with its outboard motor and went ashore to arrange with Mr. Edmunds, the manager of the ranch operating on the island, for supplies of fresh meat, vegetables, and fruit and to arrange for laundry work.

The next day we all took to horses and rode eight miles and back to see the famous Easter Island images. Great numbers of images still stand or lie about in confusion over the sides of the mountain from which they were carved, whereas others stand over the platforms and graveyards which line the coast. Apparently Easter Island was chosen as the graveyard for the chiefs of a large island archipelago which suddenly disappeared. When this occurred, the thousands of slaves who were kept at work carving out the images, were left without a food supply and they fell on each other until only a few remained. No record of these events has ever been found, and the island's history rests only on inference.

Here, as at the island of Barbados, simultaneous observations were made of the potential gradient on ship and on shore, using two recording instruments. They were operated continuously night and day for three days. There were also carried on thirteen hours of continuous observation of the magnetic declination, horizontal intensity, and inclination. In the daytime the observing tents on shore usually were surrounded by natives, curious as to what the visitors were doing and watching for an occasional cigarette. Some group singing was done for us by the young folk of the island, and their songs were similar to those one hears in Samoa, Hawaii, and Tahiti.

On December 12 all work had been completed, the equipment was all on board, and plans for a picnic and feast with the natives on shore had been made when the manila cable for the anchor parted, causing the loss of the 1900-pound bronze starboard anchor; the rope had worn through on the hard coral sandy bottom, the wind being fairly strong all the time. Fortunately this happened about 10h when all were on board and in daylight. The lighter port anchor was let go at once but it dragged. Rather than risk the vessel in such close proximity to the rocks without sufficient anchors, it was decided to sail and word was sent ashore to get our supply of fresh meat killed and sent out to us. In the meantime the vessel stood out to sea and back again under easy sail and engine power. By 15h, after all arrangements had been completed and supplies had been brought on board, sail was set for Callao.

The ranch's supply steamer was due any day on its yearly visit. We undertook to find out by radio when it had left Valparaiso since Mr. Edmunds was assembling the live sheep and cattle which he expected to ship back to Chile. Owing to adverse radio conditions, the reply did not reach us until the morning of our departure. The reply stated that the steamer Antarctico was sailing December 20--information which Mr. Edmunds was glad to receive. Three weeks after we sailed, as we were idling along with light winds twelve hundred miles east of Easter Island on our course up toward Callao, we sighted smoke on the eastern horizon. No steamer would be likely to be on that course except the Antarctico and, as we had predicted, a small steamer stopped off our lee quarter three hours later and we exchanged greetings and news with the skipper and crew of the Antarctico bound for Easter Island. She had left Valparaiso December 29, and Juan Fernandez Island or Robinson Crusoe Island, January 1. After ten minutes of conversation, we wished each other good luck and sailed away on our separate courses--two small ships, lonely travelers meeting and greeting in the vast solitude of the South Pacific Ocean.

After leaving Easter Island the Carnegie was driven three hundred miles to the south and out of her course by continuous head winds. We reached 40°5 south latitude before being able to head up on the course and entered the southeast trade-wind region on January 5, the day after greeting the Antarctico. Steady progress was then made until reaching Callao on January 14.

On January 8 the shotgun devised for measuring ocean depth was out of order for the morning sounding at 8h. At 10h 30m repairs had been made and a sounding gave a depth of 1445 meters as against a depth of 4000 meters the previous evening. At noon the depth was 1186 meters, so orders were given to heave the vessel to for a wire sounding and bottom sample. A water bottle, with protected and unprotected thermometers, was sent down also. The wire angle was 12°, which gave a depth of 1188 meters. The thermometer gave a depth of 1168 meters, thus giving a close agreement between all three methods. The bottom sampler brought up an excellent sample of greyish white globigerina ooze. Thus a new ridge was discovered about ten miles across and 3000 meters higher than the surrounding ocean bed. Soundings were made at intervals of two hours during the afternoon. At 15h, three miles after the vessel had left the position of the ocean station, the depth was 1260 meters; at 16h, nine miles distant, it was 2751 meters; at 18h, twenty miles distant, it was 3620 meters; and at 20h, thirty-two miles distant, it was 4115 meters. Thus in a distance of thirty-two miles the depth changed from 1168 meters to 4115 meters. Ten miles was the distance run between the first sounding of 1445 meters (25° 03ʹ.2 south, 82° 20ʹ.0 west) and the sounding of 1260 meters (24° 54ʹ.0 south, 82° 13ʹ.0 west) before it began to deepen.

This ridge, named "Merriam Ridge" in honor of the President of the Carnegie Institution of Washington, Dr. John C. Merriam, is probably an extension to the northwestward of the peaks terminating in the islands of San Felix and San Ambrosio, one hundred and forty miles to the southeast. Time and the limitations of maneuvering a sailing vessel did not permit more exploration in this region.

The last five days of the cruise were characterized by unusually cloudy weather, so that the program of declination observations twice daily was not possible. The temperature of the surface water dropped from 21°.5 to 19° C, when the vessel was seventy-five miles southwest of Callao, and remained at 19° C until our arrival there. The drop was sudden, indicating that we had entered the cold Humboldt or Peruvian Current which flows northward as far as Ecuador.

The vessel's position was determined by star sights early in the morning of January 14 on Rigel and Arcturus, seen for brief moments through rapidly moving clouds. Course was then set for the north end of San Lorenzo Island, off Callao, and for over fifty miles this course was not changed, bringing the vessel to within one mile of the desired point at 14h. The <u>Carnegie</u> then proceeded under engine power and was anchored in Callao harbor a few hours later.

During the part of the cruise from Balboa to Callao the following observations were made: 96 declination measurements, 34 inclination and horizontal-intensity measurements, 36 ocean and townet stations; 143 sonic depths; 8 atmospheric-electric runs of twenty-four hours; 44 pilot-balloon flights; 12 series of evaporation measurements; 50 days of complete potential gradient records; 43 biological collections; 23 bottom samples; and regular continuous records of thermographs and barographs. Observing conditions were excellent during the entire time with the exception of only one or two days.

The radio conditions were difficult during the better part of the last two months. The indications were that the difficulty may be in local conditions of the general region traversed; whether this is a permanent condition of the region or only a temporary one is an interesting question.

CALLAO, PERU TO PAPEETE, TAHITI, FEBRUARY 5 TO MARCH 13, 1929

The <u>Carnegie</u> sailed from Callao Bay under her own power at 15h 20m, February 5, using the engine until the next morning because there was no wind. Here the regular observational program began with an ocean station, and continued without interruption, except for a stop of one day at Amanu Island, until arrival at Papeete, on March 13. The weather was excellent, with good breezes and no storms. The engine was not required except when the trade wind was interrupted among the Tuamotu Islands and during the squally weather near Tahiti.

The magnetic work was carried out as usual by Torreson, Soule, Scott, Paul, Jones, and Ault. Experiments to determine horizontal intensity with the earth inductor were continued by Soule and Torreson. Various coils were used and some encouragement was given for ultimate success by the improved agreement of results with those of deflector 5.

The usual atmospheric-electric program was carried out by Parkinson, assisted on diurnal-variation days by Torreson. Twenty-three complete potential gradient records were obtained and three and one-half diurnal runs were made. Considerable time was spent by Parkinson in attempts to operate the radioactive content collector and some progress was made.

The oceanographic work was entirely successful as carried out by Ault, Soule, Seiwell, Paul, and the deck and engine-room force under Erickson and Leyer. One of the new bottom samplers made at Callao gave some trouble by failure to close, but the difficulty was overcome by Leyer. The lead weight was countersunk to allow it to fit down over the clamping spring, thus bringing the center of gravity of the falling snapper nearer to the jaws, to insure that they strike the bottom in an upright position. Only once did the attempt to secure a sample fail. At one station no attempt was made. The samples themselves have shown considerable variation, the colors ranging from white to gray, light brown, blue-green, coffee-colored, chocolate, and black mud, sand, ooze, and lava. One of the new Sigsbee reversing frames (fig. 29) was modified to hold two of the Richter and Wiese thermometers, and was sent down on the drift wire, 20 meters above the snapper, at each ocean station after February 27. Thus the bottom temperature and the depth were secured in addition to the bottom sample. Experiment showed that it requires 25 meters of vertical haul to reverse the thermometers.

Up to February 28 five minutes had been allowed to elapse after the bottle series had reached the proper depth before releasing the messenger for reversal. Owing to a slight discrepancy between the two temperatures at the overlapping depth, it was decided to allow ten minutes to elapse hereafter, before reversal begins. The temperatures undoubtedly were accurate for the protected thermometers, but there might be some lag in the unprotected tube with its load of surface water to cool off and the pressure effect to register. An improvement in the agreement between the overlapping temperatures has since been noticed.

Only on rare occasions does a deep-sea reversing thermometer fail to function. Two or three of the unprotected ones required replacement. The water bottles all reversed and locked properly except on one occasion when five of the shallow series were reversed too soon for some unknown reason.

The Pettersson plankton pump fails to operate occasionally and must be sent down again. It was completely overhauled on February 19. Considerable patience is required to operate it and the ingenuity of Seiwell and Leyer is being taxed to the utmost to keep it in condition and to improve its operation. The results should be an extremely valuable addition to the qualitative as well as the quantitative data on plankton life and distribution.

During some of the ocean stations when the vessel was rolling and pitching more than usual, the silk townets were torn by the quick jerking of the ship's motion. Use then was made of the airplane rubber rope, the inboard end of the towline being secured to a 20-foot length of rubber rope to ease the strain on the towline when the vessel surges. The rubber rope would increase its length to twenty-eight feet at times. The nets have not torn since using this device, but the seas have been much smoother.

The balloon work by Torreson, Scott, and Ault has been unusually successful, owing to clear skies and moderately smooth motion. Some thought has been given to possible improvements to increase the efficiency of the theodolite when it is to be used in stormy latitudes. The use of the sextant for measuring altitudes increases the time of following the balloon considerably, especially on rough days. It permits the observer at the theodolite (Torreson) to keep one hand on the counterweight below to assist in keeping the instrument level, while the other hand operates the horizontal-circle screw. If the balloon is lost to the theodolite, the sextant gives its altitude and Scott can give Torreson the approximate bearing of the balloon by the direction of the sextant pointing.

In view of the length of time one must hold up the sextant and of the weight of the new balloon sextant, it became necessary to devise some method for supporting the instrument. One of the deck chairs was provided with arms and two upright pieces supporting an overhead bar. A coil spring was suspended from this bar, and the sextant is now used hanging from this spring. The entire weight is supported at the height of the observer's eye and the freedom of motion is in no wise restricted. The chair can be moved to the most advantageous position on deck for observing the balloon; the use of the sextant now involves no strain on the observer's arms (fig. 30).

On February 12, occasion was taken to have Parkinson secure pictures from the dinghy of the vessel under sail, this time in the early morning with the sails full of sunlight. Pictures were taken also after the vessel was hove to for an ocean station.

Soon after leaving the Peruvian coast the trade wind was found to be more southerly than was expected, so we could not at first follow exactly the route planned. Later the part of the 1916 track from 112° west and 12° south to 122° west and 17° south was followed exactly. At the latter position it was decided to head west, directly for Tahiti, through the Tuamotu Islands, instead of continuing south around this group. This would increase the value of the oceanographic work, by giving a long cross section almost due west from the coast of Peru to Tahiti, and by giving additional data as to depths in the Tuamotu group. Tatakoto Island was sighted early on March 7, and on March 8 the vessel was hove to off Amanu Island while the scientific staff made a visit ashore. About two hundred and seventy people live on Amanu, chiefly engaged in gathering copra. They appear healthy, happy, and prosperous, and of a very high class of South Sea Islander. There are no white people on the island. They gave us a large number of coconuts, and when we returned to the vessel in the afternoon, the chief and a boatload of men and women accompanied us to see the ship.

The oscillator has given excellent service since repairs at Callao, and a valuable series of soundings has been taken by Soule, Jones, and Paul. On February 8 the depth finder receiver was moved from the radio room to the control room, to decrease the crowded condition of the radio room and to provide for an enlarged program of depth finding, without disturbing the radio operator at all times of the day and night. The change has worked out well and has increased the comfort and efficiency all around. On February 19, Soule, assisted by Leyer, completely overhauled the depth finder and substituted spare parts for worn ones, At his request, Paul was instructed in the use of the depth finder in order to secure a sounding in the early morning in connection with his meteorological observations at Greenwich mean noon.

On February 16, at 17h 19m ship's time, latitude 15°.1 south, longitude 98°.3 west, the depth shoaled rapidly from 5380 meters to 3403 meters, after which it again deepened to 4530 at 17h 29m, when again there was a gradual decrease to 4080 meters. The deep thus revealed was named "Bauer Deep" in honor of Director Louis A. Bauer. Throughout the cruise from Callao to Papeete the bottom has been very irregular, as evidenced also by the many echoes, as many as six surfaces being indicated.

While passing through the Tuamotu Group, many soundings were taken in order to develop the bottom contour in this region. Thirteen soundings were taken on March 7, eleven on March 8, and nine on March 9, giving a valuable contribution to our knowledge of the formation in the vicinity of both Tatakoto and Amanu islands. A new ridge, 2000 meters above the general contour was discovered at 17° 40′ south and 141° 37′ west, between Amanu and Hikueru islands. A few miles later, at the ocean station, we had hard bottom, with a few fragments of black lava, with no trace of ooze, showing the possibility of fairly recent volcanic origin.

Jones found unusually good radio conditions prevailing after leaving Callao and was able to arrange frequent schedules with amateurs in various parts of the United States, Honolulu, Jamaica, and Panama. Later it became necessary to communicate with the American Radio Relay League station W1MK at Hartford, Connecticut, which has been so continuously helpful on this cruise, through two relays, namely, Yosemite, California (W6CIS) and Fort Madison, Iowa (W9BCA). Thus it was possible to keep the office fully informed of the daily progress and of urgent needs.

During the passage from Callao to Papeete, observations were obtained as follows: 63 declination measurements, 17 inclination and horizontal-intensity stations; 3 and 1/2 eye-reading, 24-hour atmospheric-electric series; 23 complete 24-hour potential gradient records;

17 ocean stations, including townets and plankton pump; 206 sonic depths; 35 balloon flights; 9 evaporation series; and one biological station. This summary of work done speaks for the smoothness and efficiency with which the members of the party, individually and as a whole, are carrying out the work of the expedition.

PAPEETE, TAHITI TO PAGO PAGO AND APIA, SAMOA, MARCH 20 TO APRIL 6, 1929

The Carnegie left Papeete at 15h 35m on March 20 under her own power, heading to the northward of Moorea. The next day the wind hauled ahead and we were obliged to proceed southward of Huaheine and Raiatea islands. Soundings showed new shoals south of this group, as also south of Mapehaa Island, farther to the westward. Before the western islands of the Society Group were cleared, it was necessary to use the engine on several occasions because of light and variable winds. The engine was operated also for three days continuously before arriving at Pago Pago on April 1, 19h 30m. The easterly trade wind was entered March 24, and this breeze continued until March 28. The usual program of work was carried out daily.

Considerable time was spent in trying to operate the new Coast and Geodetic Survey sounding machine, which had been installed on the port side of the quarter-deck, near the meteorological shelter house, during the stay in Papeete. The machine is built so that the drum is floating and must be moved along its axis to engage either the brake or the clutch. When the vessel rolls, the tension on the brake is changed by the movement of the drum so that the speed of paying out cannot be kept under control. When paying out on the clutch, letting the weight of the snapper-type bottom sampler unreel the drum against the motor, the momentum of the drum becomes too great for the speed at which the snapper is going down and the wire slackens and kinks. To stop it, the drum must be moved away from the clutch, through neutral or no control, across to engage the brake, and hence is stopped with a jerk which parts the wire. The drum as received did not hold more than 4700 meters of wire; in Apia it was machined out to hold 7000 meters. This experimental work was very destructive of bottom samplers and wire, so that no bottom samples were obtained during this part of the trip.

On March 26 one of the air tanks in the engine room exploded, the detached end breaking through the bulkhead into the gasoline tank room; the tank itself flew aft out of its cradle, and fell against the air compressor. Fortunately no one was injured and none of the instrumental equipment was seriously damaged, except for the severing of several electric cables. The compressor was operating, but the relief or safety valve was in good working order apparently, so it was not a case of overcharge but of weakness in the tank.

The following observations were made during this part of the cruise: 20 declination measurements, 6 inclination and intensity measurements, 6 ocean stations, 63 sonic depths, 10 pilot-balloon flights, 1 atmospheric-electric series, 3 potential gradient records, and 2 evaporation series.

After taking on gasoline, oil, and kerosene at Pago Pago, the Carnegie left for Apia April 5, arriving the next morning, going the eighty miles under engine power.

APIA, SAMOA TO GUAM TO YOKOHAMA, JAPAN, APRIL 20 TO JUNE 7, 1929

After completing the work of intercomparing the ship's magnetometer and earth inductor with those of the Apia Observatory, standardizing deflector 5, and carrying out simultaneous ship and shore potential gradient observations, the ship sailed from Apia April 20 en route for Guam and proceeded northward toward the Union Islands, with light and variable winds. When only sixty-five miles from Apia, two stowaways came on deck out of the forepeak. It was decided to return to Apia and land the boys back home to avoid later trouble and expense, since there was no place for them on board.

Soon after leaving Apia the second time, the wind became favorable and the engine was stopped. During the following week the winds were variable and calms were frequent until April 28, when the northeast trade wind began. This breeze continued without interruption until Guam was reached on May 20. The regular daily program was carried out in spite of frequent rain squalls, which, however, were usually of short duration. The date May 6 was omitted, owing to the crossing of the 180th meridian of longitude.

Wake Island was sighted early on May 11 and passed within one-quarter mile of Peacock Point, the southeast point of the island. Observations checked the position given for the island by the U. S. S. Tanager expedition of 1923. The highest point is only twenty-one feet above sea level; there are no coconut trees, only low-spreading umbrella trees and shrubs. Numerous birds were flying about. No signs of life or of buildings were seen. Glimpses of the beautiful green-blue lagoon seen through the break in the south side showed a considerable area free from obstructions which might make a suitable harbor and landing for seaplanes.

Rota and Guam islands were sighted on May 19, and the vessel was safely moored in Port Apra early on May 20.

Between Apia and Guam the following observations were made: 48 declination measurements, 13 inclination and horizontal intensity measurements, 14 ocean stations, 20 pilot-balloon flights, 3 atmospheric-electric series, 22 potential gradient records, 159 sonic depths, and 3 bottom samples.

After several attempts to use the new Coast and Geodetic Survey sounding machine, it was decided to resume use of the winch as before for getting bottom samples. As indicated in the previous report, the construction is such that the machine cannot be readily controlled when mounted, as it is on the Carnegie, with reel axle athwartships. On April 24 the 4-mm aluminum-bronze cable failed in seven or eight places, the heart strands breaking near the points where water bottles usually were clamped. This wire has been in use since leaving

Balboa in October 1928. It was necessary to discard about 2700 meters of wire. With over 4000 meters out, the 120-pound lead weight on the end and seven or eight bottles in series, the strain on the wire is very great, especially when there is any current or drift. On the same day, difficulty in controlling the new sounding machine caused a break in the piano wire, and the loss of snapper no. 7. The piano wire was shifted to the winch on April 25, but owing to shortage of snappers no bottom samples were secured after April 28 until en route from Guam to Japan.

On April 28 the deep water-bottle series had to be repeated because the first messenger caught in a jellyfish. On April 30 the messenger-chain caught under the wire-guide on one water bottle and the deep series again had to be repeated. On May 2 the vessel was rolling and surging so heavily that the piano wire of the bottom sampler fouled the bottle-wire and they came up entangled. Seven hours were required to untangle the wires and finish the station, and 2000 meters of piano wire were lost. The deep series thus was repeated three times, owing to accidental interference with messengers and with wire. In order to have at least 3000 meters of bottle wire, it was necessary to splice on 1100 meters remaining from the wire used in the Atlantic. This made it necessary to use one messenger on a long chain to clear the splice. Bottle M was attached above the splice and its messenger, hanging on the long chain, was attached below the splice. This chain later was replaced by a wire to avoid trouble due to the chain catching on parts of the bottle.

When attempting to get a bottom sample on May 9 the usual 50-pound weight was used with the snapper. The vessel was drifting with the wind and current so rapidly, however, that the angle soon reached 75° and the attempt was abandoned. It was decided to experiment with heavier weights to be detached when the snapper struck bottom. The Sigsbee releasing-device was removed from the tube and attached to the end of the snapper rod. Apparently the arrangement should have functioned but, unfortunately, the splice parted where the drift line was attached to the piano wire. The weights used, 120 pounds, were too heavy. It is intended to use this scheme after suitable weights and snappers are made in Japan.

The sonic depth finder results were of unusual interest in that we crossed over many shoals and deeps, showing a generally mountainous region on the ocean floor. One region varied in depth from 6500 meters to 4000 meters and back to 5700 meters. Another varied from 5600 meters to 1340 to 5130 meters, to 1900 meters, and back to 5800 meters. Two days before reaching Guam, at 14° 32′ north, 147° 28′ east, the depth was 8060 meters, the previous depth, twenty miles northeast, being 2892 meters. This is the northeast end of Nero Deep.

During the five days' stay in Guam the old 4-mm aluminum-bronze cable was removed from the reel and the new wire, 6000 meters, received at Callao was installed. Six new weights were cast for use with the Sigsbee sounding tube and the exhaust pipe for the Buffalo engine was brazed where cracked.

The magnetic station at Sumay was reoccupied. The stay was all too brief but was much enjoyed through the very generous hospitality which was extended by Governor and Mrs. Shapley, and the Navy and Marine personnel, as also by Superintendent Mullahey of the cable station, who placed his home and his car, with himself as chauffeur, at the disposal of the party.

After taking on fresh water and gasoline, sail was set for Yokohama on May 25, keeping the easterly trade wind for four days and making good daily runs. The wind then shifted to the south and varied between southeast and southwest until June 2. On the night of June 1 the positions of a typhoon for the two preceding days were received by radio from the Manila Observatory through amateur station K1AF. The wind had been increasing in force all afternoon and the sea was becoming heavier. We at once plotted these positions on the chart and predicted the path which the storm center would follow. By rough estimation of its rate of travel, it seemed due to intercept the Carnegie's track within a few hours. The barometer had dropped four millimeters during the preceding eight hours and it seemed wise to head east by south and place the vessel in a safer position to avoid the path of the storm. After running eastward for two hours, the barometer began to rise and the wind moderated so we hove the vessel to and waited for wind and sea to moderate further. After another wait of two hours, course was again set toward the northwest, the vessel riding on the tail of the typhoon. The wind continued to shift to the right, showing that the storm had passed on to the eastward. We got a great thrill out of this first experience in handling a storm by radio, and everything worked out like clockwork and exactly as predicted, from information received within the hour by radio.

There followed four days of rough sea, contrary winds, and engine running. During this period radio reports gave the location and speed of another typhoon coming toward the southern part of Japan. When within fifteen miles of the entrance to Tokyo Bay, late on Wednesday night, June 5, a rapidly falling barometer and rainy, threatening weather made it necessary to heave the vessel to in order to judge the nature of the storm and to see the headland. After waiting until 5h on June 6, conditions became worse and it was decided to get offshore to increase the margin of safety. After running the engine five hours, the wind and sea had risen to such an extent that again we had to heave the vessel to, this time on the southern edge of the typhoon. The ship was now about eighty miles offshore. About noon, on June 6, the barometer appeared to reach its lowest point and became steady. The wind began to moderate and back from south toward west, the storm center apparently having passed to the west and north. The Thursday radio report from Manila gave the typhoon center a position ten miles north of us on Thursday noon. Two sails were lost and several minor accidents happened on deck, but the vessel rode through the heavy seas in good order. By early Friday morning, June 7, the sea had moderated and the wind had shifted to northeast. Sail was set and by 11h Tokyo Bay was entered, the vessel going up to Yokohama under engine power and arriving at 19h 45m.

The following observations were made while en route from Guam to Yokohama: 21 declination measurements, 6 inclination and horizontal-intensity stations, 5 ocean stations, 5 bottom samples, 48 sonic depths, one atmospheric-electric series, and 4 bottom temperatures.

With the sonic depth finder a new deep was discovered on May 29 at 23°8 north, 144°1 east, and was named Fleming Deep, in honor of J. A. Fleming the Assistant Director of the Department. The greatest depth observed was 8650 meters. This deep was traversed in a south to north true direction and was 9 miles wide at 8600 meters, 20 miles at 8000 meters, 34 at 7000 meters, 47 at 6000 meters, 74 at 5000 meters, 106 at 4000 meters, and 162 miles wide at 3000 meters. Only five localities are known to be deeper than the Fleming Deep, namely, Kermadec, Guam, Philippines, Juril Islands, and off the southern islands of Japan.

Bottom samples were secured with the new cable and sounding tube installed at Guam, at each of the five ocean stations. At station 111, 6385 meters of piano wire were paid out before bottom was reached. The one drawback in using the winch is that the bearings become somewhat warm, so that when the deep bottle series is hauled in, the tremendous pressure against the clutch bearing necessary to maintain the clutch's grip on the reel, because of the heavy weight of wire and bottles, dragging at some speed through the water, overheats this bearing, and a delay is necessary for cooling to avoid ruining the bearing surface. Some changes to overcome this difficulty will be made at Yokohama.

The second Coast and Geodetic Survey propeller-type reversing frame was modified to hold two Richter and Wiese thermometers, and this frame, called Z2, was used at the last four stations. Bottom temperatures were secured at these four stations and at the last three the depth was determined by means of an unprotected thermometer used together with one protected thermometer.

The Japan Stream was entered on June 4, at 19h 30m at 33°.0 north, 141°.8 east. The temperature began to rise suddenly and in twelve hours it had risen three degrees.

Comment must be made on the excellent spirit of cooperation maintained among the members of the party since Apia. Owing to concerted action, practically all records were ready to mail on June 5, two days before arrival at Yokohama.

YOKOHAMA, JAPAN TO SAN FRANCISCO, CALIFORNIA, JUNE 24 TO JULY 28, 1929

After leaving Yokohama June 24, the first ten days were characterized by light variable winds and calms. The engine was operated frequently and the average day's run was about ninety miles. Advantage was taken of a smooth calm sea on June 27 and 28 to swing the vessel for magnetic deviations. One helm for declination observations was made on June 27 before the clouds covered the sun; all the next day was spent in making a swing with both helms for inclination and horizontal intensity.

About July 4 the region of cold surface water was entered with practically one hundred per cent of clouds, mist, fog, drizzle, and rain, which continued until July 21. The wind was somewhat stronger, but not favorable. Adverse winds during July 9 to 12 drove the vessel three hundred miles to the southward of the proposed track. From July 5 to 26 the weather was so cold that the copper heating stove was used in the cabin. On July 14 the wind freshened from the southwest and for sixteen days the average daily run was about two hundred miles. Better weather was met between July 22 and 29, the wind still continuing fair and strong.

During the cloudy, foggy weather the program for declination was sadly interrupted. No observations could be obtained on July 6, 7, 12, 13, 14, and 19. On some of the other days, the observations were made with the sun at such high altitudes and with such rough seas that the accuracy was seriously impaired.

During the same period no balloon flights could be made. The alternation of ocean stations with magnetic stations was maintained throughout the trip, except that July 14 and 15 were interchanged, on account of strong wind and rough sea. The ocean station on July 15 was not successful below 500 meters. The messengers would not reverse the bottles, owing to large wire angle. For the later stations with strong wind, 170-pound lead weights were used on the end of the bottle wire, and the newer and heavier messengers were made still heavier by filling two drill holes with lead, bringing the weight per messenger up to thirteen ounces, as compared with seven ounces for the ones previously used. These changes enabled us to secure temperatures and salinities down to 3500 meters during wind force 6.

The sonic-depth program was carried out as usual. Some difficulty was experienced owing to noisy microphones during high speed of the vessel through the water. No unusual variations in the depths were noted, except that on July 24 some irregularities were observed indicating the existence of several surfaces and some rapid changes in depth.

Tests with the new balloon sextant chair gave good results. The azimuths given by the chair differed from the regular theodolite by 1°.5 with an extreme range of 5° in thirty-five readings. A few improvements and more experience will decrease this range. Thus, in rough weather, when the balloon becomes lost to the observer at the theodolite, the observer at the sextant can carry on until the balloon disappears. Even now when the observer at the theodolite loses the balloon for a moment, a glance at the azimuth circle of the chair gives him the approximate theodolite readings and enables him to relocate the balloon.

The first ocean station after leaving Yokohama required seven hours to complete. Owing to strong currents the bottom-sampler wire fouled the bottle wire and required some time and care to untangle and to avoid breakage and loss of wire, thermometers, and snapper. The current took the wires underneath the vessel, and the sampler wire caught on the sonic depth oscillator also. In an effort to locate and remedy the trouble the "divinhood" (fig. 31) was used, but the rolling of the vessel made the attempt dangerous because of the likelihood of the helmet being lifted off the head. Sufficient depth was reached to show the trouble, however, and a lead weight was then lowered along the piano wire, thus clearing it from the oscillator.

The new scheme of leaving the lead weights on the ocean bottom has increased the efficiency of the bottom sampling and decreased the time required. The 60-pound weight is in two halves, and each is suspended by a wire from the hook on the Sigsbee releasing device which has been installed on the end of the shaft of the Ross-type snapper. The bottoms of the two weights are fastened together by two staples driven in fairly tight. When the snapper hits bottom, the hook releases the wires, allowing the two weights to fall apart outward from the top, thus forcing the lower staples out and the weights fall free. The snapper is driven into the ground with such force by the 60-pound weight that it has never failed to release the catches and it has come up full and closed. At two stations, the snapper was sent down twice, and was successful each time. Because of drift and limited length of wire, no bottom sample was attempted on the days of high wind and rough seas. There is an economy of time, power, and personnel in using the main winch for the bottom sampling instead of a separate machine. The only delay is on occasions when the pump could come up sooner, but must wait until the bottom sample is ready to come up.

The atmospheric-electric work has suffered some interruption because of bad weather, particularly in the few eye-reading diurnal-variation runs obtained. Unusually good potential gradient traces were secured, however, in spite of the foggy, misty, rainy weather.

Radio conditions were good and schedules were maintained every night. Exceptional cooperation has been shown by our amateur friends, and especially by the "San Francisco Examiner" radio station KUP.

The following observations were made during the period June 24 to July 28: 40 declination measurements, 18 inclination and horizontal intensity measurements, 2 atmospheric-electric series, 26 complete potential gradient records, 12 pilot-balloon flights, 17 ocean stations, and 166 sonic depths.

SAN FRANCISCO, CALIFORNIA TO HONOLULU, HAWAII, SEPTEMBER 3 TO 23, 1929

There were three new members of the scientific staff when the Carnegie sailed from San Francisco on September 3. Scott E. Forbush replaced O. W. Torreson, H. W. Graham replaced H. R. Seiwell, and S. L. Seaton replaced radio operator L. A. Jones (fig. 32).

The entire trip of twenty days was characterized by light airs and calms, with only a few days of regular trade wind, the northeast trade wind not appearing until September 17. The extremes in daily run were 66 to 177 miles, the average being 108.8 miles. The engine was used frequently. The new ball-bearing friction band on the winch, installed at San Francisco, has proved entirely successful. Several deep water-bottle series were sent down and brought up without any overheating or difficulty.

The new pelican bottom snapper was successful on the first trial. On another occasion apparently it struck a whale at about 500 meters. On two occasions, the spring was not tight enough and the pressure of the water on the inside of the jaws as the snapper went down rapidly was sufficient to open them, allowing the tongue catches to fall down and close the snapper, so that when it struck bottom it was closed. Enough mud was secured from the outside of the jaws to examine for classification. The snapper came up full on four occasions, yielding about one and one-quarter liters of material, one sample weighing nearly two kilograms. It is expected that one hundred per cent efficiency with this snapper will be had after final adjustments.

A peak or mountain which existing charts show at 32°.2 north and 128°.2 west, with a depth of fifty-eight hundred feet of water over it, was relocated thirty miles northeast of the above position, or at 32°.4 north and 127°.8 west, and with a least depth of forty-six hundred feet. We have named it Hayes Peak in honor of Dr. Harvey C. Hayes of the Naval Research Laboratory, Washington, D. C., who developed the sonic depth finder for the United States Navy. The slopes of the mountain are very steep, dropping off over eighty-five hundred feet in six miles. The peak rises out of a general depth of over fourteen thousand feet. Thus the peak is about ten thousand feet in height. The absence of soundings south and east allows the possibility of its being a ridge instead of an isolated peak.

The new balloon theodolite received at San Francisco is a decided improvement over the first one. The larger field of view permits keeping the balloon in sight continuously until it disappears owing to distance. The new sextant chair was used on several occasions to extend the time of observed flight, the time being as long as fifty-nine minutes on one occasion. As the supply of six-inch, uncolored balloons was low, it was necessary to use black balloons on several occasions, but their visibility was so poor that nine-inch uncolored balloons were used after that.

The regular program of observations was carried out and included 10 ocean stations, 9 stations for dip and intensity, 27 stations for declination, 96 sonic depths, 11 potential gradient and 10 conductivity records, 14 pilot-balloon flights, and 5 evaporation series.

The gravity apparatus which had been installed at San Francisco (figs. 33 and 34) worked successfully on only one occasion. Forbush made several attempts to obtain gravity determinations while at sea, but most of these were unsuccessful because the amplitudes of the pendulums got too large and in some instances there was actual slipping of the knife-edges. Several factors were thought to cause the increase in amplitudes of the pendulums; horizontal acceleration due to rolling of the ship, horizontal accelerations due to surface waves striking the hull of the ship, and elastic vibrations of parts of the apparatus or its support. Bracing of the gimbal frame of the gravity apparatus was tried but no improvement in operation was noted.

The vessel arrived at Honolulu at noon, Monday, September 23, after an unusually quiet approach the previous night.

HONOLULU, HAWAII TO PAGO PAGO, SAMOA, OCTOBER 2 TO NOVEMBER 18, 1929

The seven-week passage to Samoa was a period of good weather but feeble winds. The engine was used frequently in order to keep on schedule as well as possible. In the first few days after leaving Honolulu the ship passed through a series of wind squalls that reached such force as to rip the middle staysail, gallant, and foresail. These were old sails but were repaired and put back into use to save the new suit of sails for a later part of the voyage. On October 7 some remarkably long swells were encountered, coming from the northwest. These were observed to be about six hundred feet apart. Brief stops were made at Penrhyn Island on November 10 and Manahiki Island on November 12.

Heavy cross currents near the equator caused considerable loss of oceanographic equipment. The Counter Equatorial Current flows at a rate of thirty miles per day on the surface, near its northern boundary at 9° north, but has no velocity at a depth of two hundred meters. On October 25 the wire of the bottom sampler and the wire of the water-bottle series became entangled and the latter wire parted when caught on an outboard platform. Forty-two hundred meters of wire were lost, nine water bottles, and eighteen deep-sea reversing thermometers. To avoid similar loss in the future, the program was altered and the water-bottle series was not lowered until the bottom sampling was completed. This, however, almost doubled the time required for each oceanographic station.

Other equipment losses were experienced earlier. On October 11 two silk nets were lost when the tow wire jumped its sheave and wore through. On the same day a bottom sampler and some bottom temperature equipment were lost when a splice in the wire caught on the meter wheel. On November 5 the silk plankton nets towed from the bow became entangled with the wire of the bottle series which was lowered from the quarter-deck. Two thermometers were lost on this occasion and the nets torn slightly.

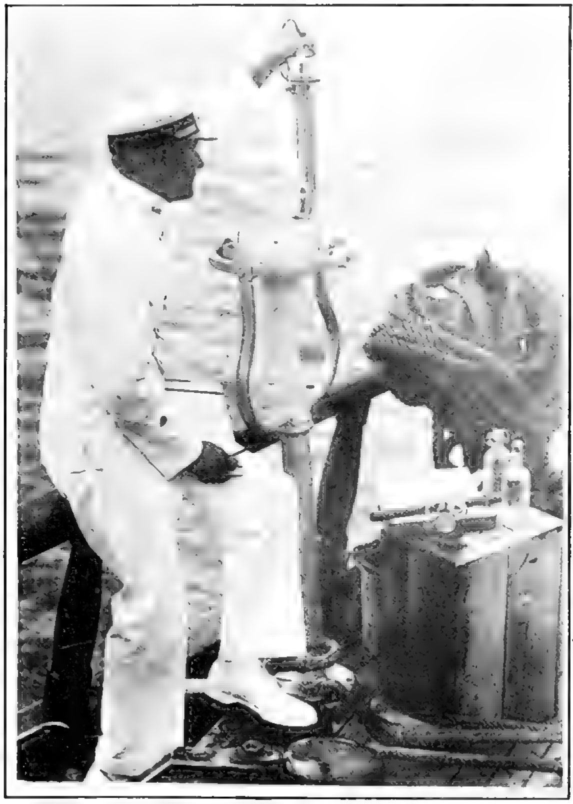
After leaving Honolulu, various attempts were made to get satisfactory measurements of gravity, but without success. The roll of the ship, the vibrations imparted by waves striking the ship, and the instability of the mounting of the gravity apparatus all prevented successful operation of the apparatus. While in the lee of Penrhyn Island on November 10 a gravity measurement was made; this was the only successful measurement made between Honolulu and Pago Pago. A satisfactory measurement had been made at Honolulu before departure and additional successful determinations were obtained while in the harbor at Pago Pago.

On November 8, at 7h 30m, the sonic depth finder gave a sounding of 5200 meters. Later, during the oceanographic station, another sounding indicated a depth of only 1200 meters, a shoaling having occurred within a few miles. In the island regions such irregularities were noted frequently.

The full program in magnetism, atmospheric electricity, oceanography, and meteorology was carried on without interruption; 47 complete days of record of conductivity were obtained, 29 complete and 16 partial days of potential gradient, and 23 oceanographic stations occupied. Magnetic measurements were made regularly on days alternating with those on which the oceanographic work was done. The temperature of the ocean bottom was measured frequently after leaving Honolulu and at a station near Pago Pago the lowest value was found--1°1 C. Measurements with the sonic depth finder showed that there is no deep trough between Penrhyn and Manahiki islands, as the charts would lead one to believe. Pilot-balloon observations were very successful owing to fine skies and the new theodolite. The latter was so well adapted to observing conditions that the sextant chair was seldom used. Radio conditions were unexcelled throughout the trip.

Entering Pago Pago harbor in the early afternoon of November 18, the engine was used, as strong wind squalls were swooping down from the mountains surrounding the bay. Anchorage was made at a buoy until the following morning.

LIST OF FIGURES



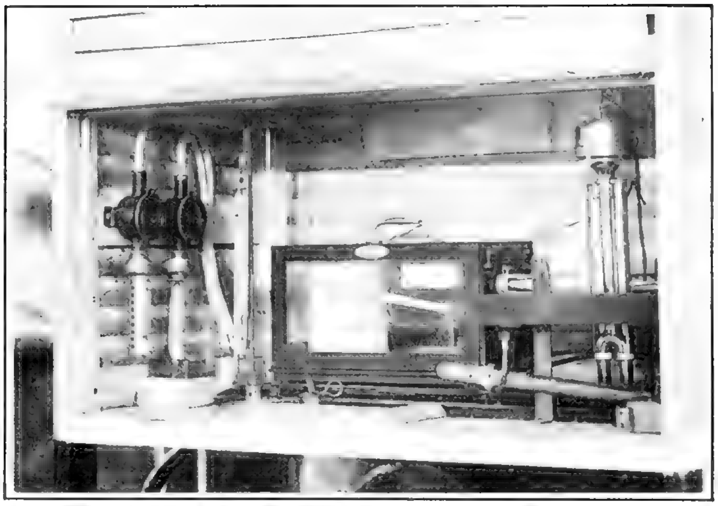


Fig. 3. The Stevenson meteorological shelter on the quarterdeck, housing instruments to measure temperature and humidity of the air

Fig. 1. Paul at the evaporimeter. The evaporation of sea water is enormous--at the equator it appears to be about seven and one-half feet per year. Facts concerning evaporation are essential to an understanding of many problems in the field of meteorology

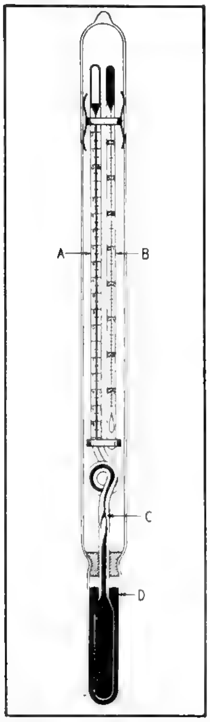


Fig. 2. A Richter and Wiese deep-sea reversing thermometer protected against pressures encountered in the depths of the ocean. (A) Sea water thermometer, (B) auxiliary thermometer for making correction for air temperature on deck, (C) point at which mercury capillary breaks on reversal, (D) mercury shield which protects bulb from pressure of the sea

Fig. 4. A "snapper" type of bottom sampler

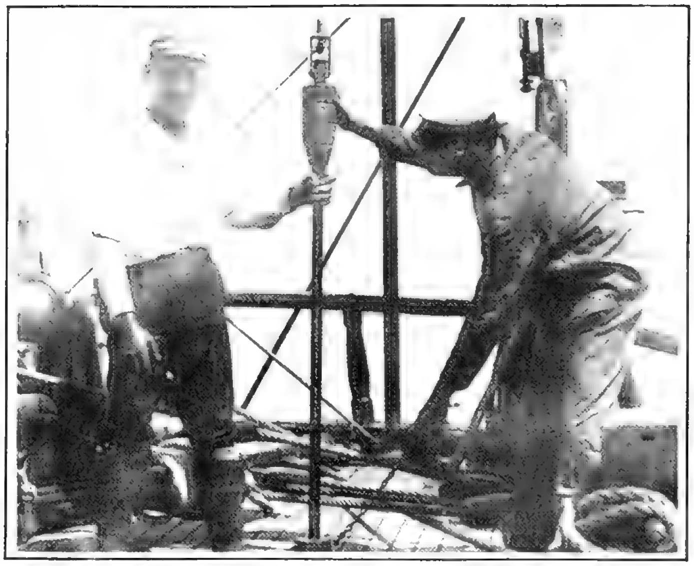


Fig. 5. Meteor "glass-tube" type of bottom sampler

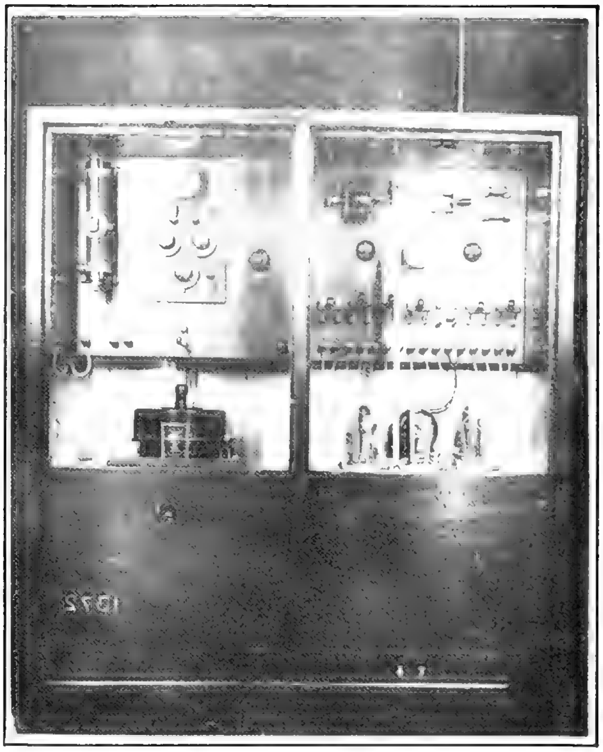


Fig. 7. The Wenner salinity bridge. An apparatus giving the salt content in a sample of sea water by measuring the resistance it offers to the passage of an electric current

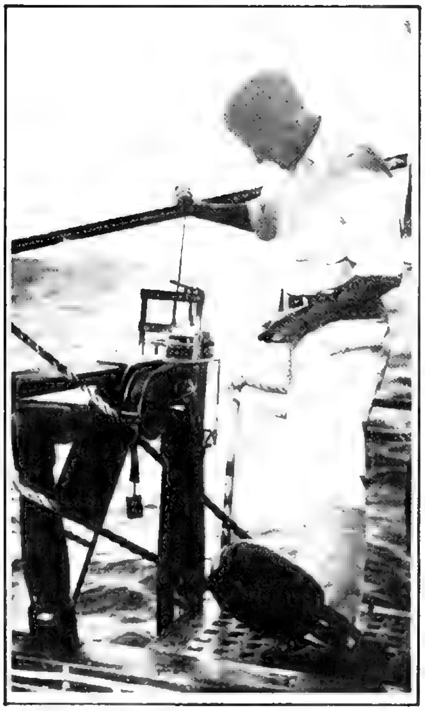


Fig. 6. Paul at the plankton pump. This device makes a census of the microscopic life floating at any desired depth

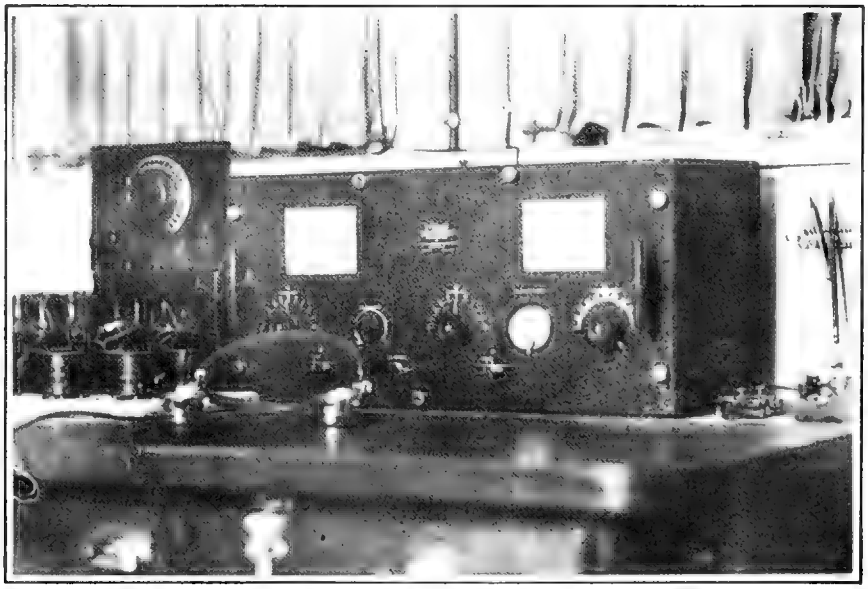


Fig. 8. The radio receiver designed by the Naval Research Laboratory and used on the Carnegie, bringing us messages from home and keeping us in touch with headquarters through radio amateurs in all countries

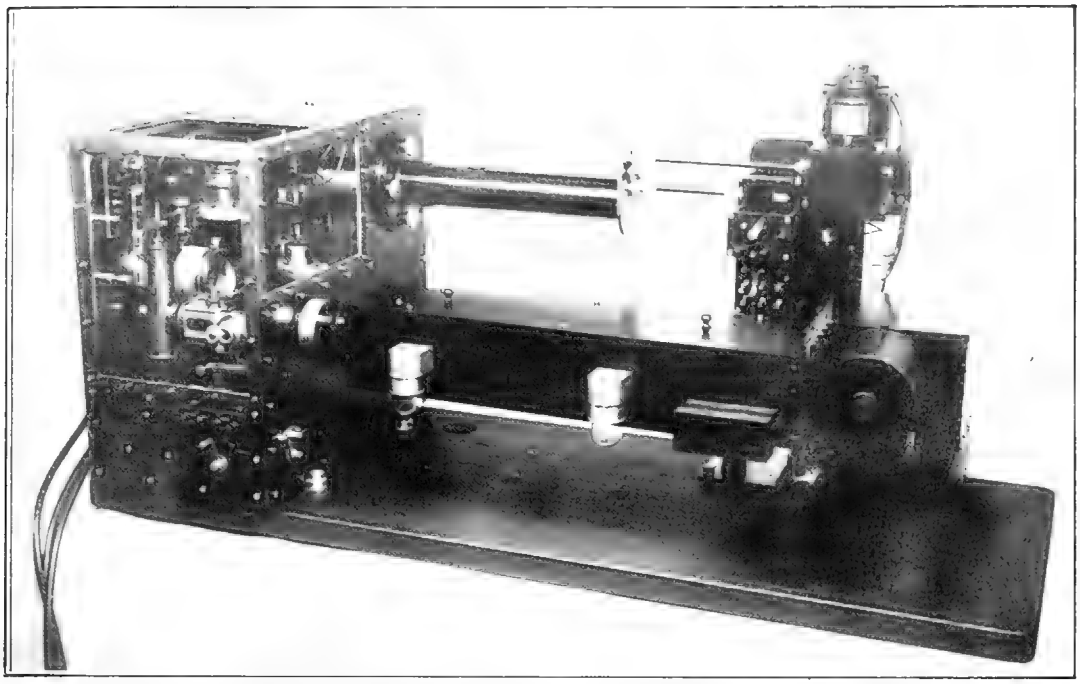


Fig. 9. Recording apparatus for electrical conductivity of the atmosphere

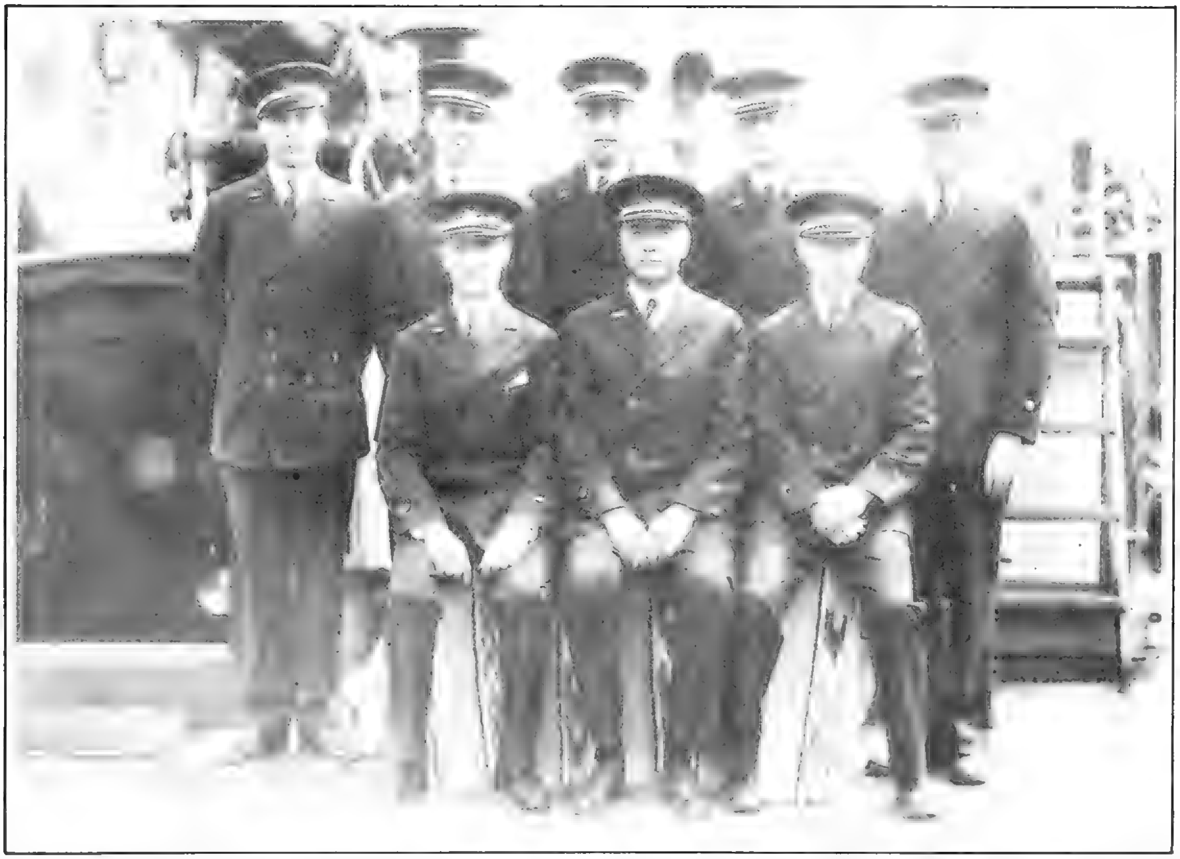


Fig. 10. The scientific staff aboard the Carnegie. Front row, left to right: W. C. Parkinson, senior scientific officer; Captain J. P. Ault, commander and chief of scientific staff; J. H. Paul, surgeon and observer. Back row, left to right: F. M. Soule, electrical engineer; J. A. Jones, radio operator and observer; W. E. Scott, navigator and commissary; H. R. Seiwell, chemist and biologist; O. W. Torreson, navigator and executive officer

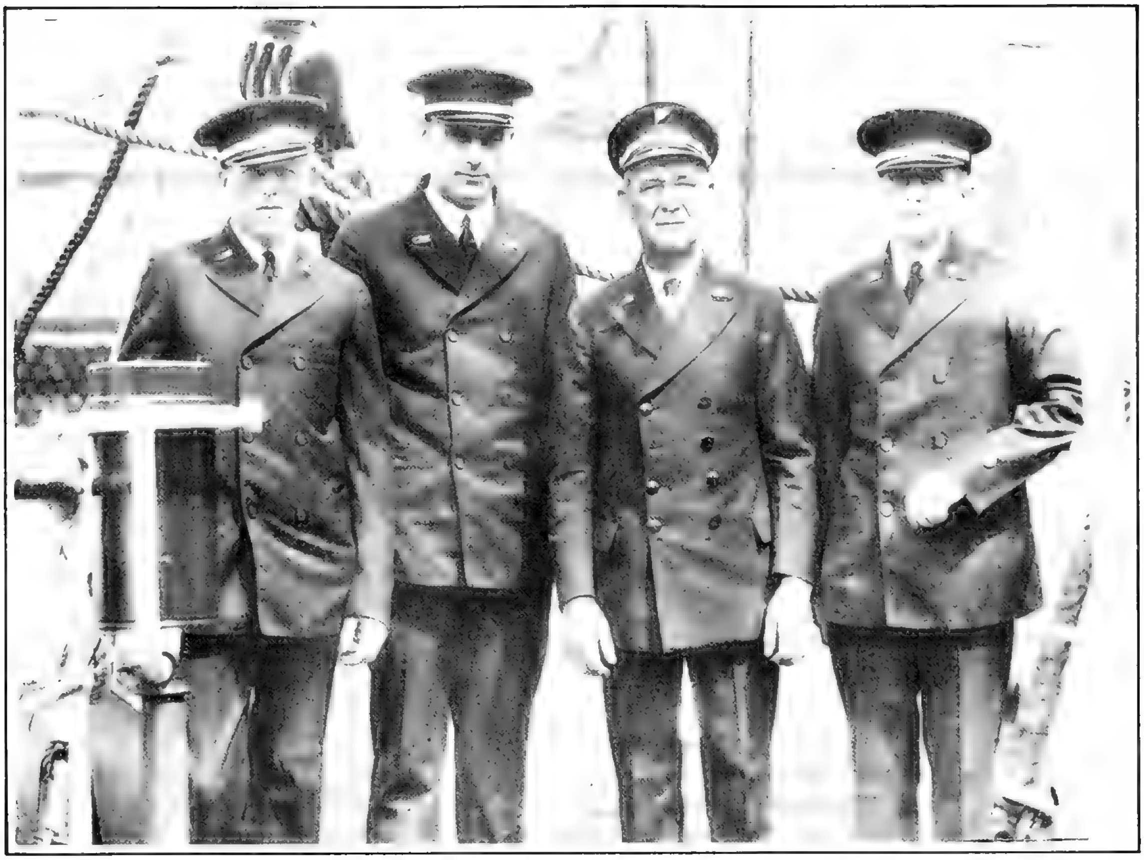


Fig. 11. The watch officers and the engineer. Left to right: Jentoft, third mate; Leyer, engineer; Erickson, first mate; Unander, second mate

Fig. 12. Steward, cook, and messboys

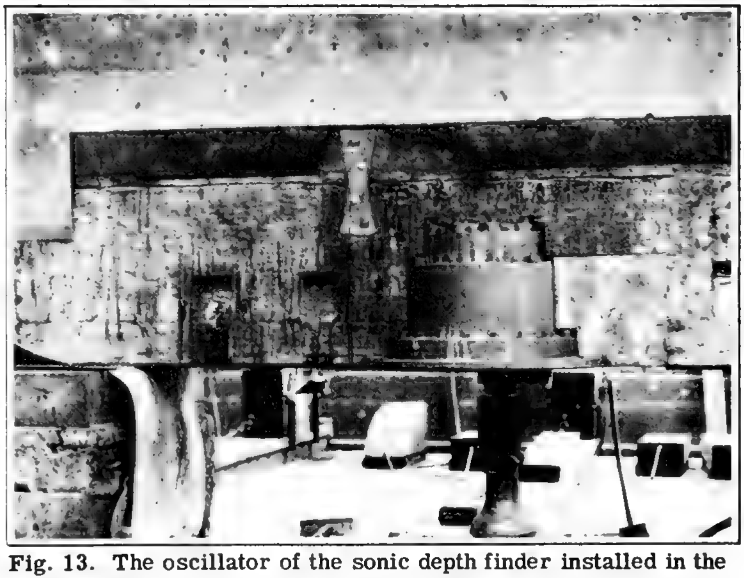


Fig. 13. The oscillator of the sonic depth finder installed in the keel. The vibration of this heavy diaphragm sends to the bottom the sound wave whose echo is picked up by the microphones

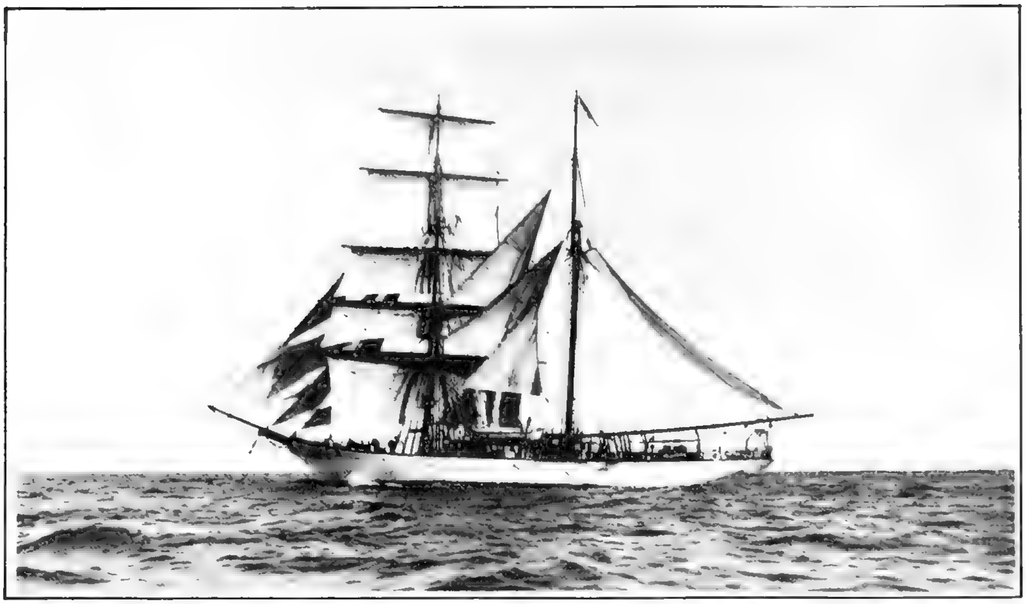


Fig. 14. The Carnegie under a full spread of canvas in the Pacific

Fig. 15. Declination observations with the marine collimating compass

Fig. 16. Scott at the "deflector." An instrument to measure the strength of the earth's magnetic field in different parts of the world

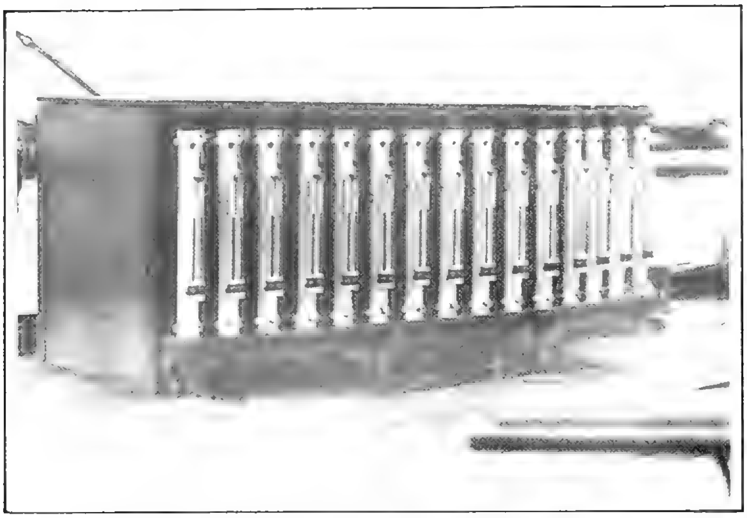


Fig. 17. Nansen water bottles, rack and storage box, on quarterdeck

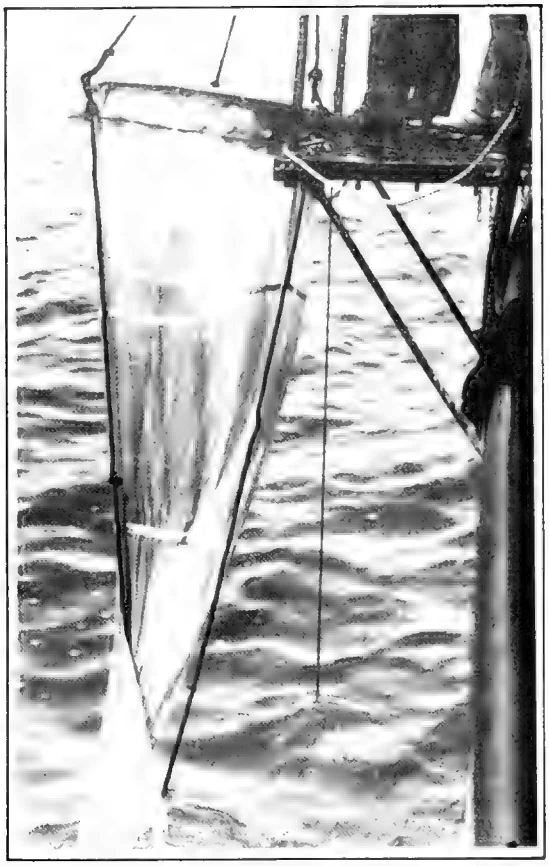


Fig. 18. A silk plankton net coming up after being towed. Used to collect the microscopic forms of life floating in the ocean

Fig. 19. Seiwell at work in the chemical laboratory. Analyses were made for many substances, like phosphates and oxygen, which are concerned in the life of the plankton

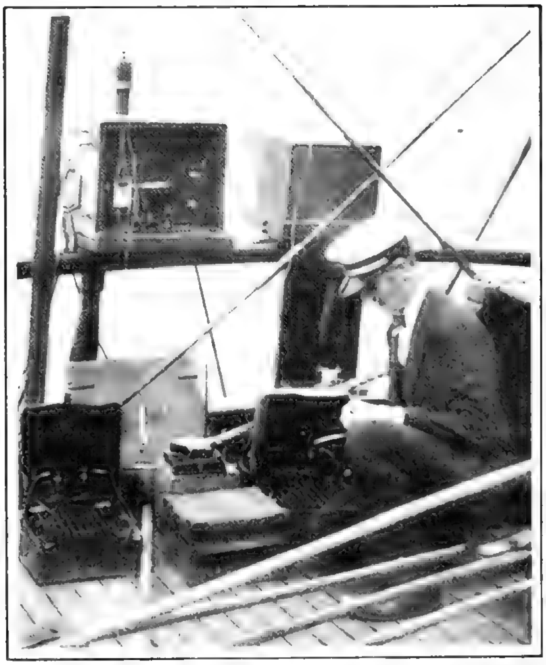


Fig. 20. Parkinson testing the potential gradient recorder. This instrument measures the potential gradient of the atmosphere

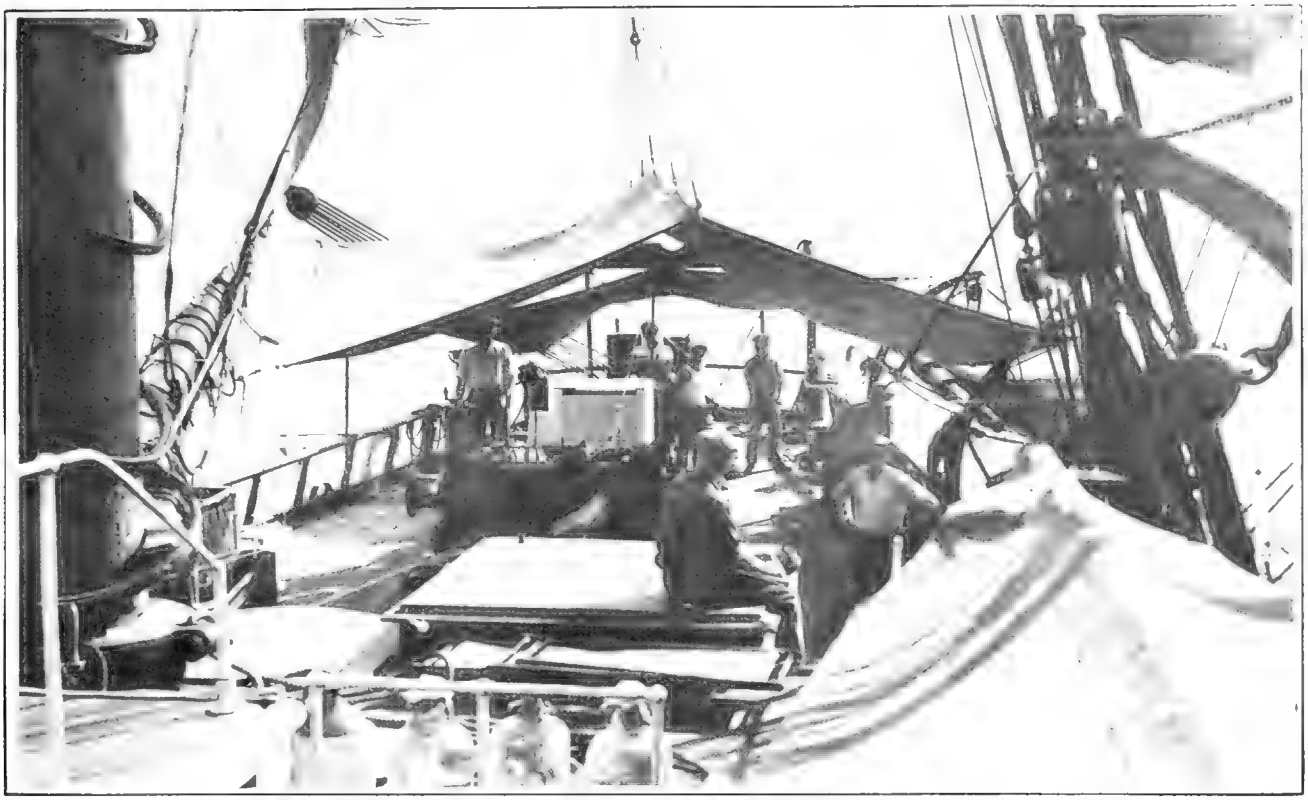


Fig. 21. Quarter-deck of the Carnegie during an oceanographic station when the ship is hove to and the instruments are lowered into the sea to collect samples of the bottom and to take temperatures and sea water for analysis

Fig. 22. Captain Ault about to remove a "Nansen bottle" which contains a sample of sea water obtained from the deep. The thermometers attached to the bottle give the temperature at the level at which the bottle was reversed

Fig. 23. Paul and Soule preparing bottles for the water samples. These samples are collected in the depths of the sea to be analyzed later in the chemical laboratory

Fig. 24. Withdrawing samples of sea water for chemical analysis. Such specimens were obtained down to a depth of three miles at some stations

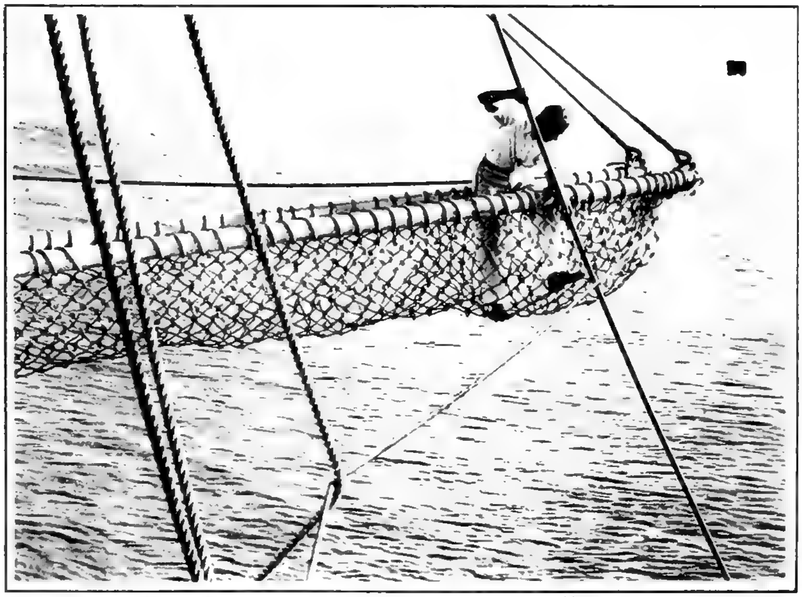


Fig. 25. The biologist using a dip net from the "boom walk." The boom walk consists of two thirty-foot booms with a net between and enables the observer to collect specimens beyond the disturbance caused by the ship's wash

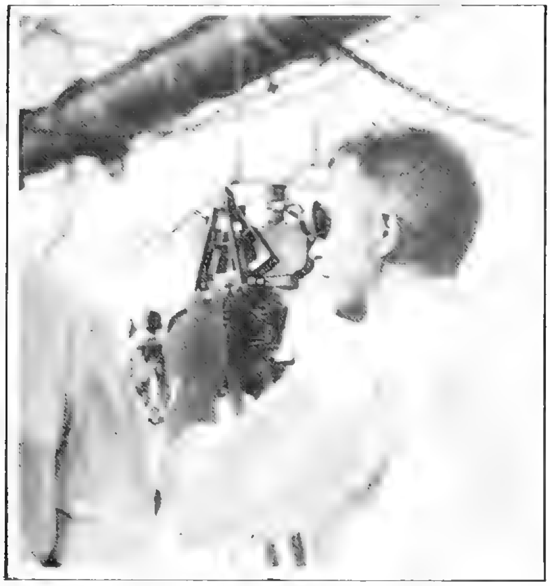


Fig. 26. Torreson observing a pilot balloon with the specially designed theodolite loaned by the United States Navy

Fig. 27. Weighing the hydrogen-filled balloon. This is followed in ascent to a height of from two to seven miles in order to plot the air currents

Fig. 28. Captain Ault releasing a pilot balloon. These globes ascend at the rate of about six hundred feet a minute and are wafted here and there by the winds they encounter in the upper air

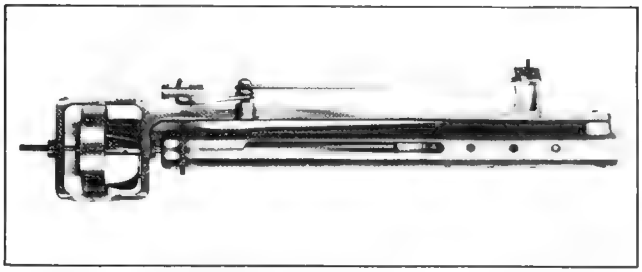


Fig. 29. A propeller device for reversing deep-sea thermometers. This is attached to the bottom-sampling wire, and when the sampler is hauled in, the propeller turns and releases the pin which holds the thermometers upright as they plunge to the bottom. Temperatures of the ocean bottom have been measured only rarely, although they are of great interest to oceanographers

Fig. 30. Captain Ault, Torreson, and Scott following the pilot balloon

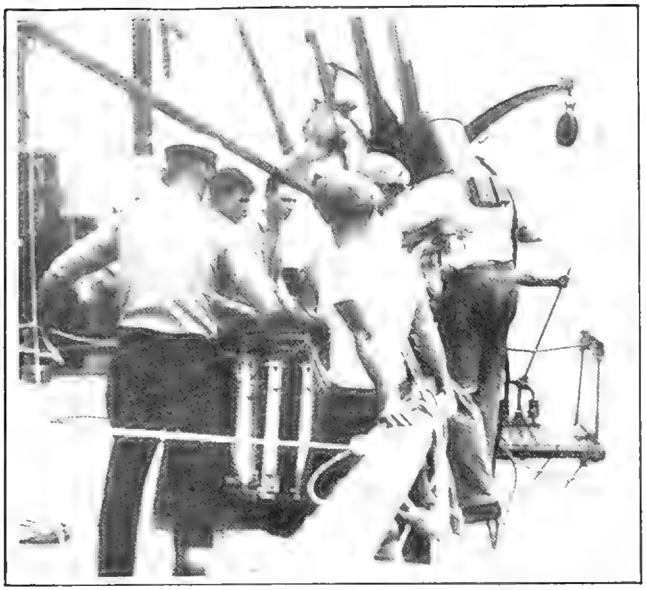


Fig. 31. Captain Ault about to descend in the diving helmet to untangle the sounding wires which had fouled the oscillator in the keel during an oceanographic station

Fig. 32. The scientific personnel of the Carnegie on leaving San Francisco in September 1929. Front row, left to right: Parkinson, Captain Ault, Soule; back row, left to right, Forbush, Seaton, Scott, Graham, and Paul

Fig. 33. Pendulum apparatus installed in the cabin for measuring the force of gravity

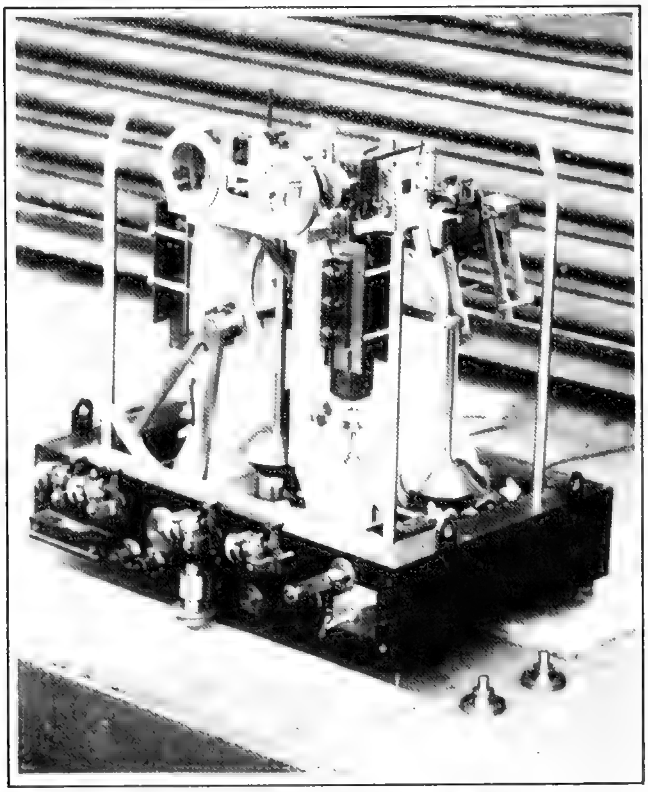


Fig. 34. The pendulums of the Vening Meinesz gravity apparatus. Installed on the Carnegie at San Francisco to obtain measurements of the force of gravity in different parts of the world, which are of great interest to geophysicists in their study of the earth's crust. These pendulums are made of "invar," an alloy which does not contract or expand with changes in temperature

WORK OF THE CARNEGIE AND SUGGESTIONS FOR FUTURE SCIENTIFIC CRUISES

II

NARRATIVE OF THE CRUISE

CONTENTS

NARRATIVE OF THE CRUISE
FROM "THE LAST CRUISE OF THE CARNEGIE"

INSTRUMENTS

While docked in San Francisco after our first year at sea, a celebration was held aboard the Carnegie commemorating the twenty-fifth anniversary of the Department of Terrestrial Magnetism. Following the ceremonies, the vessel was open for public inspection for a period of several days. The popular interest shown in the ship and its scientific equipment was keen--three thousand visitors having made the rounds in two days. This experience suggests that the reader of the present volume may also find of interest such a conducted tour. It certainly will give a more concrete idea of what we set out to accomplish.

Coming on the quarter-deck from the pier, one's attention is drawn to the shiny three-ton bronze winch and its two reels of aluminum-bronze wire. With this electrically driven "gold hoist," as the sailors call it, deep-sea soundings can be made, water samples collected, and temperatures taken down to a depth of three or four miles. From the winch the wires lead through blocks, over meter wheels to davits overhanging the water. One of the winch heads was cut down to hold steel piano wire which was used later in the cruise for collecting samples of the bottom, and for getting temperatures at depths greater than could be reached with the bronze cable. Although this steel wire was very long, it weighed little, and was so far removed from the magnetic instruments as to have no observable effect on them. The drums and heads of the winch were ingeniously constructed to work independently, so that to save time several operations might be under way simultaneously: for example, paying out on the bottle wire, and hauling in on the bottom sample. Aluminum-bronze wire previously had been used by the German Atlantic expedition of the Meteor, on which it had been shown superior to any other cable for deep-sea purposes and fitted in admirably with our nonmagnetic requirements.

Mounted over an outboard platform near the winch is the "plankton pump." This apparatus is lowered to various depths to count the number of miscroscopic animals and plants existing at each water level. Owing to an insufficiency of power, our biological work was limited to the study of these minute, drifting organisms found everywhere in the oceans. A small conical net made of very fine-meshed silk bolting-cloth, such as millers use in sifting flour, is attached to the end of the bronze cylinder. A pump actuated by a falling lead weight forces a measured volume of sea water through the net. One has only to lower the apparatus to the desired depth, drop a brass "messenger" down the wire to release the catch on the pump, and gravity does the rest. The cylinder is closed while being lowered and raised. This avoids contamination of the desired sample by plankton living in the upper layers of the water.

From this description, the plankton pump seems to be a clever little mechanism which does its appointed task uncomplainingly. But of all the pieces of machinery aboard, this one required the greatest display of ingenuity and the most severe strain on one's good humor, to keep it in operation. Wires and valves, rubber bands and springs, weights and releasing forks--all had an abominable habit of getting tangled up once the mechanism was safely hidden from view in the waters under the vessel. It was a rare day when three consecutive hauls were successful. Nevertheless with its aid we were able to make a census of the sea's population in various regions and at the various depths--a valuable contribution to our knowledge of life in the ocean. The pump was designed by Dr. Petterssen of Norway, and had been tested off the coast of that country by Dr. Sverdrup, a Research Associate of the Carnegie Institution.

Immediately inboard from the plankton pump platform is a large "gear box" filled with oceanographic instruments. Standing on the outside in ranks, like well-drilled veterans, are the reversing water-sampling bottles, designed by the late explorer Nansen. These remarkable brass cylinders may be attached in series to the bronze wire, lowered to the desired depths, and the first bottle reversed by sliding a brass messenger down the cable from the ship. Each bottle has a messenger hanging at its lower end, so that when the first bottle reverses end-over-end, its messenger is released and slides down the wire to upset the next, and this continues with all the bottles. The two valves at the ends of each bottle close automatically when reversal takes place, imprisoning about a quart of water, to be analyzed by the chemist in the laboratory on deck. To each of these bottles is attached a small frame containing the all-important deep-sea reversing pressure thermometers.

Inside the gear box are several types of "bottom samplers." Some consist of brass tubes surrounded with lead weights which fall off after the apparatus plunges into the ocean floor. Others operate like a clamshell or turtle's jaws, snapping up a sample of bottom deposit. A third kind is a long, glass-lined metal tube with a heavy weight permanently attached to it, which procures a vertical section of the mud or ooze, showing the successive layers in which it has been deposited. But the sampler most commonly used is a modification of the telegraph "snapper" of the clamshell type. Like the plankton pump, this mechanism required considerable nursing, and even some surgical operations as time went on.

On the basis of these samples, a study of the nature and origin of marine bottom deposits will be made ashore. This collection will prove of great interest, because of the scarcity of material, especially from the Pacific. Workers in the Geophysical Laboratory of the Carnegie Institution of Washington are interested in the chemical analyses. From the amount of radioactive material found in them, thorium and radium, they hope to get some idea of the age of the earth. Scientists studying the origin of oil deposits will be furnished samples. The American Telephone and Telegraph Company wish to determine the corrosive effects on their cables. Then too, it is now known that bottom-living creatures feed on organic matter found in muds.

In the gear box is kept the brass bucket for collecting diatoms from the harbors we visit. These exquisite microscopic plants, displaying inexhaustible patterns of form, are present in all the waters of the earth from pole to pole. They are almost the sole food for the larval stages of fish, and therefore are of immense importance. Some of the largest marine creatures use these tiny plants as food. So minute are they that a hundred of them might be placed side by side on the head of a common pin. The harvest of fish has been increased noticeably by adding silicates and phosphates to the water to augment the supply of diatoms, just as nitrates and phosphates are used in agriculture. The work on board was planned to include a study of the relation of these chemicals to the abundance of diatoms and plankton. In fact, the source of silica in the surface layers of the ocean, where the diatoms thrive, is not well known, for the great red-clay silica deposits are sometimes several miles below and seem to be increasing in extent.

In higher latitudes the diatoms show great changes in abundance with change of season, for they are plants and depend directly on sunlight as their source of energy. It is for this reason that they are found in a living state only in the uppermost few hundred meters of the sea, and on the bottom of shallow waters near shore. It is not always realized that sunlight is totally absorbed in the clearest sea water in less than a mile from the surface.

Leaving the gear box we walk aft to the Stevenson meteorological shelter, which gets its name from its designer, the father of Robert Louis Stevenson. Here are housed some of the various instruments used in studying the circulation of the atmosphere, just as the oceanographic equipment is used to give us a picture of currents in the ocean. There are three forms of apparatus for measuring the changes of humidity. One is a recording psychrometer, ventilated by a motor-driven fan, procured in England and designed to give a continuous record of "wet-" and "dry-" bulb temperatures. From this record is calculated the degree of saturation of the air by water vapor. Another is one unit of an electrical-resistance psychrometer, which measures the humidity at three heights over the ocean--on deck, at the main crosstrees, and at the masthead. In the control room, which we shall visit later, is the automatic recorder for these three pairs of electric thermometers which registers at intervals of thirty seconds the six wet- and dry-bulb temperatures in consecutive order. The third is of German make, and has very accurate thermometers. It is ventilated by clockwork, and is read directly by the eye of the observer. This is used daily to check the accuracy of the other two.

In the shelter is also kept the little instrument for measuring wind velocity--the anemometer--as well as the standard sea-surface thermometer and other meteorological equipment.

Walking aft a few feet, we stand at the steering gear of the ship. There is no cozy wheelhouse on the bridge for the quartermaster of a sailing ship. He must stand at the very stern, with an unobstructed view of the sails. When sailing "by the wind" his eye is glued to the weather side of the uppermost sail; he keeps it drawing a trace of wind, but never lets it fill. It is true that the Carnegie had a "bridge," but this was used only by the pilot when entering or leaving port, and by the lookout during the night.

The steering gear itself is a constant source of interest to visitors, for it is one of the many features of the old-time windjammer to be found on the Carnegie. The whole mechanism is operated by hand; a whirl of the wheel to starboard brings the helm to port and turns the ship itself to starboard. The old-fashioned method of giving orders to the steersman, called "port" or "starboard," almost wrecked us one day in Samoa, when a shore pilot in a tight place overlooked the fact that we did not use the modern code in which the order refers to the ship's head and not to the helm. The binnacle, which stands before the man at the wheel, is also a carry-over from bygone days, for the compass reads in "points" and not degrees. As each man finishes his two-hour trick at the wheel, he calls out to his reliever: "east by south half south," and not "107 degrees."

On one side of the wheel, mounted near the rail, stands the rain gage; and on the other, the evaporimeter. The latter is made of glass, and is used to measure the rate of evaporation of sea water from day to day. This subject is part of the general investigations made of the influence on climate of movements of large bodies of warm or cold water. We wished to study the transfer of heat between the sea and the atmosphere; and the evaporimeter, together with the electric-resistance thermometers, gives us much needed information.

On the taffrail around the stern is the automatic recorder for the potential gradient of the atmosphere's electricity. The negative charge on the earth's surface causes an electric pressure in the air increasing with height above the earth's surface. Ordinarily this rate of increase or gradient is in the neighborhood of one hundred volts per meter near sea level. There are daily variations, aside from the local changes due to disturbances in the atmosphere near the ship. The chief of these is a mysterious surge in the potential gradient which occurs simultaneously over the whole earth. It was discovered after examining observations obtained on previous cruises of the Carnegie, and our aim now was to collect records from widely separated geographical regions to confirm this. Any attempt to discover the cause for the earth's permanent negative charge must be based on a knowledge of potential gradient.

This automatic recorder gives us traces at about tenfold the rate possible with the eye-reading apparatus used on former voyages. It is also very sensitive to changes in the electric conditions of the air, because ionium collectors are used. Ionium is an element which has the property of giving "air molecules" in its neighborhood an electric charge, thus turning them into "ions." These ions, acting as carriers, facilitate the transfer of electricity from the air to the instrument, and eliminate any lag during rapidly changing conditions.

We shall now walk forward on the port side of the quarter-deck past the jaunty little dinghy hanging in its davits. The control room built alongside the companionway contains many essential parts of our equipment. The time-measuring device for the sonic depth finder with its control panel is located here. This electric sounding device, loaned by the United States Navy, is made up of three important units--the oscillator, the microphones, and the timing mechanism. The oscillator, a large steel diaphragm set face downwards in the keel of the ship near the stern, is put into periodic vibration by electromagnets and produces a sound wave which is reflected from the ocean bottom. The echo is picked up by microphones set in the vessel's hull, and carried to the headphones of the observer, who sits at the control panel. An accurate time-measuring device gives us the exact time interval between outgoing signal and returning echo. With this information we can easily calculate the depth, for the velocity of sound in sea water is known. It is roughly one mile a second, depending, however, on the temperature and salinity. But as these factors for each water level are determined on board, we are able to sound with an unusual degree of precision. For example, the observer reports that it took two seconds for the echo to return. This means that the sound wave traveled about two miles, and the sea is one mile deep. This is the underlying principle, although actually the procedure is somewhat more complicated.

The great advantage of this method is that the ship need not heave to and consume one or two hours for a sounding with line and lead. A sonic depth may be made with the ship on her course in from five to ten minutes. We are able to check these soundings by the old-fashioned lead weight, and do so on alternate days.

In the large box on the floor are our pressure thermometers. With these we have an ingenious method for checking the depths recorded sonically and by wire. Besides this, the marvelous instruments can tell us precisely at what distance from the surface each of the "Nansen bottles" was reversed.

These German-made thermometers are of two types. Some are protected from the enormous pressures encountered in the deeps, and give the true temperature. Others are unprotected, and give a fictitious reading: the sum of the true temperature and the effect of the pressure exerted mechanically on the naked bulb by the weight of the column of water above it. The difference between the readings of such a pair is then a measure of the pressure. By rather complicated calculations we may then convert this to meters of depth.

The thermometers are sent down, inverted, in their frames on the side of the Nansen bottles. They are given time to assume the temperature of the surrounding water and are then reversed along with the bottle, when the messenger comes down the wire from the surface. This reversal breaks the thread of mercury in the tiny capillaries in such a way that the changes in temperature and pressure encountered on the way back to the surface will not be registered, and the observer on deck can get a true picture of conditions at the desired depth.

By the use of these readings and the salinity values for each sample, we are able to calculate "dynamic pressures" for each water level to the bottom. Plotting the figures on a chart we can determine the speed and direction of the ocean currents below the ship--a subject of great importance to oceanography. These charts are made in much the same way as weather maps prepared by the Weather Bureau--based as they are on pressure readings taken at a multitude of stations, from which winds can be predicted.

There are more direct means for measuring ocean currents. We may trace the course, speed, and direction of floating objects. This is not satisfactory, for only the surface current is represented, and the effect of changing winds on the object may confuse the true picture. A more useful method is to lower from an anchored ship an instrument similar to an anemometer. We had insufficient power for hauling in a deep-sea anchor, and so we relied entirely on the "dynamic-pressure" computations.

The configuration of the ocean floor is of great interest to seismologists studying the movements of the earth's crust. Oceanographers also are able to explain certain peculiarities of ocean currents by the contour of the ocean bed. But enormous areas are still unexplored.

On the wall of the control room hangs the German multithermograph which was referred to when we looked into the Stevenson meteorological shelter. Below it is an inflation-balance for use in connection with soundings of the upper atmosphere. Rubber balloons filled with hydrogen are released from the deck. These extremely light globes are deflected from their upward course by every breath of air they meet. By following them with a theodolite, an instrument for measuring elevation and direction through vertical and horizontal angles, we can study the air currents at heights up to six or seven miles. Besides the general scientific interest in the movements of the earth's atmosphere, the aviator some day will come to rely on pilot charts based on these soundings, just as the mariner relies on wind and current charts for the ocean surface.

Before leaving the control room we must glance at the long array of switches, galvanometers, batteries, and ammeters stretched along a table against the starboard wall. Although it is part of the equipment for measuring the elements of the earth's magnetic field, some of this apparatus contains small pieces of steel, and must be set up well away from the observatory domes. One observer sits at this table to control the constant-speed motor for the "marine earth inductor" which we shall see later. He is in communication through a brass speaking tube with the second observer in the dome. At given signals he records the readings of the ammeters or galvanometers before him.

In the control room we also find the Sperry gyroscopic pitch-and-roll recorder. Magnetic measurements at sea usually are affected by small errors caused by rolling, pitching, and scending of the vessel. Though small, these errors are important where accurate determinations are desired of progressive changes in the earth's magnetism and of their distribution--as on the Carnegie. A study based on records from this instrument has shown that when the vessel heads on any one of the four cardinal points of the compass, no error is introduced into the measurements. A record of the rolling and pitching of the ship during magnetic stations can be studied later at headquarters to detect these disturbing effects.

We have spent a long time in the cramped quarters of this little room, but one can see that in it lies the central nervous system of the magnetic and oceanographic equipment. A few steps down and we have left the quarter-deck. Standing in the waist of the ship we see curious nets hanging from the whale-boat platforms. These long cones of silk bolting-cloth are used to collect plankton. They are towed from the ship during oceanographic stations, and may be lowered to any depth desired.

It is true that the lack of fishing and dredging equipment deprived us of the excitement of bringing up fantastically shaped monsters from the deep. But in the plankton nets we can catch a hundred bizarre forms to every one recovered from a dredge; we can find animals painted with all the colors of the rainbow, whereas the deep-sea organisms are either black or red. Anyone who has once seen these exquisite creatures through a microscope will never again envy the man with a deep-sea dredge.

Two parallel booms supporting a net between them project over the water from the fore rigging--a glorified pirates' plank, as someone has suggested. This boom was similar to that used on Beebe's expedition. On calm days it may be lowered for the use of the biologist, who is thus able to dip up floating objects beyond the wash of the vessel.

A step over the high doorsill and we are in the chemical laboratory. Here each water sample is analyzed for salinity, phosphates, silicates, oxygen, and hydrogen ions. All these substances are intimately related to the life of plankton. We limit ourselves to such determinations as can be made on board, for we have no room to stow away samples for study ashore.

There are several unusual features about our chemical work. The salt content of the sea water is measured electrically by a resistance-bridge designed for our use by Dr. Wenner of the Bureau of Standards in Washington. By measuring the electrical resistance of a sample of sea water, we are able to calculate its salinity. This method is checked regularly by the conventional titration of samples with silver-nitrate solutions.

The apparatus for measuring the so-called "hydrogen-ion concentration" of sea water at various depths is ingenious. It avoids the use of permanent color standards in test tubes, and gives more accurate readings than are ordinarily obtained at sea. It is a modification of the double-wedge comparator described in technical journals by Barnett and Barnett.

To analyze for phosphates and silicates, chemicals are added to the specimen to bring about the development of a certain color, the intensity of which is a measure of the phosphate or silicate present. After treating with the same chemicals a second solution (whose composition is known) we have only to match the intensity of one color against the other to obtain a value for the unknown sample. The presence of as little as one part of phosphate per billion parts of water can be detected in this way.

When the reports of the oceanographer, the chemist, and the biologist are correlated, we have a good picture of the life of plankton. We can see what limits of temperature and salinity they tolerate; what substances they need for food; and what influence variations in sunlight, oxygen, and acidity have on their growth.

The usual equipment of a chemical laboratory is more familiar and will be passed by. But there are, besides this, microscopes, dissecting instruments, and preservatives for the use of the biologist.

Over in the corner of the room is a self-recording sea-water thermograph. This device keeps a continuous record of the changes in surface temperature as we sail down the latitudes. A large bulb of mercury is mounted on the outside of the vessel's hull. It communicates with the recorder through a capillary tube. Any changes in the volume of the mercury in the system, due to changes in sea temperature, are transmitted through a hollow coil spring to a recording pen.

A short walk forward, a few steps up, and we are on the "bridge." From here we can look upward at the lofty rigging, more bewildering in detail than many of our instruments. Or, we may look toward the forecastlehead and see, coiled on the deck, the two great hawsers which serve us for anchor chains. But a weird object, suggesting an automaton in a brass helmet, stands at the center of the bridge, challenging attention. This is the "marine collimating compass." It gives the magnetic declination, or "compass variation" as sailors call it.

The principles on which it operates are simple enough. We wish to find the angular difference between true geographic north and the magnetic north as indicated by the compass. We can use the sun as our point of reference, since we know its true bearing from the ship by using the Nautical Almanac. In the collimating compass, the card ordinarily viewed from above is replaced by a set of vertical scales which may be seen by looking horizontally through openings in the sides of the compass bowl. An observer brings the image of the rising sun, let us say, to one of these vertical scales with an ordinary sextant and measures the horizontal angle between them. With the sun's image on the vertical scale he can make continuous readings of its position, as the compass swings back and forth with the roll of the ship. By taking the mean of many such readings, he has made an accurate measurement from which the declination may be computed.

This instrument was designed by Peters and Fleming of the Department of Terrestrial Magnetism, and was made in its shop. The method is superior to older methods used at sea which depended on hasty readings taken as the sun's image, or a shadow, flits across a moving compass card on a rolling ship. Three observers are required to take a declination measurement. One man's duty has been described. A second reads the altitude of the sun from time to time, for it seldom happens that weather conditions are perfect exactly at sunrise or sunset, and corrections for altitude must be applied. The third observer is the recorder. He must be a sleight of hand artist, because he has to write down the readings of the other two and keep a second-to-second record of the time when each of these is made.

On the starboard wing of the bridge is located an apparatus for collecting the radioactive materials in the atmosphere, which are present in only infinitesimal amounts. When a measured volume of air is drawn through the collector over negatively charged metal foil, the desired particles are deposited on the foil because they carry a positive charge. Let us now follow the observer into the atmospheric-electric laboratory, where he will measure the amount of radioactive material collected. This electric laboratory is located just abaft the bridge, directly amidships. It is entered from the foot of the steps leading to the bridge. The observer places the metal foil in an ionization chamber where the rate at which the radioactive material produces electrified particles or ions is measured. This rate gives a measure of the amount of radioactive material collected.

Another instrument counts the ions normally present in the atmosphere, by extracting them from a measured volume of air. Over the oceans there are usually about 30,000 of these per cubic inch, half with positive charge and half with negative. Under the action of the earth's electric field, positive ions are traveling toward the earth and negative ions upward into the air, giving rise to an air-earth electric current which makes no impression on our senses. The rate at which this interchange takes place would neutralize the earth's negative charge in a very short time, were there no recharging agent. Up to the present, however, the mechanism which generates the recharging current has not been established, and remains a major problem in studies of the electricity of the earth and atmosphere.

Penetrating radiation, or "cosmic rays," long have been known to ionize the air. These exceedingly powerful rays can penetrate several feet of lead, and seem to originate entirely outside our solar system. An apparatus carried on board measures the amount of this energy received by the earth. Over the oceans this accounts for most of the ionization of the atmosphere.

Intimately connected with the number of ions in the air is its electrical conductivity, or its ability to carry an electric current. It is measured in this laboratory with an automatic photographic recorder. A stream of air is drawn through a duct past a cylinder at its center. The ions in the air cause a current of one millionth of a millionth of an ampere to pass through the air between the duct and cylinder, and a delicate electrometer measures this current as the air's conductivity.

The air over the sea is much more free of dust than over land, but the influence of this pollution on the elements of atmospheric electricity is so great that systematic "dust counts" must be made even far from land. Some years ago, when the volcano Krakotoa erupted, such quantities of dust were blown into the atmosphere that it took two years for it to settle over the earth. Even in normal years pollution may vary from 1,000,000 particles per cubic inch to a few thousand. When dust is abundant, the atmospheric conductivity is decreased and the potential gradient rises to as much as 300 volts per meter. The Aitken counter is used to determine the pollution of the atmosphere. When moist air is suddenly expanded, the water present condenses as droplets, provided some dust particles are present to act as centers of condensation. In the Aitken counter, the droplets so formed are enumerated and not the dust particles themselves. Other materials besides dust act as centers in the counter, for it is believed that such particles as salt spicules, and even aggregates of water or ammonia molecules, may act as condensation centers.

In the chart room under the bridge is the navigational equipment including sextants (sixteen of them), barometers, log books, marine charts, and pilot books. There are six desks where the observers do their computing. Complete sets of graphs, tables, and calculating books are at hand to facilitate the work. These desks are always filled except when a magnetic or oceanographic station is being occupied; for a large part of our duties consist in preparation of records. Large windows supply plenty of air and light to the men at work.

In the center of the chart room stands the "standard compass," which furnishes a correct reading for magnetic north. The "earth inductor" in the forward dome, and the "deflector" in the after observatory, both use this compass for standard magnetic readings.

Visitors have often expressed surprise that such a well-equipped vessel had no gyroscopic compass, or "metal mike," as it is referred to by sailors. The apparatus may be employed to actuate an auxiliary device, which is fast becoming standard equipment on ocean liners, and steers the ship automatically on any desired heading. But on a sailing ship the course must be constantly changed to take advantage of wind and squalls. The gyroscope would have required precious power for operation, and would have introduced magnetic materials on board. For these reasons it was out of the question. Besides this, we were seldom trying to make a beeline from one port to another.

We shall now climb into the forward observatory dome to inspect the marine earth inductor. It determines the "dip" of the magnetic needle, or inclination. It is essentially a rotating coil of wire which is connected to current or potential meters in the control room. Any coil rotating in a magnetic field, with its axis perpendicular to the lines of force, will generate a current in the circuit in which it is placed. It is on this principle that ordinary dynamos operate, except that they use either permanent magnets or electromagnets, whereas we use the feeble magnetic field of the earth.

If we move the coil around to such a position that its rotation axis is parallel to the lines of force (pointing exactly to the magnetic pole), no current will be generated. This is true because the magnetic field is being cut so that the effect of one half of the coil exactly neutralizes the effect of the other. So when the observer in the control room signals that no current is being produced, the man in the dome reads off the angle of inclination. In actual practice the procedure is somewhat more complicated than this.

In the after dome is the "deflector" which gives us the strength of the magnetic field acting on the compass needle. Briefly, we balance the effect on the compass of a small magnet of known strength against the effect of the earth's magnetism. In other words, we find how far a measured artificial magnetic field deflects the compass from its normal position.

Modern magnetic charts of all oceans are based largely on the work of the Carnegie. So promptly are our observations computed and forwarded to the world's hydrographers, that the "Variation Chart for 1930," published in October 1929, by the United States Navy, included our measurements through September. These charts are used, of course, by air pilots as well as by mariners.

The cabin on the Carnegie occupies the space ordinarily used for cargo on a sailing ship. It can be entered by companionways from the quarter-deck or from the chart room. Although there are no portholes, because the room is below the water line, good ventilation and light are afforded by several large skylights. Everything possible was done to make our living quarters comfortable. Each observer has his own stateroom, a wise provision, because the working hours for some of the men are very irregular. Each one may decorate his room in his own way, and can secure a semblance of privacy.

In the cabin is the ship's library. There are books of reference, technical handbooks, general literature and an extraordinary collection of books of polar exploration and oceanography. In addition, each man has ample space in his stateroom for his personal choice of reading.

There is a splendid phonograph with a good assortment of records, bought chiefly by the observers themselves. A card table near the library occasionally is swept clear of typewriters and account books for a game of bridge or poker. Photograph albums and a highly prized guest book lie in a corner of the bookshelf. This register contains many famous names from every corner of the earth, and was one of the two books rescued from the flames in Samoa.

The center of the room is taken up by our dining table. Around this are eight ordinary cane-bottomed bentwood chairs, with brass screws instead of iron ones. They are not fixed to the floor as in most vessels. This little detail does much to disguise the fact that we are cooped up in a ship. Anyone who has travelled in an ordinary steamer will know how uncomfortable the usual swivel chair can be--made as it is to accomodate the fattest passenger. Only on the very rough days is it necessary to brace ourselves at the table.

But even the cabin cannot be kept free of scientific apparatus. Our chronometers lie in a row on green cushions under the bookshelves, with time-signal headgear hanging above them. The constant-speed motor is here, with its shaft running forward to the earth inductor. A barograph gives us a continuous record of changes in atmospheric pressure. And wedged between the dining table and the bookshelves is the complicated pendulum apparatus for measuring the force of gravity at sea.

This no doubt is the most delicate device on board. It has long been known that, in general, gravitational attraction varies with latitude, but certain irregularities which occur in the force of gravity over the face of the earth still await explanation. Many determinations have been made on land, but only recently have successful attempts been made to measure the mysterious force at sea. Dr. Vening Meinesz of Holland, who designed this instrument, used it on a circumnavigation cruise in a submarine; and the United States Navy also loaned a similar vessel for this purpose. A subsurface ship is free from the disturbing motion of the waves, and is much better suited to these studies than the Carnegie, although it was hoped that with smooth seas useful results might be obtained, even on a surface vessel.

Below the cabin and under the staterooms are water tanks, specimen bottles, preservatives, tents, a diving helmet, and a general assortment of ship's gear. The wooden water tanks keep our fresh water very sweet even on such long stretches as from Panama to Callao, some three months at sea. The supply is carefully rationed, and a reserve tank always kept for emergencies. Each receives about two quarts of fresh water daily for washing hands and face, and the steward issues all that is needed for the galleys. Every man is entitled to a full bucket once a week for washing clothes, or for a fresh-water bath. On the shorter trips there is an abundance for all hands, but when rationing is strict we rely on rain squalls.

The galley for the staff mess lies just abaft the cabin. It is always the center of attraction for feminine visitors, for they all wish to see what a nonmagnetic kitchen looks like. The kerosene stove is bronze, and all kettles and pans are either of copper or aluminum. On earlier cruises the cook's knives and the table cutlery were placed in the lazarette during magnetic observations; later it was found that this small amount of magnetic material did not have any effect on the instruments situated in the domes. A small electric refrigerator is set back in a recess from the after galley. It serves to keep us in fresh food for only about a week after leaving port. Still, it is good to have cool water to drink for the remainder of the trip.

We now walk past the "office" on the opposite side of the companionway. Files of scientific records, correspondence, and accounts line the walls and smother the desk. There are also comptometers, typewriters, drafting instruments, and cupboards filled with blank forms for the observations. The bathroom is situated abaft the office. A great porcelain tub filling half the room serves chiefly as a place to drain rain-soaked clothes, since we all prefer to take salt-water baths from a shower on deck.

Those who are interested in machinery might go up to the quarter-deck and descend through the hatch to the engine room. The main engine is cast of bronze. It originally operated on gas produced from coal, but later was adapted to the use of gasoline for fuel. In fact, the Carnegie was the first ocean vessel equipped with a "gas-producer." It could take the ship 144 miles a day without the use of sails, on seven dollars worth of coal.

A small auxiliary gasoline engine connected to an electric generator furnishes power for our oceanographic and magnetic operations, as well as for radio, lighting, sounding, and recording instruments. Large storage batteries are provided, since the demand for electric current is very heavy for such a small vessel. As a matter of fact, a considerable part of the gasoline fuel we carry is devoted to electric requirements.

Switch panels for the sonic depth finder, radio generator, and bronze winch, line the walls. A machine shop, containing a lathe, leads off to one side while the photographic darkroom is wedged in between the gasoline tanks and the battery recess. A sail locker and storage space for spare instrumental equipment also are accessible from the engine room.

It is always a relief to leave the engine room, for it is infernally hot. We ascend to the quarter-deck, step down into the waist of the ship on the port side, and enter the radio cabin. A short-wave experimental receiving set, built for us by the United States Naval Research Laboratory, brings us time signals, weather reports, and news from home. Our transmitter is powerful enough to keep us in communication with the United States almost every day, through the cooperation of amateurs. Special apparatus for making investigations of radio signal-strength is set up on the workbenches. The equipment is very complete, because the radio operator has a unique opportunity for studying radio conditions at sea; he can correlate variations of signal-intensity with magnetic and atmospheric-electric changes. Regular short-wave schedules give us information about radio "skip-distances" over the oceans.

The American Radio Relay League with headquarters in Hartford recommended our first operator, Mr. Jones, and cooperated with us throughout the whole voyage. The value to us cannot be exaggerated of the services rendered by hundreds of amateurs throughout the world.

THE CRUISE

On May 1, 1928, the seventh cruise of the Carnegie began. Whistles roared from the harbor craft, and pleasure boats jockeyed for position to escort us down the Potomac. At midnight we reached the mouth of the St. Mary's River in Chesapeake Bay, and anchored till dawn. We were to spend four busy days here, "swinging ship," to be sure that our magnetic instruments and standard compass were not influenced by the new oceanographic equipment. A magnetic station had been set up on shore where simultaneous magnetic observations were made. To ensure ideal conditions for the land station, a magnetic survey of both sides of Chesapeake Bay had been completed a few days previously. Six "swings" of the ship on different headings were made, before everyone was satisfied that all was well.

The radio outfit was given its first trials here. Schedules were made with the Naval Research Laboratory and with headquarters of the American Radio Relay League. And throughout these four days, the atmospheric-electric instruments were being compared with similar ones ashore whose accuracy was well known.

The days spent here in the St. Mary's River had given the new observers an opportunity to become acquainted with their new duties. They now knew what a long day's work was involved in swinging ship, a procedure we were to repeat in many parts of the world. They learned the technique of intercomparison of instruments with those ashore, for in most of the ports of call this was to occupy a large part of their time--especially where there were permanent observatories like those in Germany, Peru, Samoa, and Japan.

At dusk on May 5, all hands were summoned to heave up the anchor for the short trip to Hampton Roads--our first passage under sail. A stiff, steady breeze from astern bowled us along in grand style. Although we were not carrying full sail, we had the rare satisfaction of overtaking several steam vessels.

We were anchored off Newport News by eight o'clock next morning, and were greeted at once by "bum boats," little launches which were to be our inseparable companions in every port. They offered laundry service, taxis, provisions--everything we needed, and some things we did not.

Everyone was impatient to put to sea, so it was a great disappointment that we were forced to go into drydock here. The oscillator of the sonic depth finder required some changes, and Mr. Russell of the Navy Yard in Washington had come personally to supervise the work.

On May 10 we were towed out into the Roads, and set sails, while photographers on the tug made pictures. The breeze was just sufficient to give us steerage way. We had cast off our last ties with shore, and were at last headed for the open sea. Our last sight of land was Cape Henry at sunset.

It was a real relief to settle down to our ocean routine. The hectic past months gave place to as simple a life as possible. Meal hours were so arranged that in spite of their various duties, the staff could eat together. The radio operator and atmospheric-electric observers occasionally kept irregular schedules which made this not always possible. The watch officers and the engineer had their mess in the wardroom forward; and the forecastle was served from the same galley. The deck force was separated into two watches, as is usual on a sailing ship; the men spending four hours on and four off, with two "dogwatches" of two hours each between four and eight in the evening.

Our first morning out, May 11, was chosen for the first magnetic station. The ship was now fifty miles off the coast and away from local disturbances ashore. At sunrise the officer on watch calls the observers to the bridge for the declination observation. When they are assembled the ship's course is changed, if necessary, to keep the foresail from hiding the sun. Captain Ault and Torreson make readings of the marine collimating compass; Erickson measures altitudes of the sun with his sextant; and Scott enters each reading on special forms, with a time record for each observation. From these measurements we could tell how much the "variation" of the compass had changed since former cruises.

After breakfast is over, and when time sights on the sun have been made for longitude, the observers take their places at the magnetic instruments in the domes. Soule stands at the earth inductor; Torreson sits in the control room on the quarter-deck; and Paul reads aloud the heading of the ship from the standard compass in the chart room. This allows Soule to keep the rotating coil properly oriented. As Soule places the coil in various positions, Torreson reads the ammeter or potentiometer in the control room. From here he also starts and stops the constant-speed motor which rotates the coil. These observers determine the "dip" or inclination of the earth's magnetic field.

Meanwhile, Scott is in the after dome at the deflector. He places magnets of known strength near his compass and reads off their effect on it. Jones makes simultaneous readings of the standard compass in the chart room, and records for Scott. These two men measure the strength of the earth's magnetic field.

The afternoon is occupied in calculating the values for the magnetic elements. The observers were furnished special forms for recording, and these were so printed as to make the necessary tabulations as simple as possible. The formulae used in computing appeared in these, together with space for entering data derived from tables. By using these sheets it was practically impossible to overlook essential control records, such as air temperatures and chronometer readings. It is very easy to make these omissions when the observer's attention is directed primarily to the operation of the instrument itself.

For some of us the time-keeping on board was quite confusing at first. The ship's routine was operated on Local Apparent Time, with a resetting of clocks every morning at eleven. Many records were kept on Local Mean Time, others in Greenwich Mean Time. Then there was 75th Meridian Time for certain radio schedules, while a Sidereal-Time chronometer later became part of our equipment for gravity observations. In addition, for the most accurate time-signal comparisons, an "offset chronometer" was added, that loses one second in sixty-five of mean time.

After the evening time sight and the declination observation, we noticed a change in the color of the sea. It lost its grayish-green tint and became clear blue. The sea-water thermograph had shown great variations in temperature for several hours, and now read 75° Fahrenheit. At noon it had been only 46°. We were in the Gulf Stream.

The ship had been supplied with a solarimeter, for measuring the quantity of radiation reaching the earth from the sun. We gave it a first trial on May 13, but it was apparent at once that conditions would not be favorable for using it on a sailing ship. The effects of rolling and pitching were minimized by mounting in gimbals the sensitive photoelectric cell; but the greatest difficulty was shade cast by the rigging, and back reflection from the lofty sails. After a few more trials it was found impracticable. The information it gives is used in studies of world weather. It would have made an excellent adjunct to our meteorological program, for we were concerned with heat-transfers between sea and air, and with evaporation rates in various regions.

While we had been anchored in St. Mary's River, a gyroscopic stabilizer had been installed on the earth inductor. It was hoped that this device, in addition to the gimbal mountings, might make the coil more independent of the ship's motion than the gimbals alone. But all attempts to use it had failed, because the strain when the constant-speed motor was started or stopped was too severe on the shafting. Several changes in design would be necessary before it could have been employed, and after a few more trials it was discarded for the time being.

It was always a rule on the Carnegie to analyze and put in form the scientific data collected on each leg of the cruise, for the immediate use of hydrographers and oceanographic workers ashore. This feature of our routine kept the observers occupied between observing periods at sea and for several days after reaching port.

For example, tables were drawn up showing the values of declination, horizontal intensity, and inclination, as given by the latest British, German, and American charts for the regions traversed by the ship. Against these we tabulated the measurements made on the voyage, so that errors in the charts might be corrected in future editions. Differences of as much as 1°5 in declination were discovered on the passage from Newport News, with corresponding errors in the other elements. This serves to emphasize the importance of repeated surveys of the earth's magnetism, to determine the changes constantly taking place in the distribution of this mysterious natural force.

By early September our procedure at an oceanographic station had become somewhat standardized, and it might be of interest to describe just what takes place. On the morning of September 15, we are about two hundred miles from Barbados. At eight bells the new watch comes on deck and finds everything in readiness for heaving to. The winch is uncovered, the wires are threaded through blocks to the davits, outboard-platforms are in place, and running gear is laid out on deck ready for shortening sail. With the sound of the ship's bell still in our ears, the men dash to the tackle, blocks rattle and yards creak as the squaresails are taken in. The lower topsail alone is not furled, and is set aback to check our headway. Then one after another the fore-and-aft sails come down until only the mainsail and middle staysail remain. The ship is now hove to and comes up into the wind or falls off alternately with the helm alee.

The oceanographic team consists of four members of the scientific staff (Captain Ault, Soule, Seiwell, and Paul), the mate (Erickson), the engineer (Leyer), and the watch officer with his four seamen. Practically all operations take place on the quarter-deck. Mr. Erickson immediately attaches the bottom sampler to the piano wire, drops it over the stern, and signals to Leyer to pay out on the winch. Meanwhile Captain Ault and Soule are attaching the Nansen bottles, with their reversing thermometers to the aluminum-bronze wire. As these bottles are lowered one after the other in a long series, Paul reads the meter wheel. When the desired length of wire has been paid out he signals to Leyer to apply the brake. Another bottle is attached, more wire is paid out. This goes on till some eight or ten bottles are strung on at intervals of from five to five hundred meters.

At this station we are to reach down five thousand meters, so it will be necessary to send down two bottle series. The first, or "short series" will consist of nine bottles lowered to 5, 25, 50, 75, 100, 200, 300, 400, and 500 meters respectively, while one bottle is reversed at the surface. As the greatest difference in temperature and chemical salts occurs near the surface, the intervals are fairly short there. But in the "deep series," which is sent down later, the bottles are spaced 500 meters apart. The strain on the wire would be far too great were we to lower twenty bottles at once.

During this time Seiwell has put out the plankton nets. These are lowered in series, much as the bottles, but only three are used; one goes to 100 meters, another to 50 meters, and the third to the surface. Microscopic life in the sea is chiefly concentrated near the surface because sunlight does not penetrate water very far. All animals depend on plants for food, directly or indirectly, and of course it is sunlight which is utilized as a source of energy by plants such as diatoms.

Ten minutes are allowed for the lowered Nansen bottles to take up the temperature of their surroundings. Captain Ault now slides a brass "messenger" down the wire to reverse the first bottle in the series. As each bottle tips over, its own messenger is freed to proceed to the next bottle, and so on down the line. It takes from ten to forty minutes for the messenger to reach the lowest bottle. When they are inverted in this way, the valves automatically imprison a sample of water from the desired depth. Also, the mercury capillary of the thermometer separates in such a way that the temperature of that level can be read off on deck, no matter what temperatures are encountered on the way to the surface.

It is not possible to raise the bottle series until the bottom sampler has struck. With depths like five thousand meters this may take an hour. When the signal is given that the piano wire is slack, Leyer ceases to pay out, Erickson reads the meter wheel, and Captain Ault measures the vertical angle made by the wire. From these readings the depth can be calculated. Soule has meanwhile made an echo sounding to check this value.

The winch then brings up the bottle series and bottom snapper together. The bottles are removed from the wire and placed in sheltered racks. Paul collects water samples for chemical analysis, and Soule takes specimens for salinity determinations. When this is done, the deep-sea thermometers are read and the Nansen bottles prepared for their second plunge--this time to greater depths.

While all this is going on, Seiwell or Paul has put the plankton pump into operation. This apparatus is lowered three times, to levels corresponding to the depth of the townets. A measured volume of sea water passes through a fine silk net. The number of organisms captured, divided by the number of liters of water pumped, gives the "density of population" at each level. The plankton nets are hauled in after an hour or so. The specimens collected are preserved and labelled for future study.

It now remains to bring up the deep series and collect the sediment from the bottom sampler. This done, the sails are once more set and we proceed on our way. If everything has gone well there is still an hour before lunch in which to start the chemical work. The delicate hydrogen-ion tests are made first, to avoid the possibility of changes in the samples from contamination by the air or by sunlight. The other chemical characteristics are determined after lunch, along with the salinity.

These mornings are strenuous. There are many operations going on at once. Wires lead in all directions from the winch. The sun glares on the water, making it necessary to wear dark glasses. And only careful coordination saves us from utter confusion. Each man has his appointed tasks, but is always ready to lend a hand should things go wrong for the other fellow. And it was a rare day when something did not go awry. Wires might foul below the ship. Messengers might fail to reverse the bottles; or a "jellyfish" get in the way. The piano wire might snap, or the plankton pump fail to operate. Anything might happen, without warning, to upset the regular order.

In Barbados we found ideal conditions for trying out our diving helmet, and we made two expeditions to the reefs. For several of the men it was an entirely new experience. Only a poet could imagine the beauty and romance to be found under the waters of a coral reef. And certainly only a poet could describe what we saw in this fairyland of color and form. The dinghy is anchored at the selected spot, preferably in 15 to 30 feet of water, and the observer climbs over the side with a heavy copper helmet resting on his shoulders. A hose connected to a hand pump in the boat keeps him comfortably supplied with air, and he can wander about at will on the bottom.

One is in a new universe. Everything has a soft, ethereal outline except for the fishes that come to within an inch of the observers' nose to gaze at him in wonder through the plate-glass window. They are the most brilliantly colored of living creatures. One's sense of perspective seems to have been lost. Put out your hand to brace yourself on a coral head, and you find it far out of reach. Walking itself seems ridiculous; for in the water one's buoyancy is so great that the slightest spring upwards on the toes takes one off the bottom for a slow easy flight through space. Gravity has ceased to exist. Captain Ault described what he saw in a letter from which the following words are taken: "... schools of marvellously colored fish ... forest of submarine trees waving in the water-surges ... baskets of shell ... jewel-cases of coral growth ... grottoes of blue and sapphire .. .. trees of growing coral with jewel tips ... bristling, black-spined sea-urchins ... a basket made of cocoanut-palm leaves gathered together at the top, perhaps full of treasure left by pirates ... a wonder-world not reproduced elsewhere, not even in an aquarium."

Specimens were collected by the observers. A long screw driver and a heavy brass bucket were lowered on a rope, and on a signal from below the material was hauled up to the dinghy. Although the coral sand did not promise to be very rich in diatoms, we secured several bottles full for forwarding to Washington.

In the Pacific, after October 1928, the weather was perfect for pilot-balloon flights. The new equipment, supplied by the United States Navy, worked well and observations were made daily. With strong winds we were able to follow the balloon for only fifteen to twenty minutes, but sometimes it would be visible for an hour. By tying two together we could often follow them long after a single one would have been lost to view. In this way we traced the direction and force of the wind in the atmosphere up to heights of from two to six miles.

Three men take part in a balloon flight--usually Captain Ault, Torreson, and Scott. A pure rubber balloon is inflated with hydrogen from a tank, until it is about three feet in diameter. By "weighing" it we are able to calculate its rate of ascension. The scales operate upside down, of course, for the balloon pulls the pan upwards. At a signal from Scott, the recorder, the glistening globe is released. At one-minute intervals Torreson reads the azimuth, or horizontal position of the balloon with respect to the ship's heading; and Captain Ault checks the altitude by using an ordinary sextant. It was possible, of course, for Torreson to read off both altitude and azimuth from his theodolite; but the rolling of the ship often caused him to lose track of the object, while it was still clearly visible to the sextant observer. By reading the altitude from the sextant, it was possible for Torreson to sweep the sky at that level until he had again picked up the elusive sphere.

As a result of a multitude of observations on wind and weather conditions at sea, we have today fairly accurate "pilot charts" of the ocean, for the use of mariners. Now that transoceanic flying is coming to be a serious enterprise and not merely a stunt, it is highly important that aviators have "pilot charts" as well. They must know the direction and velocity of the wind at many levels, if they are to make successful flights over the great expanse of the ocean.

The month of February was a notable one for us in that we made several important changes in our instruments and methods. Ever since our departure from Washington, an attempt had been made to use the marine earth inductor for determining the strength of the earth's magnetic field in addition to the angle of inclination. All the trials up to the present time had failed to give results as reliable as those obtained with the standard "deflector." By changing the method slightly we now were getting comparable readings.

The Carnegie has ever been on the alert for new and simpler methods for making physical measurements at sea. In fact, her contributions in this respect may be considered among the greatest of her achievements for science, because little advance can be expected until reliable and practical instruments are available.

In collecting samples of the ocean bottom we had been using a "snapper" type of collector, in which a large lead weight surrounding the shaft was made to close the jaws when bottom was struck. It often happened, however, that the apparatus hit at an acute angle and not head-on; in which case it would fail to close. By countersinking the weight so as to bring it down over the spring, the center of gravity was lowered. Thereafter, only one failure was recorded from that cause. When it is realized that it took from two to three hours to make a sounding, and used a considerable amount of our supply of gasoline, it will be apparent how greatly this simple change helped us.

Another advance in methods was the modification of a Sigsbee reversing frame to contain two thermometers instead of one. This frame was attached to the sounding wire near the bottom snapper, and the original single thermometer gave us only the temperature of the bottom water. This information itself is of great interest to oceanographers. We needed a check on the depth from which the deposit was collected--a check which would be more reliable than that offered by the length of wire paid out and the angle. Owing to the drift of the vessel and crosscurrents in the deeps, the wire almost never dropped in a straight line to the bottom. We were able to calculate depths accurately from the difference between the readings of two reversing thermometers sent down together. One of them was protected against the enormous pressures at great depths to give the true temperature; the other, being unprotected, gave a reading which represented the temperature plus the mechanical "squeezing" of the mercury bulb due to the weight of the water column above it.

Our echo-sounding device gave us a third check on bottom depths, of course. In scientific work such as we were doing, there are never too many checks. Even the simplest procedure is subject to error at times; and our aim was to attain the highest degree of accuracy possible in every measurement made on board.

During heavy weather we often found our silk townets torn by a sudden surge of the vessel. These nets were very expensive, and had to be made to order in Washington. So we made every effort to save them. On February 18, we tried attaching the nets to the ship by a long rubber rope commonly used in the landing gear of aircraft. Afterwards, we seldom lost a net. In addition, after February 6, the plankton tows were made from the forecastlehead, thus reducing the danger of fouling the other wires which were lowered from the quarter-deck.

The work with the pilot balloons was made very successful by the beautiful blue skies we enjoyed after clearing the dense clouds of the Peruvian coast. These flights often lasted thirty to sixty minutes, so one can imagine the severe strain on the muscles holding a heavy sextant for that length of time. It was necessary to devise some method for supporting the instrument. One of the deck chairs was fitted with arms and uprights to support an overhead bar. The instrument was suspended from this by a long, thin coil spring. In this way the entire weight was removed from the observer's arms; while still allowing freedom of motion. The whole outfit could easily be moved to whatever part of the deck was most favorable for observing the balloon. Captain Ault dubbed the device the "Joshua Chair," in honor of the Old Testament hero who commanded the sun to stand still. He had also suggested that it might better have been named in honor of Moses who at one critical moment in history had to call in the assistance of two men to support his arms.

Captain Ault says: "With this device we perhaps have carried the matter to an extreme, and caused the balloon to stand still. On at least three occasions, the balloon has suddenly appeared to be fixed in the sky, moving only very slowly in altitude and azimuth. On the first occasion, Torreson, the observer at the theodolite, was observing the balloon for fifteen minutes without getgetting much change. Finally Paul, who had been watching the flight, accused Captain Ault, the sextant man, of looking in the wrong direction and of reading altitudes that were far too low. It turned out that the theodolite had gotten sidetracked to Venus, and the difference between its altitudes of 76° and the altitudes by sextant of 45°, could no longer be ignored. On the second occasion both observers got sidetracked to Venus."

It is remarkable how closely a white balloon floating at a great height resembles the planet in the sunshine of the late morning or early afternoon. For most of us it was a great surprise to know that Venus could be seen at all in the middle of the day. Captain Ault told us that he had occasionally used this planet for determining geographical position at sea. This trick appears to have been known to mariners of former times, but has fallen out of use.

On February 8, Soule and Leyer moved the sonic depth finder from the radio laboratory to the control room on the quarter-deck. This was done to enable us to take additional night soundings without disturbing Jones who slept in the radio room. Paul had learned the technique of using the apparatus and now took a sounding after he had completed his Greenwich Mean Noon meteorological observations. Jones had by this time resumed a large number of schedules with amateur radio stations and had to get his sleep whenever he could, for he had regular magnetic observations and computations to do in the daytime.

New equipment was brought on board at San Francisco. Mr. Gish had tested out a new Kolhörster penetrating radiation apparatus in Pasadena and with Parkinson subjected it to further trials under the waters of Crystal Lake near San Francisco. This instrument registers the quantity of penetrating rays reaching the earth and may be lowered into the sea to determine the depth at which this powerful form of energy is absorbed. Mr. Gish also supervised the installation of a photographic conductivity recorder which had just been designed and constructed in our shop in Washington.

Forbush had brought with him several new chronometers and a photographic time-signal recorder with which time comparisons could be made accurately to one-tenth of a second and approximately to one-hundreth. These delicate time checks were necessary for the "gravity apparatus." He also brought new silk plankton nets for capturing organisms floating in the sea.

Graham had just come from the Scripps Institution in La Jolla where he had spent a month in studying the methods used in chemical oceanography. He and Dr. Moberg spent most of their time in San Francisco in reconditioning the oceanographic laboratory and in preparing new standard solutions. It was impossible to use the delicate chemical balance on board so these men set up the instrument on the pier. Graham also found time to calibrate the bottles which were to be used in determining the amount of oxygen in sea water. We had had such difficulty in obtaining distilled water of sufficient purity for our chemical work that it was decided to buy a small still of our own. Before Graham could take it on board he had to sign five copies of an affidavit that it would not be used for making liquor.

The gravity apparatus which was installed in the cabin by Dr. Wright was now to be tried out for the first time on a surface vessel. Cruises in Dutch and American submarines had shown that it might be expected to give reliable measurements if the roll of the ship did not exceed 10°. Besides this we were not bothered with constant vibration due to engines. The pendulum equipment was designed by Dr. Vening Meinesz of Holland and perhaps was the most delicate instrument on board. It recorded photographically the swings of three pendulums and recorded on the same paper the beats of a chronometer whose rate was known with great accuracy. From this trace the force of gravity at any place could be calculated.

On the passage to Honolulu Dr. Moberg and Graham divided the duties in the chemical laboratory, thereby allowing Paul time to record for the pilot-balloon flights. This relieved Captain Ault, for Scott now read off the sextant altitudes. Graham was slightly handicapped in his work because of an accident he had suffered a few days out of port. As he emerged from the chart room one day the heavy door was slammed shut by a sudden lurch of the vessel and his finger was crushed in the lock.

The new triple-size bottom samplers, made up in San Francisco, were a grand success. With these we were able to secure about four pounds of material instead of about one, thus making it unnecessary to make multiple soundings when large amounts of deposit were required. The new theodolite sent to us by the Navy Department was a great improvement since the field of vision was increased.

Forbush gave the gravity apparatus its first trials. As this instrument had never before been used on a surface vessel, but only on a submarine, difficuities were anticipated. They came--thick and fast. First, the heavy rolling threw a pendulum out of its support. On the next trial, it was found that the foot screws were not rigidly enough clamped down. Then it became apparent that some means must be devised for damping the motion of the apparatus. Finally, it was decided that only a new mounting would solve the difficulties. Notwithstanding these setbacks, several useful records were secured.

Heavy crosscurrents near the equator caused appalling losses of oceanographic equipment. On October 11 two silk nets were lost when the tow wire jumped its sheave and wore through. To avoid this trouble in the future, the rubber shock-absorber rope was attached directly at the forecastlehead, eliminating blocks entirely. The same day brought another accident, in which we lost a complete bottom-sampling and bottom-temperature outfit, through the catching of a splice in the meter wheel.

On October 19 we had to repeat the whole deep series of chemical and temperature determinations, because a tiny piece of rope-yarn, caught by the messenger in descending, had prevented it from reversing the bottles. But on October 25 we were to suffer the most serious blow of all. The confusing currents below the surface entangled the bottom wire and the bottle series. In clearing them, the new aluminum-bronze cable was cut by catching on an outboard platform. We lost forty-two hundred meters of wire, nine reversing bottles, and eighteen of our precious deep-sea reversing thermometers. We could ill afford such depletions in equipment, so from this time on the thermal and chemical series was not lowered until the bottom sampling was completed. This change almost doubled the time required for a station.

After Graham joined the party, the chemical program was expanded to include determinations of silicates, phosphates, oxygen, and hydrogen ions at each station. With his help it was possible to add a vertical haul of a silk net from one hundred and fifty meters, at each station, besides occasionally checking the plankton pump. The pump determined the number of organisms floating in the water and to check its efficiency one filtered a known volume of sea water collected in a large bottle through a small silk net, and counted the marine plants and animals so captured.

On November 10, it was decided to heave to in the lee of Penrhyn Island to get a good measurement of the force of gravity. The apparatus had not proved a success on the open sea. This short stop enabled us to collect biological specimens and diatoms from the lagoon, and furnished a little recreation. This tiny atoll lies about midway between the Marquesas and Samoa, and is rarely visited by ships. The Carnegie had stopped there on a previous cruise, so that we were certain of a welcome from the white resident, Mr. Wilson. He was a castaway from the shipwrecked Derby Park in 1888, and since he has never left the island.

Once ashore we found, besides Mr. Wilson, a white merchant named Wilkinson, whom we had met in Tahiti in the spring; and a pearl trader by the name of Woonton. These men at once prepared a grand feast for us, while we rambled about the village, or fished the lagoon for specimens. Our hosts regaled us with many a South Sea yarn, as we sat on the verandahs drinking fresh coconut milk.

Two days later we made a similar call at Manihiki Island; here the gravity measurements were not so successful, owing to the swells coming in from the west. The Resident Agent, Mr. Williams, an old friend of a previous Carnegie cruise, gave us a hearty welcome to his charming island empire. This atoll offered a striking contrast to Penrhyn. Immaculate coral paths divided the neat little houses and flower gardens into "blocks." The natives were well dressed; the coconut palms were properly spaced and pruned for maximum production. Everywhere were evidences of a fatherly care on the part of old Mr. Williams. To the Carnegie this island is remembered chiefly for its characteristic dance. On a previous cruise photographs and moving pictures of this unique performance were destroyed by an accident in developing. And we were fated to lose ours for another reason.

We were now but a few days from Samoa, and the fast-dwindling supply of gasoline was eked out by catching every breath of air that blew our way. Reports and computations for the voyage about to close kept all hands at work till late at night.

The temperature of the ocean bottom had been measured at almost every oceanographic station since Honolulu, but just outside Samoa we recorded our lowest--one and one-tenth degrees centigrade. Another interesting observation was that in this region of long-continued calms, the surface may be almost a whole degree warmer than the water five meters below it; differences of one one or two hundredths degrees are usual, when winds mix the surface layers. There was also a two-degree diurnal variation at the surface due to the sunshine.

The outstanding result of our echo sounding was the discovery of a new submarine ridge just north of Hawaii. We were able to show that there is no deep trough between Penrhyn and Manihiki, as the charts would lead one to believe. The slopes of these two islands, as well as that of Tutuila, were carefully plotted.

Pilot-balloon flights had been very successful, thanks to the fine skies and the new theodolite. This instrument was so well adapted to conditions, that the sextant chair designed by Captain Ault was seldom used.

Radio conditions had been unexcelled throughout the entire trip. Daily schedules with many amateurs in the United States, Hawaii, and Australia had brought us the news of the world, and had kept us in constant touch with our home office. As an instance to show the faithful services of these enthusiasts, we might mention the operator of station W6DZY. He transmitted a two-hundred word technical message for us and finished by stating that he had just broken three fingers, owing to the fall of a piece of heavy machinery.

Entering Pago Pago Harbor in the early afternoon of November 19, we did not have darkness to contend with as we did in the spring, when we nearly piled up on the reef. But this time the little engine was pushed to the limit in bucking the powerful wind squalls that swooped down from the mountains surrounding the bay. Time and again we were stopped dead in our tracks by these sudden gusts, almost losing steerageway at times. Because of the danger in tying up to the wharf under these conditions, we made fast to a buoy until the following morning.

The landing this time was almost a homecoming. Our friends of the spring were on hand to welcome us, with here and there a new face among them. The hospitality of the Naval Station was extended to us, as before. Since we were to remain here over a week, we had a better opportunity for observing Samoan life and for making collections on shore. Once the records and specimens were forwarded to headquarters, we found time to make several delightful excusions to native villages and into the mountains.

Graham and Paul spent the following Monday in collecting biological specimens. A guide was furnished by the chief who had entertained the party over the week end, and before they returned to the ship they had walked over a greater part of the island, crossing the mountains several times. A large number of native birds were secured for the National Museum and a good collection of characteristic plants was made for the Carnegie Museum in Pittsburgh.

The day of our departure was drawing near and we had preparations to make. Supplies for the galleys and laboratories had to be stowed away and long-neglected letters answered. On November 27 we pushed off for Apia, arriving there on Thanksgiving morning, November 28.

On the morning of Friday, November 29, 1929, the Carnegie was at anchor in the harbor of Apia, Samoa. All morning Captain Ault and the remaining members of the staff were at work on board, the crew was engaged in loading the last of the barrels of gasoline into the ship's tanks. There remained only one hundred and fifty gallons to stow away when lunchtime came. After the noon meal, the crew resumed their task; Captain Ault unfolded a chair and sat on the quarter-deck; the engineer and mechanic were below in the engine room; and the others were scattered over the forward half of the ship, at various duties.

With a rumbling roar the ship was shaken from stem to stern by an explosion--then another. Captain Ault was thrown into the water. The men at work over the tank room were hurled to different parts of the ship. The engineer and mechanic were trapped in the engine room and in a moment the whole quarter-deck was enveloped in flame.

The steward and Soule, rushing on deck, dived overboard to save the Captain. The engineer and mechanic fought their way out of the blazing engine room by raising themselves through the gaping hole in the deck. The uninjured men dragged the others free of the flames. To save the vessel was out of the question and all attention was directed to the saving of lives.

Small boats had been launched at once from the other ships in the harbor. Captain Ault, who had been holding on to a rope as he floated in the water, was helped into one of these and with the other injured men was taken ashore. Apparently he was suffering only minor injuries; but his injuries were serious and on the way to the hospital, our Captain died as a result of them and of shock.

The other men who had been on the quarter-deck suffered fractures and severe burns. They were given immediate surgical attention by the hospital staff, who had been notified by telephone of the accident.

When the survivors were collected ashore, Tony, the cabin boy, could not be accounted for. He had last been seen in the after galley, immediately next to the tank room; so it was apparent that he too had lost his life. His remains were not discovered until December 4, when salvage operations on the charred hull of the vessel were commenced.

Seaton, Graham, and Paul had been away on a collecting trip and did not return until about three hours after the tragedy. The hospital staff and Government officials had done everything in their power for the survivors. There was nothing further to do but to await the arrival of the U. S. S. Ontario, the naval vessel from Pago Pago which the Navy had ordered to our aid.

The engineer and mechanic were too severely burned to stand the journey to Pago Pago, so they were left in the hospital at Apia. Parkinson, as second in command, also stayed to take charge of affairs there. On the day following the explosion, all the others were taken to American Samoa to await the steamer from Sydney. The three injured seamen we brought with us were put in the Naval hospital while the members of the staff were taken into the homes of the Naval officers, and the crew was quartered in the barracks.

Everything was done to make us comfortable. We were furnished necessary clothing--for the ship and all its equipment together with our personal effects, had been a total loss. Governor Lincoln, on behalf of the Navy, arranged immigration papers for entry into the United States for those who were not citizens.

On December 6, the survivors accompanied the body of Captain Ault aboard the Ventura for the sad journey home.

III

THE MAGNETIC WORK OF THE CARNEGIE AND THE URGENCY OF NEW OCEAN MAGNETIC SURVEYS

CONTENTS

THE MAGNETIC WORK OF THE CARNEGIE AND THE URGENCY OF NEW OCEAN MAGNETIC SURVEYS

The earth's surface magnetic field varies with time. The description of this field at any instant hence is difficult because it is not practical to undertake its simultaneous measurement at all points of the earth's surface. There are, in fact, some seventy magnetic observatories [see figs. 1(A) and 1(B)] where continuous simultaneous measurements of the earth's field are made, but the complexity of the field and its changes with time do not permit satisfactory interpolation of values in intervening regions. The density of observations per given area of surface is uneven, and the great oceanic areas are scarcely represented. There have been established, therefore, by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, over 10,000 stations on land and sea to supplement the results at observatories. Measurements at groups of these stations on land or sea usually are made on only one day for an occupation and constitute a magnetic survey. A few thousand of these are called "repeat stations" at which magnetic observations have been made more than once (fig. 2).

In the reduction of magnetic observations to epoch, it is aimed to determine at all stations (at epochs not too far removed from that at any previous time of observation) the intensity and direction of the earth's field freed from the effects of small superposed fluctuations in intensity. More generally, we seek to estimate from the magnetic measurements made at different times and in different locations the intensity of field at all intervening (or suitably extrapolated) times and locations.

For practical reasons the problem of describing the earth's surface field is greatly simplified by mapping only the main or permanent field. This includes only the largest slowly varying part, mapped to only a moderate degree of accuracy (one or two orders of magnitude less than that of the actual observations). As has been stated, this main field undergoes secular variation, that is, a gradual variation with the passing of the years. The strength of the main field at any time is called its normal value at that time.

Although the rough and general description of the geomagnetic field in terms of its normal value (as shown on magnetic charts) is comparatively easy, the derivation of the normal values themselves is complex and difficult. To obtain these normal values it is necessary first to remove from the individual magnetic observations the contributions of extraneous fluctuations not a part of the secular variation.

Often the extraneous fluctuations are large enough seriously to affect the estimates of secular change obtained from two or more observations made in different years. These fluctuations thus may render difficult or impossible a reliable estimate of the normal values (since the secular change may not be determined accurately either with respect to magnitude or sign) at epochs other than those of observation. When the secular change has been corrected for fluctuations in field, so that it is known with accuracy, the magnetic observations then are readily reduced to the epoch desired for a magnetic chart.

Of fundamental importance in charting the earth's magnetic field for a given epoch are the charts of secular change per year, called isoporic charts. The strength of the earth's field in some regions may change by as much as one-third in the course of only one hundred years, and there has been a surprising lack of attention to the importance of constructing such charts on the part of various organizations responsible for the preparation of isomagnetic charts. This importance arises because it provides the only feasible means of enhancing and extending the value measured at a station, say in 1920, for use in obtaining a chart value for the station, say in epoch 1945.

The first comprehensive world isoporic charts were prepared by Fisk at the Department for epoch 1922.5 (see figs. 3 to 9). These give the average annual secular change in components of the geomagnetic field during 1920 to 1925.

Figure 3 shows the isopors for geomagnetic declination or "variation," D, east declination being reckoned as positive. The values in minutes of arc per year may be interpreted in terms of force changes perpendicular to the horizontal intensity, H. Centers of increase in east declination are shown over Europe, South Africa, and the Pacific Ocean; centers of decrease appear over eastern Asia, the Indian Ocean, and North and South America.

Figure 4 shows the isopors in minutes of arc per year for geomagnetic inclination or dip, I, dipping of north end of needle being reckoned as positive. The center of most rapid decrease is in the Atlantic Ocean and that of most rapid increase in northern South America.

Figure 5 shows the isopors in gammas per year for the horizontal intensity, H. Regions of increase in H are shown in the Indian and North Atlantic oceans and regions of decrease near the south coasts of Africa and South America, North America, and Asia.

Figure 6 gives the isopors in gammas per year for the vertical intensity, Z, positive when directed toward the earth's center. Centers of increase are shown over Asia, the Indian Ocean, the South Pacific Ocean, and western South America; marked centers of decrease appear in the Atlantic and North Pacific oceans.

Figure 7 shows the isopors for the total intensity, F, derived from values for H and I. Marked areas of rapid annual decrease in F appear in the North Atlantic and South Indian oceans. Figures 8 and 9 give corresponding derived values for the geographic north and east components, X and Y, respectively.

From the cartographer's point of view the significant feature is that if the form of secular change be preserved, for say twenty years for the sake of illustration, the value of declination or variation D may change by as much as 280′ (nearly 5°), I by 5°, H by 2400 gammas (24 milligauss), Z by 3600 gammas, and F by about 3000 gammas.

The foregoing isoporic charts, widely used today, are highly tentative in a number of regions. They were not derived taking into account correction of the survey data for geomagnetic fluctuations, and the error averaged along parallels of geomagnetic latitude possibly is as much as 30 per cent. They are also, in several respects, mutually inconsistent with the known nature of the geomagnetic field, and in high latitudes the singularities in field near the poles are not taken into account.

The danger of using these charts today in mapping is that the pattern of the isopors changes rapidly. For instance, in D there is scarcely the slightest resemblance between the isopors of 1922 and those of 1942 for both Australia and Canada. Uncertainties of this kind may account for relatively large discrepancies in values shown on some recent charts, for instance, that of the British Admiralty for 1942 for vertical intensity, where there is disagreement between observation and chart of from 20 to 30 milligauss in South Australia. In other words, it is necessary not only to know the pattern of the isopors at a given time but also the trend of change in pattern. This trend can be derived only by mapping the isopors for several different epochs. This in turn requires that there be maintained adequate surveys at regular intervals and continuous observation at magnetic observatories.

The large part of the earth's surface covered by the oceans makes the determination of accurate values of the magnetic elements at sea a major objective of the world-wide magnetic and electric survey. It was not until 1905 that full realization of this objective had its beginning through the systematic oceanic survey then sponsored by the Carnegie Institution of Washington through its Department of Terrestrial Magnetism.

The first attempt to accomplish a magnetic survey at sea was the expedition of Halley between 1698 and 1700. He was placed in command of the pink Paramour and instructed to proceed "on an expedition to improve the longitude and the variations of the compass." Halley made several voyages in the North and South Atlantic oceans determining magnetic declination only--instruments for measuring magnetic inclination and magnetic intensity at sea at that time had not been devised. The results were embodied in Halley's chart "Lines of equal magnetic variation," of the Atlantic for the year 1700--the first isomagnetic chart. The next really important undertaking was the expedition under the general direction of Sabine of the Erebus, the Terror, and the Pagoda during 1840 to 1845, chiefly in southern waters. On these all three magnetic elements were observed, the Fox dip-circle for measuring the magnetic inclinations and intensity at sea just having been devised. The Austrian frigate Novara measured magnetic declination while circumnavigating the globe in 1857 to 1860. During the notable cruises of the Challenger in 1872 to 1876, and of the Gazelle, a German vessel, in 1874 to 1876, observations of the three magnetic elements were made over various oceans. Magnetic observations at sea also were made more recently by the naval services of various countries and by later antarctic expeditions, notably the Discovery and the Gauss. The accompanying figures 10, 11, and 12 show the tracks of chief vessels on which magnetic observations were made during 1839 to 1916.

All these observations were of varying degrees of accuracy set by available instruments and by disturbing factors originating in the magnetic character of the vessels, while their distribution, both as regards position and epoch, was not such as to yield coordinated charts applying to definite periods. Thus, when planning in 1904 for the magnetic and electric survey of the earth, the Department gave careful consideration to the oceanic survey.

The Institution's earliest work at sea was done with the chartered vessel Galilee during 1905 to 1908. The experience gained during her three cruises, in total 63,834 nautical miles (see table 1), proved conclusively that oceanic observations of the magnetic elements sufficient for practical and scientific needs could be assured only by a vessel designed specially for such work. The Carnegie was designed in 1908 primarily for magnetic and electric surveys and investigations, and her construction and equipment were completed in 1909. Before the loss of the Carnegie by explosion and fire at Apia, Western Samoa, November 29, 1929, seven cruises, aggregating 297,579 nautical miles had been made. The data obtained during these cruises and the three previously made by the Galilee, include declination at 3836 points, inclination and horizontal intensity at 2321 and 2322 points, respectively. The extent of the Institution's survey on land and sea is shown by figure 2.

Table 1. Summary of magnetic stations at sea, Galilee (3 cruises) and Carnegie (7 cruises), 1905-1929

Ocean	Number of nautical miles traversed	Number of observed values: Declination	Number of observed values: Inclination and horizontal intensity
Pacific	213,612	2,187	1,308
Atlantic	104,741	1,172	731[a]
Indian	43,060	477	282
Total	361,413	3,836	2,321[a]

[a] Plus one in H.

On the side of practical application the increasing use of the oceans in the commerce of nations by sea and air makes the continuation of the survey a matter of international concern and benefit. Those investigations demanding continuation of the oceanic survey in terrestrial magnetism include, among others, the following.

(a) Determination of secular variation of progressive changes of the earth's magnetic field involving particularly their accelerations which the data accumulated so far indicate cannot be extrapolated reliably over periods as long as five years. A definite control is necessary for a number of epochs to facilitate the investigation of causes producing and governing these progressive changes which, it appears, would be favored by accurate knowledge of their accelerations and distribution. The importance of the determination of secular variation over the oceans may be readily seen by a study of figure 13. Figure 14, showing world distribution of foci of rapid annual change of magnetic declination, also emphasizes the continued need for secular-variation data at sea.

(b) The study of regions of local disturbance and particularly of those indicated by the work of the Carnegie over "deep-sea" areas including accompanying determination of oceanic depths by sonic-sounding devices and of gravity.

(c) The determination of additional distribution-data in a few large areas not already covered.

The question arises whether the theoretical requirements might not be met in a less expensive way than through construction and maintenance of vessels similar to the Carnegie. A careful study was made by the Department following the loss of the Carnegie to determine what might be done in an attempt to control magnetic secular-variation data through observations on land only over the regions between 60° north and 60° south latitude. (Apparently, requisite additional data on land and ocean areas in the polar regions beyond the parallels of 60°--less than one-seventh of the surface of the globe--can be secured only, as in the past, through or in cooperation with special expeditions by land or air.) The maximum control so effected would result from one hundred and fifty secular-variation stations along the coasts of the continents and on islands; about ninety of these have been occupied by the Department one or more times during 1905 to 1943, but the remainder include the more inaccessible islands of the oceans and are subject, generally, to magnetic local disturbance. Such disturbance introduces uncertainties both in the effects on secular-variation changes and in the relation between the normal value and that on the islands, even though the accessibility of stations insures possibility of exact reoccupations. The reduction to common epoch would be more difficult because of the length of intervals between reoccupations and of the lack of the better distribution of data which would result from observations at sea. The study shows that the regions for which the necessary data for the continued investigations would be lacking are very large even if the complete scheme for control by observations on land could be carried out as based on the assumption that the distribution of secular-variation stations need not be greater than one every eight hundred miles. These areas (see fig. 15) approximate 3400 by 800 miles in the north Pacific, 3600 by 1500 miles in the east central Pacific, 3600 by 1800 miles in the south Pacific, 600 by 600 miles in the north Atlantic, 2400 by 800 miles in the middle north Atlantic, 1900 by 900 miles in the west south Atlantic, 1500 by 700 miles in the east Indian, 3600 by 750 miles in the central Indian, and 2400 by 900 miles in the southeast Indian to the south of Australia. (Local disturbances existing at many of the possible stations on islands, which doubtless would make data from a majority of them unsuitable for discussion actually make these areas greater than indicated in figure 15.) The need of continued work at sea is emphasized because these areas involve parts of the earth's surface where there are at present the greatest irregularities in the progressive character of the secular variation, namely, in the central and south Atlantic, Indian, north Pacific, east central Pacific, and south Pacific oceans.

Because of the great desirability of continuing the operation conducted for a quarter of a century by the vessels of the Carnegie Institution of Washington, it is gratifying that, in view of the Institution's decision not to replace the Carnegie by a similar vessel, the British Admiralty had designed and, in September 1936, placed a contract to build a nonmagnetic vessel, to be named Research. The chief reason for this action on the part of Great Britain was found in her world-wide maritime interests. Magnetic charts published for the last two decades by the American, British, French, German, and other governments for use at sea have been based in an increasingly large degree on data obtained by the Carnegie. There are serious gaps in the present data which would have been filled had the Carnegie completed her last cruise and had the rapid change in the secular variation in certain regions been determined. One of the first tasks, therefore, of the Research was to have been the repetition of the observations of the Carnegie in these regions to determine the secular change so that the isogonic charts might be corrected to date and prepared for succeeding epochs. The Research, of the same beam as the Carnegie and slightly greater over-all length, was launched in 1939, but the outbreak of war so far has prevented her operation. The instrumental equipment parallels closely that used on the Carnegie as it did not appear advisable to depart from designs gradually evolved from the experience of many years of observational work at sea. With the eventual continuation of the oceanic survey by the Research we may look forward to further advance in the accuracy of magnetic charts.

The task of the geophysical survey of the oceans is so great that other hydrographic services of maritime nations should be stimulated by the action of the British Admiralty to provide similar vessels with equipment and personnel to take appropriate share in the execution and in the coordination of such service. Resolutions adopted after thorough discussions by the Commission of Terrestrial Magnetism and Atmospheric Electricity of the International Meteorological Organization at Warsaw, Poland, in September 1935, and by the Association of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics at its triennial assembly at Edinburgh in September 1936, urge and recommend that other maritime nations should consider the construction of such nonmagnetic vessels. It is to be hoped that our own United States may assume its share in obtaining additional oceanic data to the further enrichment of our knowledge of earth sciences.

Two of the most important requirements to be met in order that isomagnetic charts for epoch 1945 be of good standard in accuracy are (1) provision of suitably accurate magnetic field observations of sufficiently recent date and (2) knowledge of the course of magnetic secular change in the intervening interval of time between the more recent dates of observation and the year 1945. Unfortunately the world patterns of secular change are subject to rather rapid modification in form with time. Thus, although observations made thirty years ago, say, can be used to good advantage in certain regions where secular change is small, observations made only five years ago may be inadequate in regions where the secular change is rapid.

A rough indication of those regions likely to provide defective chart values for 1945 of the general systematic field distributions is afforded by multiplying the annual rate of secular change for 1920 to 1925 by the number of years prior to 1945 of the most recent field observation in a region. Although the secular change for 1920 to 1925 sometimes will afford a poor approximation for the entire twenty- to twenty-five-year intervals, this has been done using the isoporic charts of figures 3 to 9 and lists of field observations.

Figures 16 to 18 show the products obtained by the foregoing procedure for the D-, H-, and Z-components, respectively. These tentative results give the amount of the extrapolation from the last measured observation to obtain chart values for 1945. The most striking feature is the magnitude of the necessary extrapolations in the south Atlantic, Pacific, and Indian oceans, and in north central Africa. These estimates are highly conservative because a single observation on land may, by the procedure here adopted, yield the estimate for a 30°-tessera mainly of ocean. On land there is most urgent need of resurvey in North Africa and the Pacific islands; all major oceanic areas are in need of magnetic surveys.

The present slow and costly methods of geomagnetic surveys seem likely to be superseded by new techniques and methods, the possibilities of which now are gradually becoming apparent. Clearly the old procedure of measuring the earth's field at different times in different places, in one region during one series of years and in another in a different series of years, is inefficient. What is required is a description of the geomagnetic field during a given year, based on measurements made during that year at an ordered set of points sufficiently close together and spaced in a manner nearly independent of topography, areas of land and sea, and climate. Such measurements made from planes flying along parallels of latitude no doubt will be available in the future. A project of this kind at present is feasible instrumentally and affords attractive postwar possibilities in application.

In spite of the new developments in navigation, the compact and simple compass seems likely to remain in use on the seas for many years, and likewise there are appearing newly found applications of isomagnetic world charts from time to time. The available geomagnetic data already of necessity are squeezed rather hard to obtain useful isomagnetic charts for epoch 1945 in some regions. It is apparent that measurements of the earth's magnetic field must be continued, even if entirely by the more cumbersome methods of the past which at least have the virtue of being tried and tested. The prompt undertaking of even a limited magnetic-survey program, including not only measurements of magnetic declination as at present carried out by the United States Hydrographic Office but also measurements of the other components with carefully standardized instruments, would make available data on which the isomagnetic charts for epoch 1950 may be based.

LIST OF FIGURES

Fig. 1(A). Magnetic observatories, Western Hemisphere

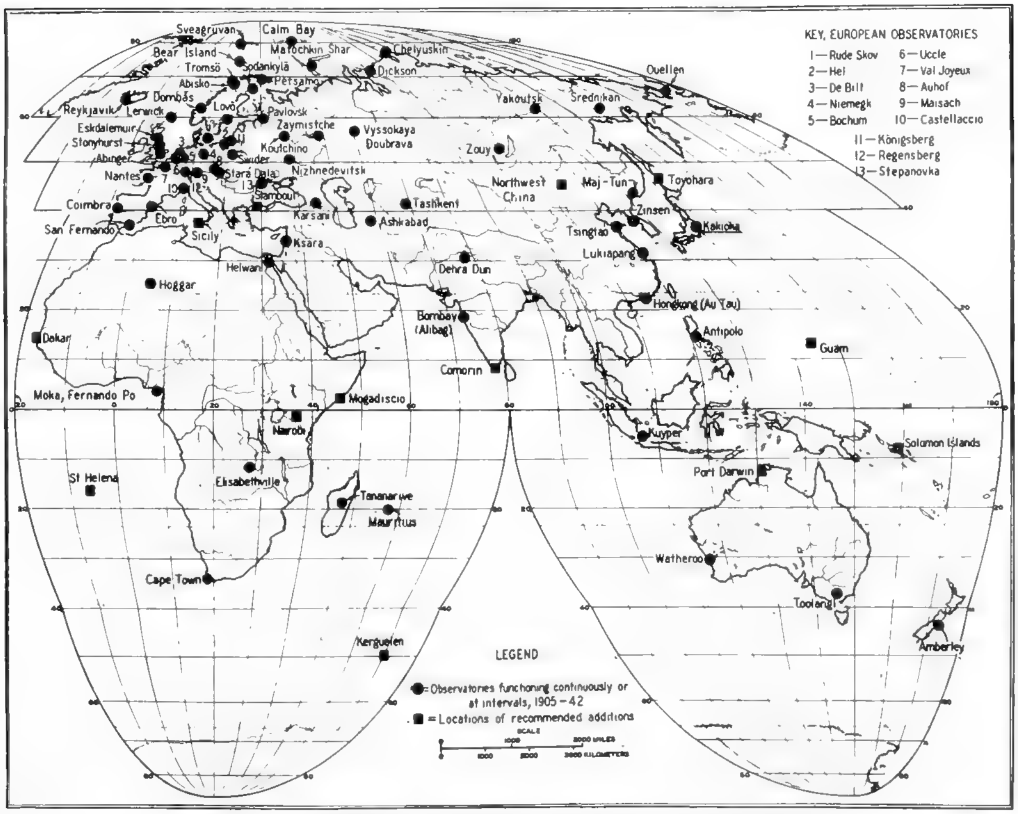


Fig. 1(B). Magnetic observatories, Eastern Hemisphere

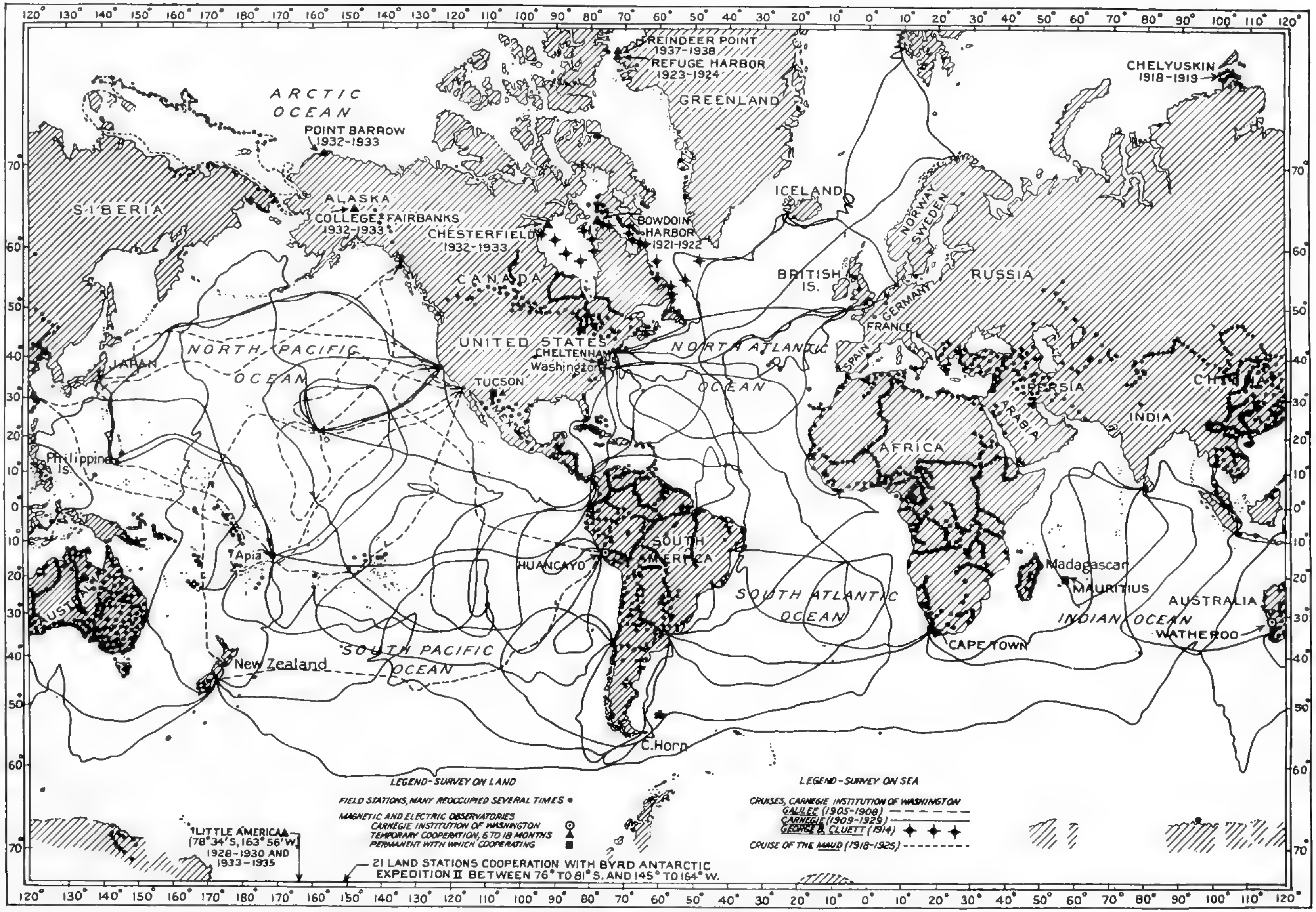


Fig. 2. World magnetic and electric survey, Department of Terrestrial Magnetism, Carnegie Institution of Washington, 1905-1938

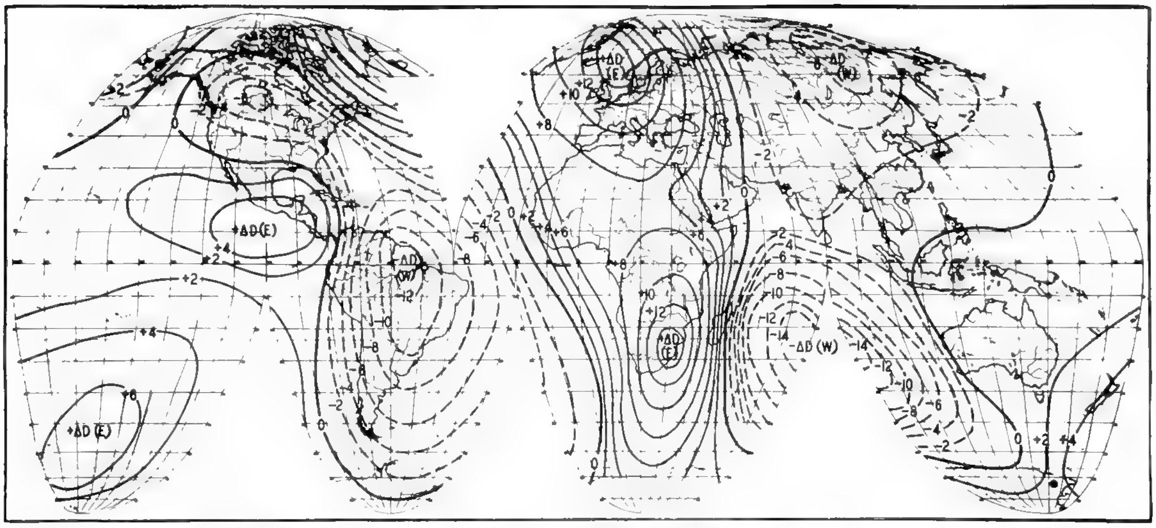
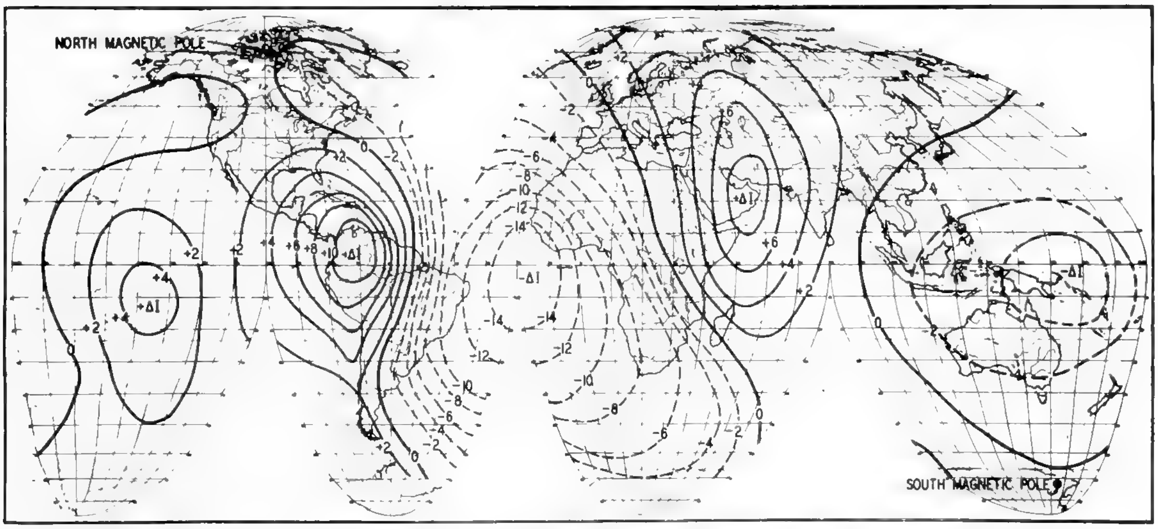


Fig. 3. Isoporic chart for declination (lines of equal annual change), approximate epoch 1920-1925



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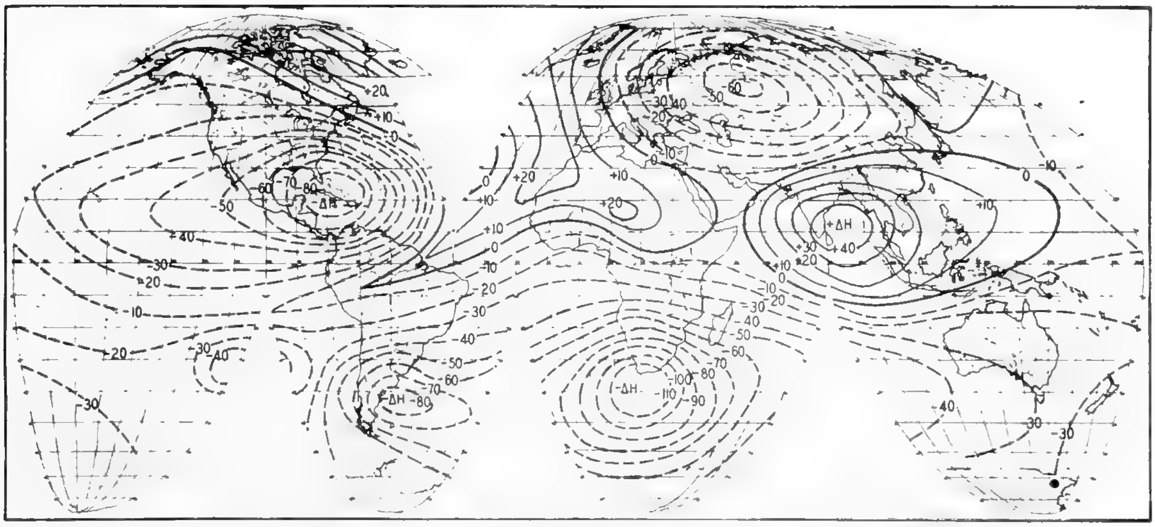


Fig. 5. Isoporic chart for horizontal intensity (lines of equal annual change), approximate epoch 1920-1925

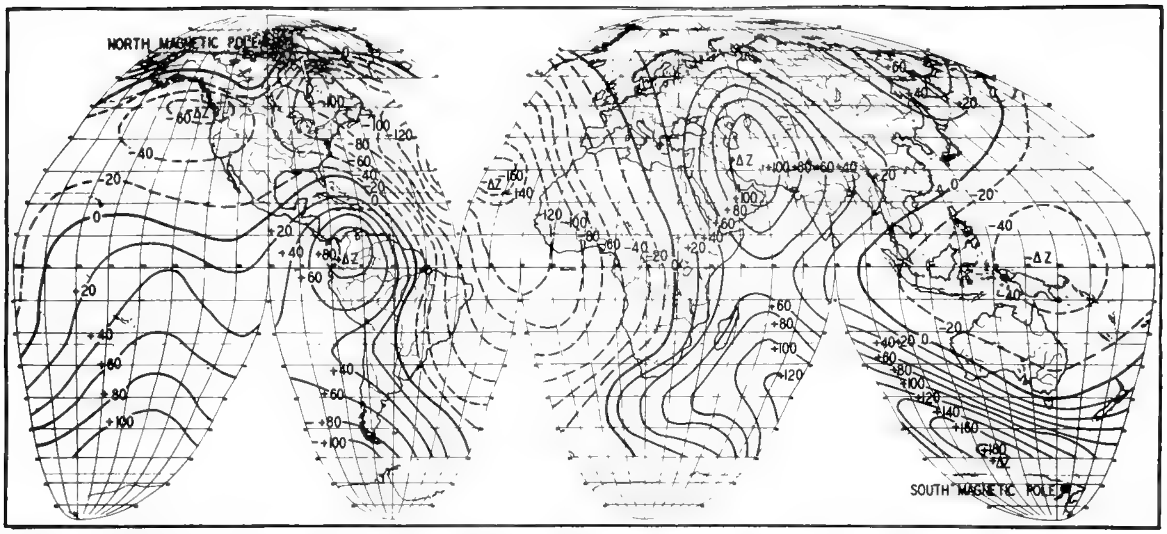


Fig. 6. Isoporic chart for vertical intensity (lines of equal annual change), approximate epoch 1920-1925 (Position of isopors in high latitudes, especially near the magnetic poles, very uncertain)

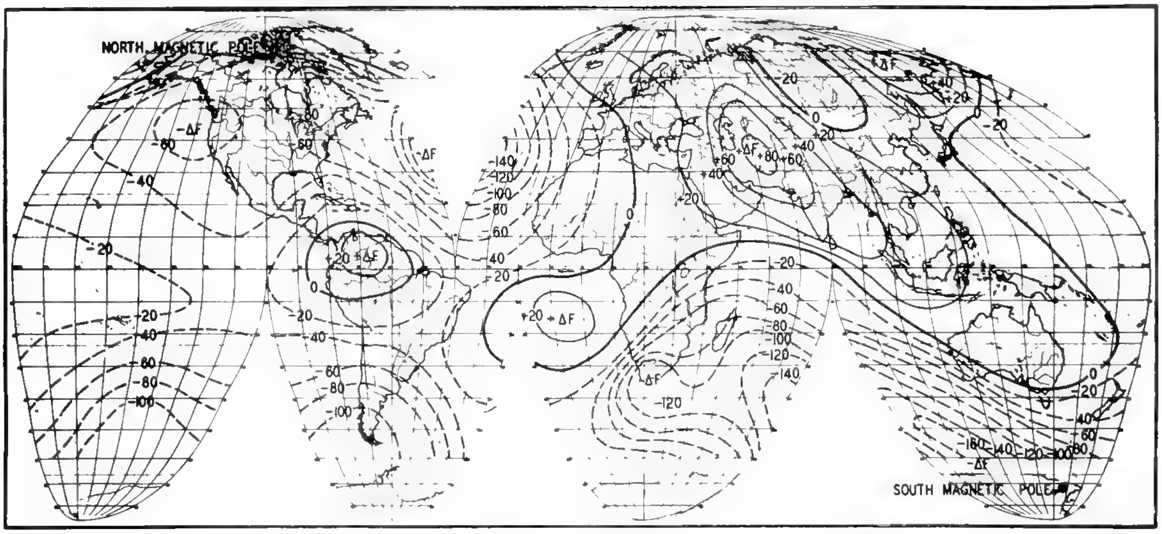


Fig. 7. Isoporic chart for total intensity (lines of equal annual change), approximate epoch 1920-1925 (Position of isopors in high latitudes, especially near the magnetic poles, very uncertain)

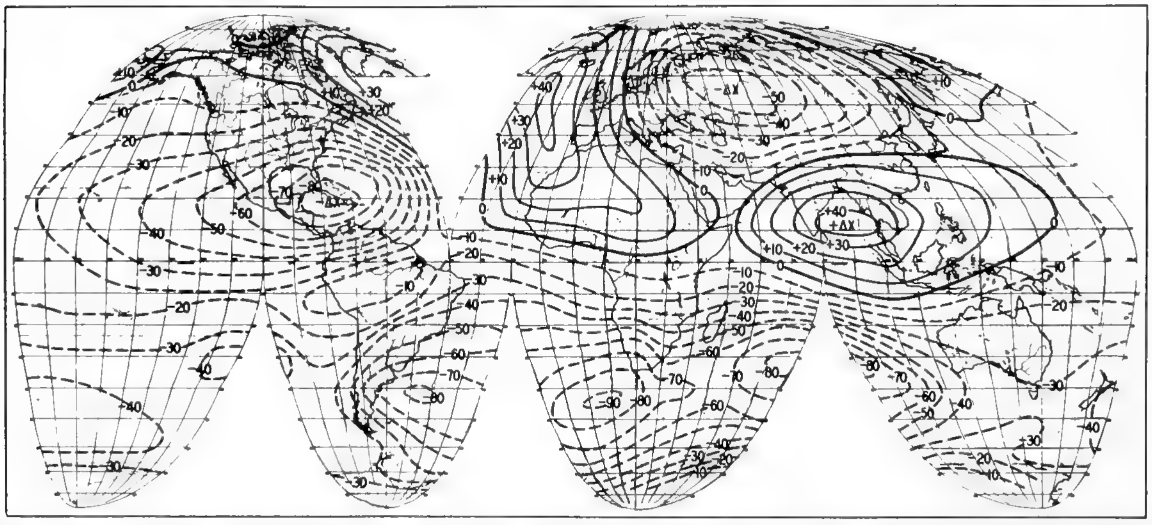
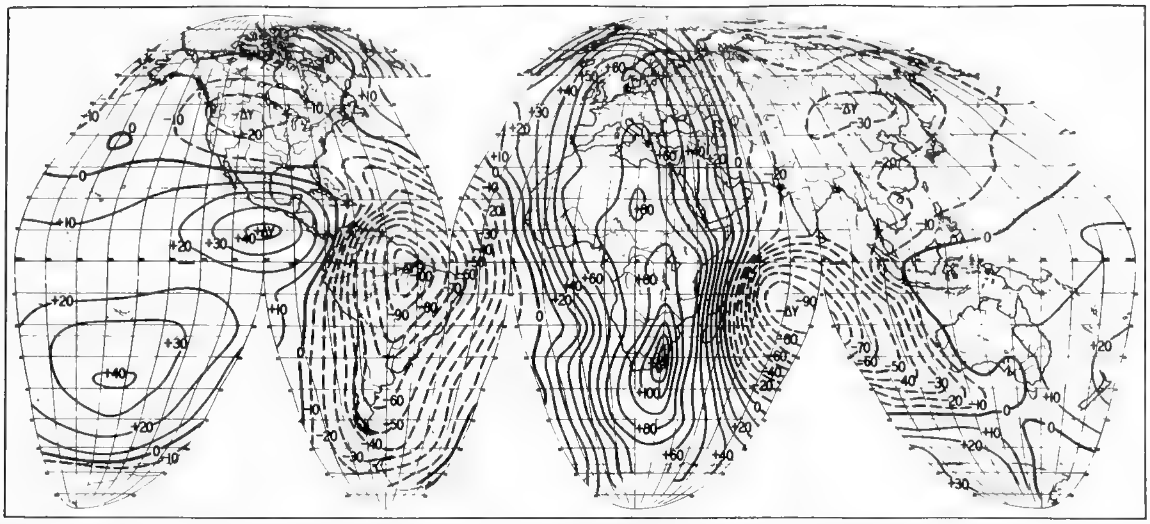


Fig. 8. Isoporic chart for north component (lines of equal annual change), approximate epoch 1920-1925



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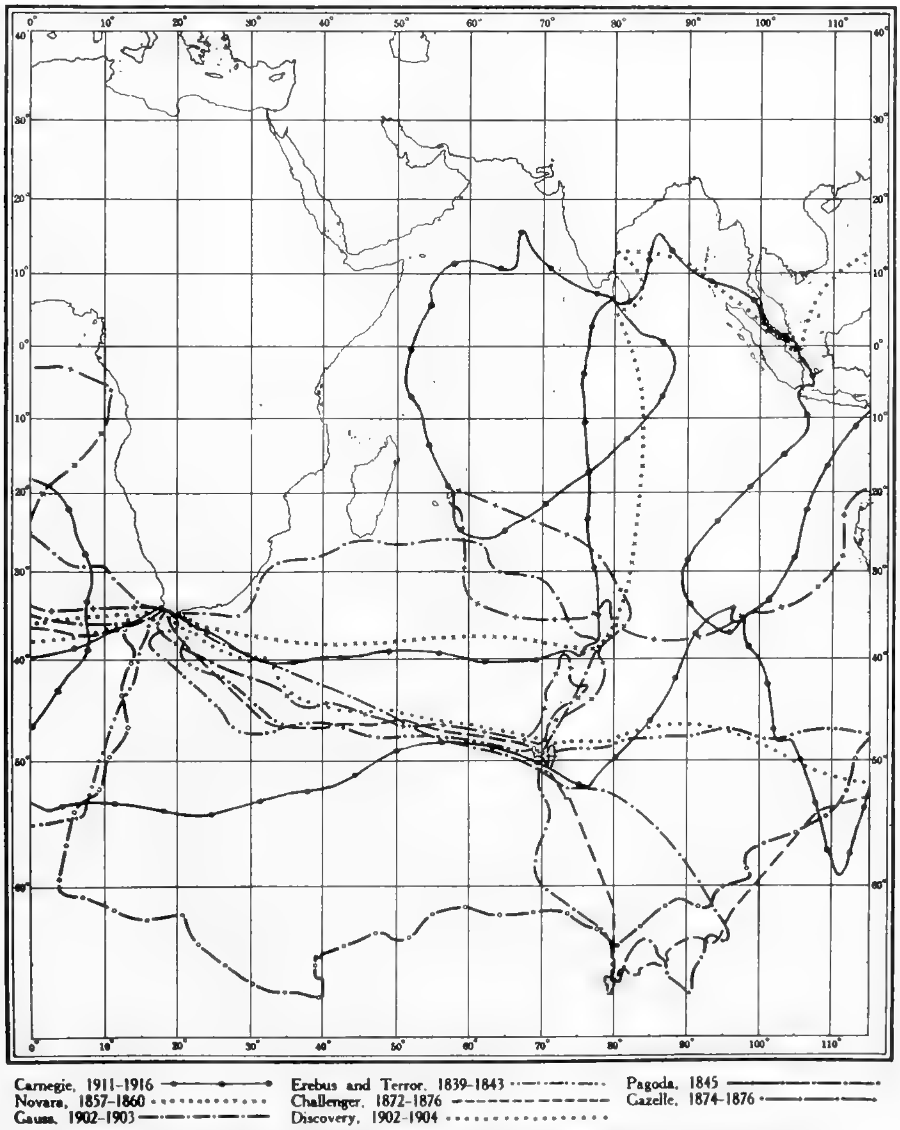
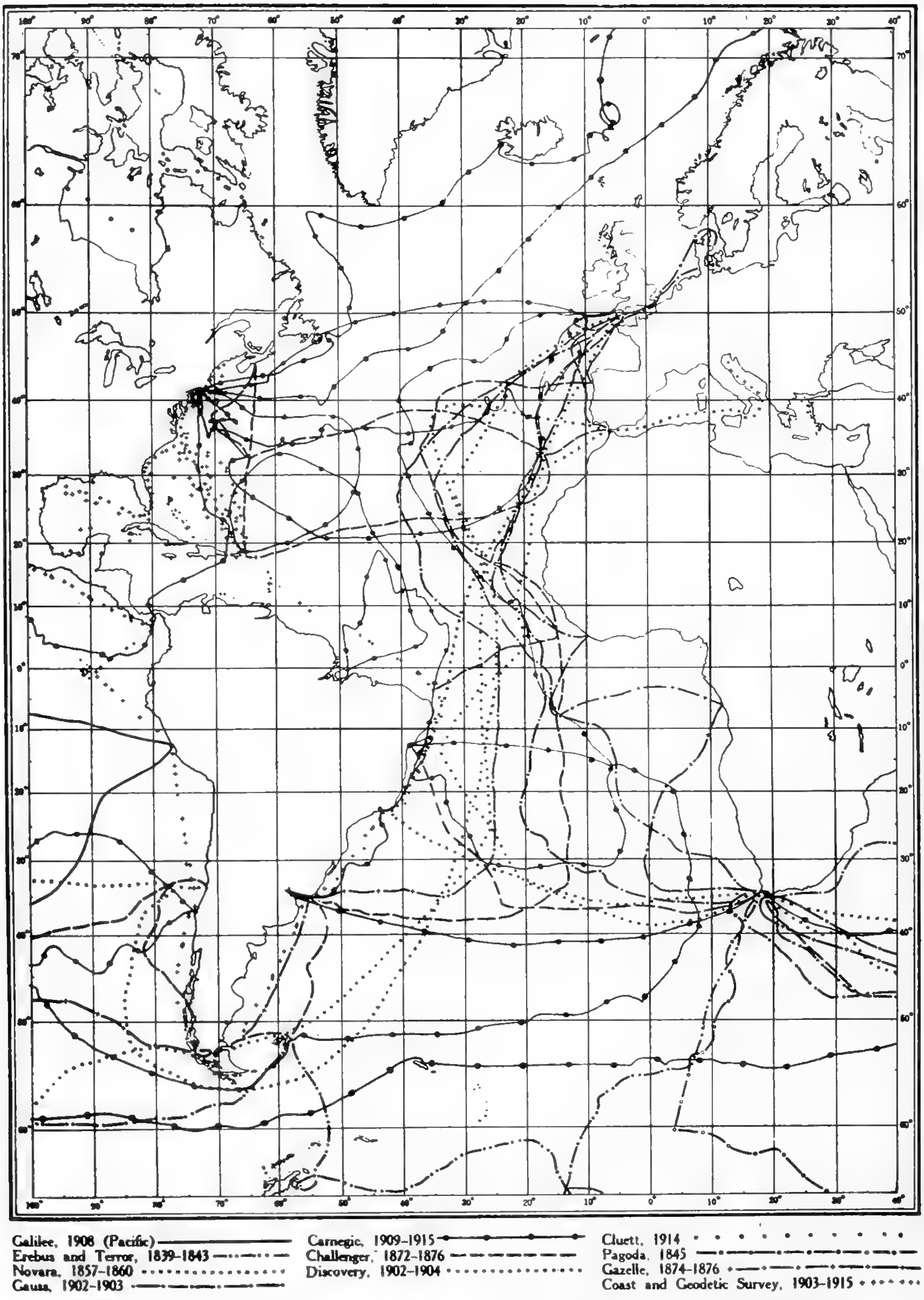


Fig. 10. Tracks of chief vessels on which magnetic observations were made in the Indian Ocean, 1839-1916



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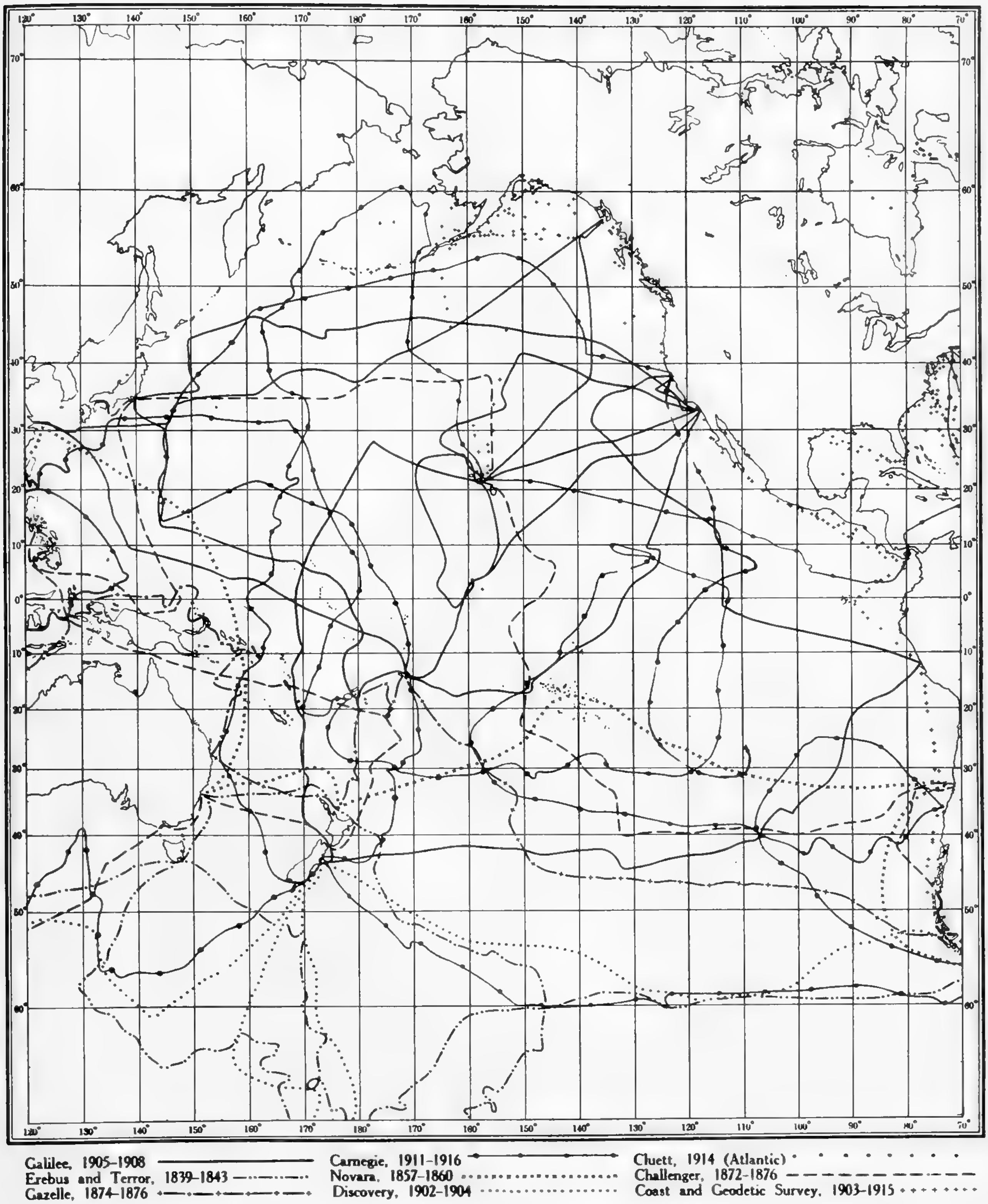

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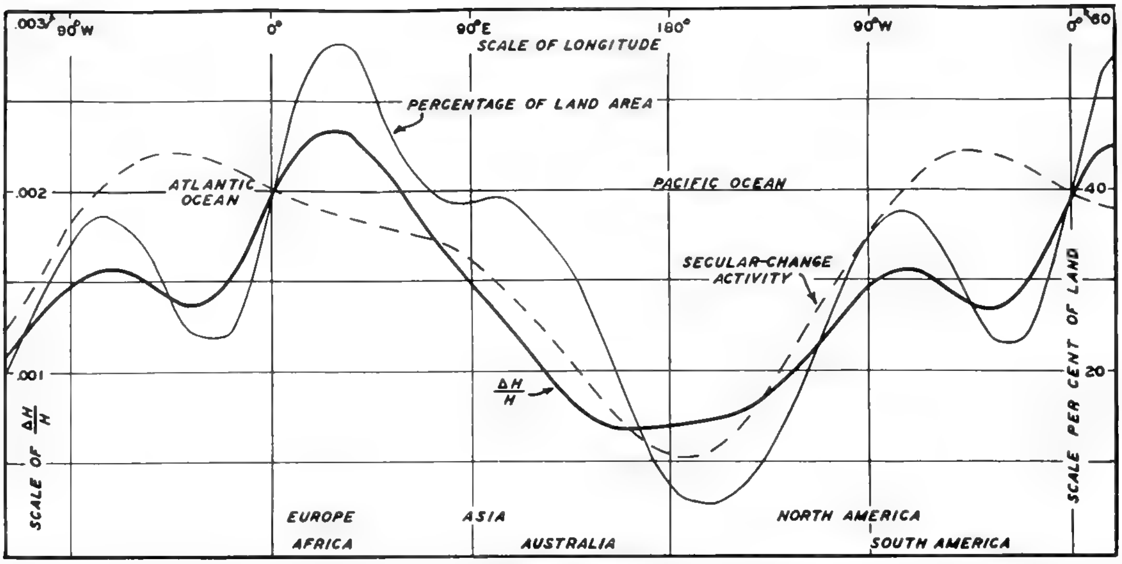
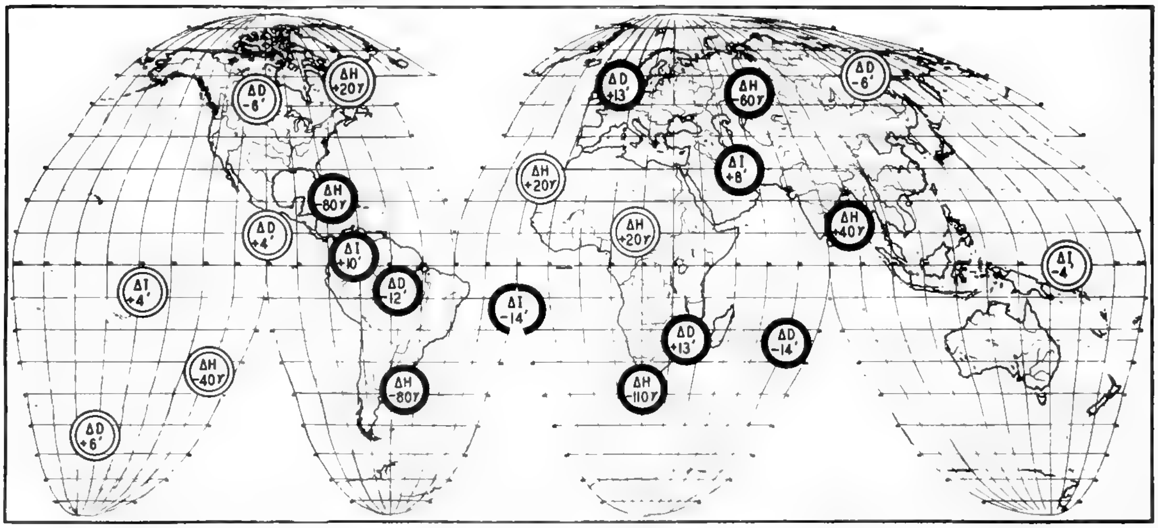


Fig. 13 Variation with longitude of ΔH/H (annual change averaged without regard to sign), of the distribution of the proportion of land and water areas, and of secular-change activity approximately determined by the density of the distribution of isoporic lines



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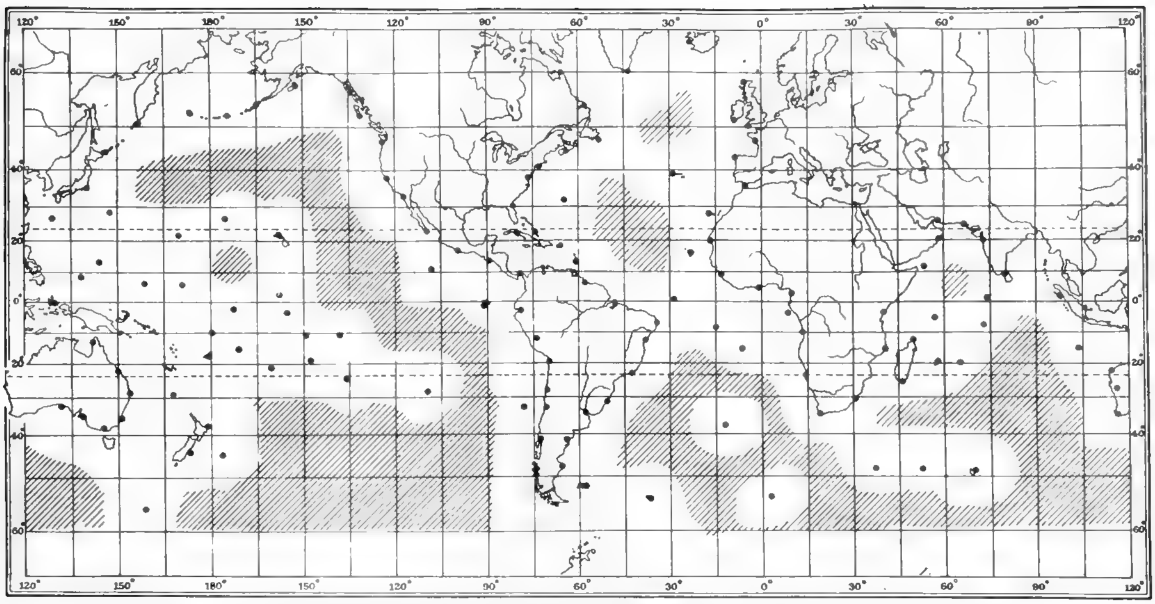

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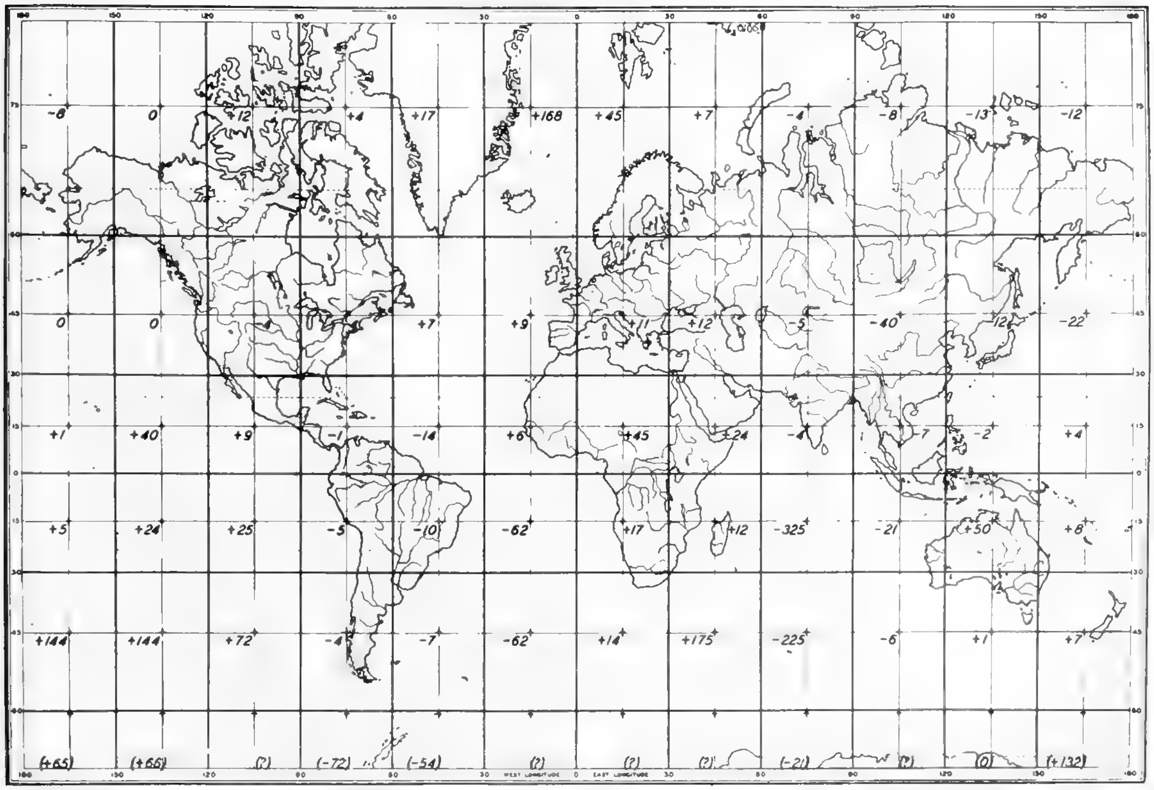

Fig. 16. Amount of extrapolation, in minutes of arc, from last survey-value per 30°-tessera to epoch 1945, magnetic declination (east declination positive), basis isopors 1920-1925

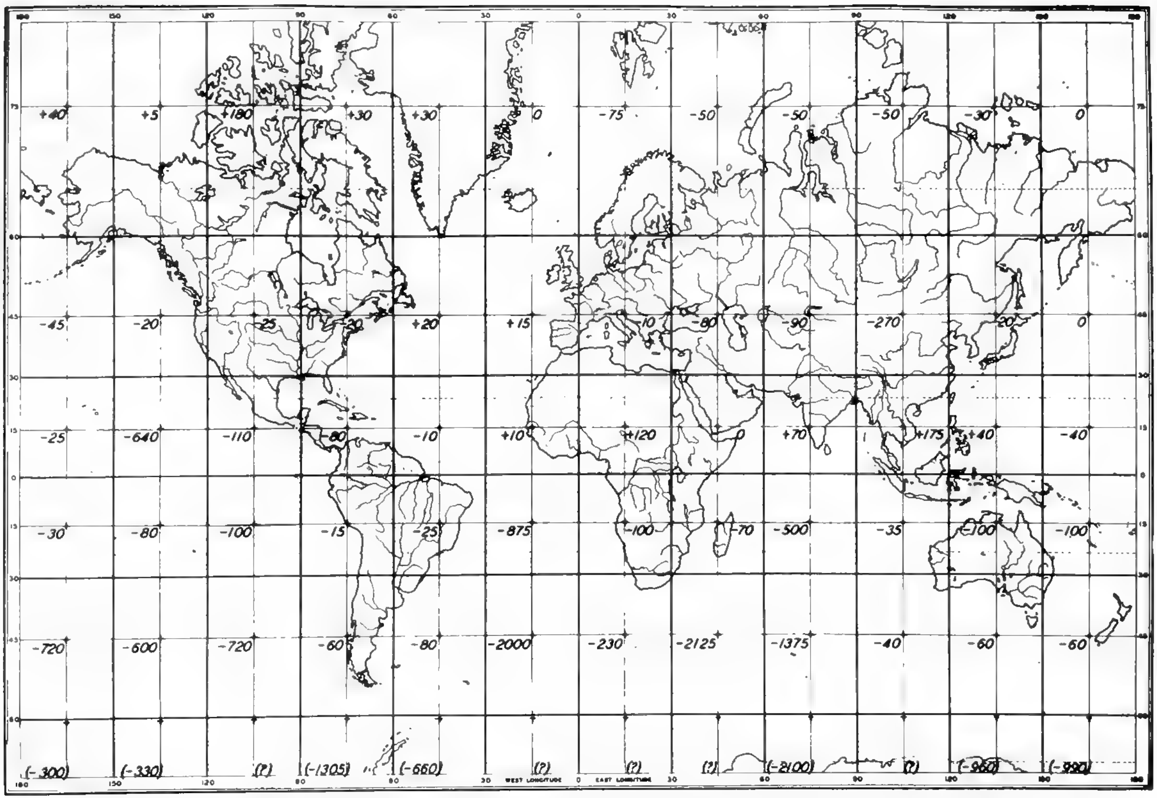

Fig. 17. Amount of extrapolation, in gammas, from last survey-value per 30°-tessera to epoch 1945, magnetic horizontal intensity, basis isopors 1920-1925

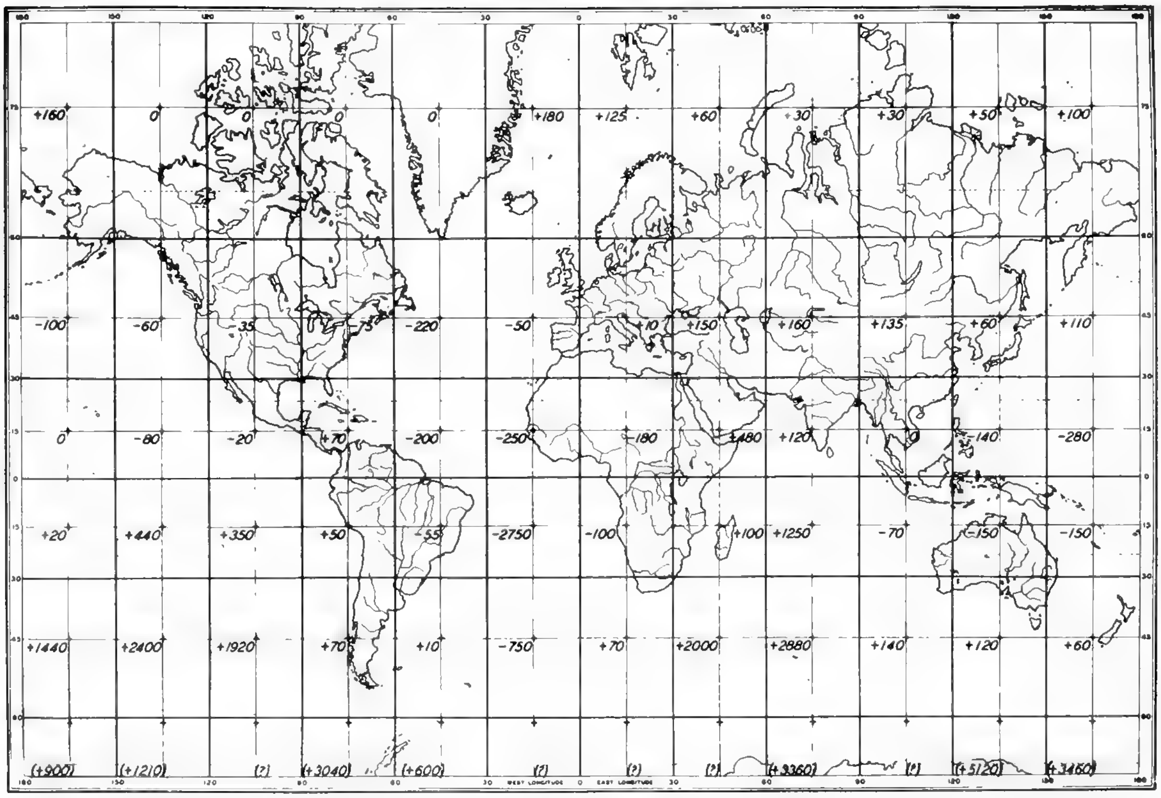

Fig. 18--Amount of extrapolation, in gammas, from last survey-value per 30°-tessera to epoch 1945, magnetic vertical intensity (positive downwards), basis isopors 1920-1925

WORK OF THE CARNEGIE AND SUGGESTIONS FOR FUTURE SCIENTIFIC CRUISES

IV

THE CARNEGIE: ITS PERSONNEL, EQUIPMENT, AND WORK

CONTENTS

THE CARNEGIE: ITS PERSONNEL, EQUIPMENT, AND WORK

Introduction

In preparing the following report on the *Carnegie*, and its personnel and program of work on cruise VII, an effort has been made to include such information as may be useful in planning other scientific cruises of similar character and scope. It is especially hoped that this discussion will call attention to the need for selecting the personnel with great care and of outlining, even in detail, the programs for the various investigations to be undertaken.

The amount of work possible on a scientific cruise will be determined, in the final analysis, by the size of the boat, insofar as it determines the amount of laboratory and working space and the number of workers that can be carried on board. For this reason it probably always will be advisable, when an extensive program is contemplated for a ship of the small size of the *Carnegie*, to carry out only the necessary work on board and to forward all material possible to a shore laboratory for detailed and final study.

Arrangement of Space on the *Carnegie*

With one exception, the living quarters are located below decks, and the laboratories and work rooms are located in the superstructures. The diagrams and the description below will indicate the arrangements of quarters for the crew and the scientific staff, and the working space for the various subjects investigated.

Below Decks (fig. 1).--Amidships is located the cabin which serves as quarters for the scientific staff. This section consists of a dining room in the center and around it seven staterooms, an office, a bathroom, and a galley. At one end of the dining room is a case for the chronometers and shelves for books. Each stateroom will accommodate only one person and is furnished with bed, dresser, washstand, book shelves, and a small desk. There is also a bed in the radio room above, which makes a total of eight rooms for scientists. Another one can be provided by eliminating the office, which at present is used mainly for filing records and storing record blanks. The office does not make a pleasant stateroom, however, since it receives no daylight.

Forward of the cabin are the quarters for the officers of the sailing staff. These quarters consist of the wardroom and three staterooms, containing a total of four bunks.

Forward of the wardroom are the forward galley and the cooks' room. The latter accommodates four persons.

Forward of the galley and cooks' room is the forecastle which contains nine bunks.

The space aft of the cabin contains the engine room, machine shop, fuel tanks, darkroom, and storerooms.

Laboratories and Other Work Rooms (figs. 1 and 2).--Practically all the space available for scientific and navigational purposes is located above decks, where superstructures have been built wherever possible. On the quarter- (or after) deck is found the largest unoccupied deck space; this is needed for making oceanographic observations and collections.

On the forward half of the deck is located the chart room, which measures 13 3/4 by 14 1/2 feet. Opening from it are four doors (two leading to the domes and one to each side of the deck), and a companionway leading to the cabin. The chart room contains a standard compass, a chart table 3 2/3 by 5 feet, cases for sextants, shelves for books, and six small desks 27 by 28 inches. The room is used for making computations and for other clerical work in connection with navigation, magnetism, sonic sounding, salinity, temperature, ocean currents, and meteorology.

Connected with each end of the chart room is a circular, glass-covered dome, 7 3/4 feet in diameter. These domes are used exclusively for magnetic observations.

Immediately aft of the after dome is the atmospheric-electric laboratory, which is built on the deck containing the cabin ventilators, about 3 feet above the main deck. This laboratory measures 7 3/4 by 9 1/4 feet and the space in it is occupied completely by electrical apparatus and one desk.

Aft of the atmospheric-electric laboratory, and toward the starboard side of the boat, is the oceanographic laboratory. Its dimensions are 8 by 11 feet but about 15 square feet of floor space are taken up by the corner of a a companionway and a mast. This laboratory contains the apparatus for electrometric determinations of salinity, a sea-water thermograph, and biological and chemical laboratory apparatus.

The room on the port side, opposite the oceanographic laboratory, is 8 by 9 feet in size and contains the radio equipment and living quarters for the operator.

Aft of the radio room is the so-called control room, which contains the control apparatus of the sonic depth finder, a roll and pitch recorder, thermographs, and racks for reversing thermometers. This room measures 6 by 7 feet but is only about 5 1/2 feet in height since it is built on the quarter-deck where greater elevation would interfere with the main boom.

On the quarter-deck are located the winch and davits used in oceanographic work, as well as a large box containing water bottles and other collecting apparatus.

Personnel of the *Carnegie*

Staff	No.	Quarters in
Scientific		
Commander	1	Cabin
Physician	1	Cabin
Business manager	1	Cabin
Radio operator	1	Radio room
Other investigators	4	Cabin
Sailing		
First officer	1	Ward room
Watch officers	2	Ward room
Engineer	1	Ward room
Mechanic	1	Forecastle
Seamen	8	Forecastle
Cooks	2	Cooks' room
Cabin boys	2	Cooks' room
Total	25	

One watch officer and four seamen stand watch alternately with the other watch officer and four seamen, each watch thus being on duty a total of twelve hours out of every twenty-four. During daylight hours only one man, the helmsman, is continuously occupied with the sailing of the ship and the others usually are free for various kinds of work, such as assisting on ocean stations, repairing sails, cleaning decks, etc. At night the watch officer is stationed on the quarter-deck, a sailor is on lookout on the bridge, and in foggy weather or under certain other conditions, a second sailor on the forecastle head. The helmsman and lookouts are relieved every two hours. Under bad sailing conditions the captain and first officer alternate on watch.

The discussion of living quarters has shown that the number of men on board corresponds exactly to the number of bunks. In the crew's quarters it would be virtually impossible to provide additional bunks, whereas in the cabin an additional room could be provided.

The Work of the Carnegie

The scientific work of the present cruise is as follows:

1. Navigation
2. Terrestrial magnetism
    - Declination
    - Intensity
    - Inclination
3. Atmospheric electricity
    - Penetrating radiation
    - Conductivity
    - Radioactivity
    - Nuclei concentration
    - Small-ion concentration
    - Potential gradient
4. Meteorology
    - Temperature (continuous air and water)
    - Atmospheric pressure
    - Humidity
    - Precipitation
    - Evaporation
    - Air currents (by balloons)
5. Oceanography
    - Depth (sonic)
    - Temperature
    - Salinity (by conductivity and, occasionally, by chlorinity)
    - Oxygen
    - Hydrogen ions
    - Phosphate
    - Silica
    - Plankton (collection of samples only)
    - Bottom samples (collection only)
    - Currents (from temperature and salinity)

Below are given two tables, the first showing the various duties of the different workers; and the second

Table 1. Duties of scientific staff

Name	Duties	Work room or laboratory	Hours per day	Total hours per day
Ault	Commander	....	?	
	Navigation	Chart room	1	
	Oceanography	Deck and chart room	7	8+
Paul	Physician	....	?	
	Meteorology	Deck and chart room	4 1/2	
	Oceanography	Deck and ocean lab	2	6 1/2+
Scott	Business manager	Office	2	
	Navigation	Chart room	3	
	Magnetism	Chart room	2	
	Meteorology	Quarter-deck	1 1/2	8 1/2
Jones[1]	Radio operator	Radio room	4	
	Magnetism	Chart room	4	8
Parkinson	Atmospheric electricity	A.-E. lab	8	8
Soule	Magnetism	Domes	1 1/2	
	Sonic depths	Control room	2	
	Oceanography	Ocean lab and chart room	5	8 1/2
Torreson[2]	Navigation	Chart room	4	
	Magnetism	Chart room	2	
	Meteorology	Quarter-deck	1 1/2	
	Atmospheric electricity	A.-E. lab	1	8 1/2
Seiwell[3]	Oceanography	Deck and lab	8	8
Total				64+

[1] L. A. Jones was replaced by S. L. Seaton; [2] O. W. Torreson was replaced by S. E. Forbush; and [3] H. R. Seiwell was replaced by H. W. Graham at San Francisco, September 1929.

Table 2. Average time per day required for scientific work

Subject	Work room or laboratory	Performed by	Hours per individual	Hours per subject
Navigation	Chart room	Ault	1	
		Scott	3	
		Torreson[1]	4	8
Magnetism	Chart room and domes	Soule	1 1/2	
		Torreson	2	
		Scott	2	
		Jones[2]	4	9 1/2
Atmospheric electricity	A.-E. lab	Parkinson	8	
		Torreson	1	9
Meteorology	Deck and chart room	Paul	4 1/2	
		Torreson	1 1/2	
		Scott	1 1/2	7 1/2
Oceanography				
Sonic depth	Control and chart rooms	Soule	2	
Ocean station	Quarter-deck	Ault	2	
		Soule	2	
		Seiwell[3]	2	
		Paul	2	
Temperature and depth correction	Chart room	Ault	2	
		Soule	0 1/2	
Salinity	Ocean lab and chart room	Soule	2 1/2	
Oxygen	Ocean lab	Seiwell	2	
Hydrogen ions	Ocean lab	Seiwell	1	
Phosphate	Ocean lab	Seiwell	1 1/2	
Silica	Ocean lab	Seiwell	1 1/2	
Currents	Chart room	Ault	3	24
Total				58

[1] O. W. Torreson was replaced by S. E. Forbush; [2] L. A. Jones was replaced by S. L. Seaton; and [3] H. R. Seiwell was replaced by H. W. Graham at San Francisco, September 1929.

the distribution of the work among the different members of the staff and the amount of time required for each subject of investigation. It should be stated that although the tables show the number of hours per day, two days are required to complete a schedule since magnetic and oceanographic stations are made on alternate days, including Saturdays and Sundays.

The number of hours given in the above tables is approximate only and, of course, subject to considerable variation. In order to have only eight hours per day per man, the time required perhaps in all cases has been underestimated. It is doubtful if the work performed on board in one day could be accomplished in sixty-four working hours, even if there were no trouble with apparatus or delays due to other causes. As a consequence, the average working day is considerably more than eight hours.

Discussion of Scientific Program

Navigation.--Whenever weather conditions permit, latitude observations are taken daily at noon and longitude in midmorning and midafternoon. Occasionally stars are used for both latitude and longitude. All observations are made and computed independently by two members of the scientific staff (and by the first officer). Dead reckoning involves a great deal of work and the amount varies with the number of scientific observations made. Whenever a scientific observation is made or a sample collected, the time and log reading are recorded. The position for each observation is computed later from the previous and subsequent astronomic positions. Also a certain amount of time is required for laying out courses and other routine work. Navigation requires a total of at least eight hours per day from two or three persons.

Medical Work.--Ordinarily the physician's professional duties are not extensive and most of his time can be devoted to other work. It is important, therefore, to have a physician who is willing to assist with other work, such as chemistry, biology, or various observations and computations.

Radio Work.--About four hours a day are devoted to sending and receiving messages, receiving news items, weather reports, and time signals, and keeping the equipequipment in good condition. The radio operator should be a man who is willing to spend part of his time in computing or other work.

Atmospheric Electricity.--One man devotes all his time to this work and one day each week, when diurnal observations are taken, a second man is required to alternate with the regular observer during a twenty-four-hour observing period. Assistance also is needed for scaling graphs and checking computations.

Meteorology.--The various subjects under this heading investigated at present are shown on page 62 but for the present purpose they may be grouped under recording instrument work and pilot-balloon work. The work consists merely in accumulating records from the instruments and the pilot-balloon flights. No computations or interpretations are made. The balloon observations require three men for approximately one and one-half hours and the rest of the work about three hours daily, making a total of about seven and one-half hours per day.

Were it considered necessary to do more with the meteorological data, an additional worker probably would be required. The computations and scaling of records can be made at the shore laboratory, however, even by a person not thoroughly familiar with the subject. It seems advisable, therefore, that on board the meteorological work be carried only far enough to enable the observers to plan the routine intelligently and to check up on the accuracy of the results.

Oceanography.--Since practically every branch of this subject utilizes to a greater or lesser extent, information or material obtained from the oceanographic stations, and since the work on these stations requires several men and a good deal of time, the oceanographic investigations must be planned carefully and coordinated so that a minimum amount of time and effort will be required for the collecting work. Since it is necessary for several members of the scientific staff to participate in the work on a station, the stations, therefore, should be occupied according to a schedule or, when this is not practicable, at a time agree on by all concerned.

In order to give an idea of the nature of the work on an oceanographic station, a discussion of the equipment used and the procedure is given below. The hoisting equipment consists of a 25-horsepower gasoline engine which drives a 12 kilowatt, 110 volt, direct current generator. This generator operates a winch which is located approximately in the center of the quarter-deck and is equipped with four drums carrying wires as follows:

1. 10,000 meters 1/16 inch steel piano wire
2. 2,000 meters 6-mm aluminum bronze stranded wire
3. 6,000 meters 4-mm aluminum bronze stranded wire
4. Not used

The piano wire is used for taking bottom samples and leads over a depth recorder (meter wheel) on a davit at the stern. The 6-mm aluminum bronze wire is used for the Petterssen plankton pump and the 4-mm wire for taking temperatures and water samples. Both bronze wires lead to sheaves attached to the after mast above the laboratory, thence over depth recorders to davits at the rails on either side of the quarter-deck and somewhat forward of the winch. Of the rest of the equipment, the following may be mentioned: Nansen water bottles, Richter reversing thermometers, various kinds of bottom samplers, Petterssen plankton pumps, and plankton nets of various sizes.

On the present cruise the ship is hove to at eight o'clock every other morning for an oceanographic station. The first apparatus lowered is the bottom sampler which is attached to the piano wire. When this has reached a depth of about 1000 meters, the 4-mm bronze wire is reeled off and Nansen bottles attached to it so as to reach the following depths: surface, 5, 25, 50, 75, 100, 200, 300, 400, 500, and 700 meters. Ten minutes are allowed for the thermometers to reach the proper temperatures, after which the bottles are reversed and hauled in. As each bottle reaches the observer, it is detached and placed in a rack. The thermometers are removed from the bottle and placed in a rack in the control room. Other Nansen bottles are then attached to the wire and lowered to 700, 1000, and greater depths down to 2500 or 5000 meters. Below 1000 meters the interval between two bottles usually is 500 meters. As soon as a Nansen bottle is placed in the rack, water is drawn from it for oxygen determination, and two (citrate-of-magnesia) bottles are filled for the other analyses. The thermomters are not read until the mercury in the auxiliary thermometers becomes stationary.

While the bottom and water samples are being taken, plankton samples are taken with the pump from the surface, 50, and 100 meters. About twenty minutes are required for the weight operating the plankton pump to descend. The rest of the manipulation of the pump also consumes time and often the other collecting work is finished before the three plankton samples have been taken.

Plankton samples also are taken with half-meter (or sometimes meter) townets, which are lowered to the surface, 50, and 100 meters, and allowed to remain for thirty to sixty minutes and drift with the boat. A vertical haul from 150 meters to the surface is taken also. The plankton nets are lowered from the bow and reeled in by hand.

The following participate in the work on an oceanographic station:

Ault and Soule; temperatures, Nansen bottles, and recording
Seiwell; oxygen samples and net hauls
Paul; plankton pump
First officer; bottom samples
Engineer; engine room
Mechanic; winch
Crew on Watch; (1 watch officer and 4 seamen), reeling in nets, oiling and placing wires, helping manipulate plankton pump, etc.

This makes a total of twelve men, four of whom are scientists. The time required is from three and one-half to five hours, the average being close to four hours. This is equivalent to sixteen hours every two days for the scientific staff or to one man per day.

Physical Oceanography.--Of the work carried on at present, the following may be included under this heading:

Depth, temperature, salinity, and current computation. The data for all these subjects are converted to the final form in which they are to be published, all computations are carefully made and checked, and the final results plotted on a rough graph which serves as a convenient index of the accuracy and completeness of the work and as a guide for making minor changes in the program. No steps are taken toward preparing the material for publication.

Sonic depth measurements are made every three or four hours or oftener when the bottom is irregular. The depth found is corrected for density by means of temperature and salinity curves for the nearest oceanographic station.

Owing to errors in the depth recorders used on the oceanographic stations and to the often very considerable wire angle caused by the drifting of the boat, the depths indicated by the depth recorders often are greatly in error, even after being corrected for the wire angle observed at the surface. Consequently the depths for temperatures and water samples are based entirely on depths indicated by the pressure thermometers. To several of the Nansen bottles are attached one protected and one unprotected thermometer. From the readings of these thermometers, correction factors for the corresponding depth recorder readings are computed and used for correcting the depths indicated by the depth recorders.

In recording the temperatures a rather involved and time-consuming method is used but this undoubtedly could be simplified without seriously lessening the accuracy of the results.

Salinity is determined by the conductivity method but for about every sixth station a number of samples are analyzed by Knudsen's method. On board ship the conductivity method probably is the most convenient. It is said that the results will not be accurate unless determinations are made within a few hours after the samples are collected. One disadvantage of this method is that a large quantity of standard water is required. This water is expensive and takes up a considerable amount of storage space.

From the temperatures and salinities current computations are made. Because the stations are too far apart, and the lines often diagonal or parallel to the current, the results may not always be satisfactory.

In regard to current measurements, the writer wishes to suggest that, whenever possible, courses should be laid out so as to cross known or suspected currents at right angles, and in certain localities stations should be made sufficiently close together to give adequate information concerning the current.

For the work in physical oceanography discussed above, the time required averages, according to the estimate given in table 2, about ten hours per day. Adding to this the time required for an oceanographic station, the average per day becomes twelve hours.

A subject that is not investigated now, but should be included on future scientific cruises, is submarine illumination. This subject has been studied by modern methods only in coastal waters and any information obtained concerning it, therefore would be of especial value. The methods for measuring the penetration of light do not appear to be in a very satisfactory condition, however, and should be studied thoroughly and standardized before being included in the routine of an extended cruise.

Chemistry.--In all the samples collected at present, four chemical substances are determined, namely: oxygen, silica, phosphate, and hydrogen ions. It is not certain, however, whether one man will be able to continue to make all these determinations properly without some assistance either with the laboratory or the clerical work. The records for the chemical studies are brought to the same state of completion as those for the physical studies.

A number of other chemical studies are desirable on a cruise like that of the Carnegie but they require more man power than is available. For example, nitrate should be determined provided the technique is improved; carbon dioxide and alkalinity studies should be made; and the total fixed nitrogen, as well as ammonia nitrogen, should be determined. Because atmospheric nitrogen in sea water probably takes no part in either chemical or biological reactions, it is no longer determined. Because of its inertness, however, nitrogen no doubt would be a better index of the origin of the water of different strata than any other chemical or group of chemicals and therefore should be studied. Nitrogen could be determined with the manometric Van Slyke (1) apparatus since it would be practically the only gas remaining after the removal of CO_2 and O_2. It also could be determined directly by other more elaborate methods. For chemistry also, then, two men would be needed if a more complete chemical program were to be carried out. One man would need to have only an elementary knowledge of chemistry and no knowledge of oceanography.

Biology.--The biological work performed on board on the present cruise consists almost entirely of collecting plankton samples which are forwarded to the laboratory at Washington and stored for possible future study. At each station, samples are taken from the surface, 50, and 100 meters, both by horizontal towings and with the plankton pump. A vertical haul with an open net from 150 meters to the surface also is made.

Although the time required for carrying out a complete biological program on board ship would be prohibitive, a fairly extensive program of plankton work is feasible. A surprising amount of plankton, even of phytoplankton, is brought up by the townets. This material should be studied both qualitatively and quantitatively.

For carrying out the more elaborate program of plankton studies it will not be necessary to have the biological identifications made on board, but provisions should be made for collecting the material and for studying the collections as soon as they reach the laboratory. The planning of the biological work probably should be left to the biologist in charge, whether on board or at the laboratory on shore. The program, however, should provide for ascertaining the quantity, either weight or volume, of the total plankton in a vertical column of water or in known volumes of water from various depths. Plankton volumes could be measured on board by any worker and only a small amount of time would be required. The data obtained would be useful in planning the collecting work.

In connection with a more elaborate biological program, collecting methods need to be given a good deal of thought and planning. Methods that would delay the work at a station much beyond the time required for the Nansen series (or about four hours) should not be considered. Such delays would be caused by the Petterssen plankton pump if an adequate number of samples were to be obtained. The closing bottle-filtration method apparently would be feasible because this bottle could be operated, at small depths at least, while the Nansen series is being taken. Such bottle samples would be useful only for microplankton studies, however, but this is true of samples collected with the pump also. There are a number of other objections to the pump. Its weight is too great for convenient and safe handling, especially in rough weather, and mechanical troubles often develop. For general plankton work the old townet apparently has not yet been replaced as the most satisfactory collecting apparatus. The Carnegie staff now devotes about six hours at each oceanographic station, or an average of about three hours daily, to biological collecting work.

Bacteriology.--This subject is not investigated by Carnegie nor has it ever been investigated by any similar expedition. In fact it is doubtful if bacteriological technique, except that of collecting samples, has ever been used on board ship. For this reason no doubt it will be more difficult to plan a program for this subject than for any of the others.

Before incorporating such a subject in the program of a cruise, it should be determined whether it will be possible to obtain results that will justify allotting the space--laboratory and quarters--necessary for including bacteriology in the program. It appears that the following matters will need further attention: media for growing marine organisms, laboratory technique suitable for work on board ship, and collecting methods.

In developing the laboratory technique various factors must be borne in mind, such as the amount of space available, what quantities of either fresh or distilled water can be carried, whether gas is available, and whether electricity can be used in large or only small amounts. For heating purposes alcohol and gasoline burners can be used.

The collecting methods must be such that a sufficient number of samples can be obtained while not delaying the rest of the station work. If samples are to be obtained at great depths, a collecting apparatus that can be attached to the Nansen bottles should be devised.

In view of the fact that bacteriology is a new subject as far as the ocean is concerned, it might be advisable to vary the investigations somewhat during a cruise. For example, one part of a cruise might be devoted to the bacteria in the water, a second to bacteria in the muds, a third to a specific group of organisms, and so on. Such a program, however, would increase, rather than decrease, the amount of work necessary before the start of the cruise.

Geology.--The methods for collecting bottom samples appear to be satisfactory. Since usually it is not necessary to analyze bottom samples immediately after collecting, that work is done largely in a laboratory on shore, but a preliminary inspection is made on shipboard.

Factors Affecting the Itinerary of a Sailing Vessel

From the point of view of oceanography, it is unfortunate that with a sailing vessel the itinerary must be determined by the tradewinds and the seasons. The importance of the tradewinds becomes obvious when one considers that for a sailing vessel it is seldom possible to follow a course exactly along a meridian or parallel of latitude and perhaps never possible to return over a course parallel to the original one, unless the two courses are several hundred miles apart. In the case of a vessel like the Carnegie, then, comparatively straight lines, such as were followed by the Meteor in the South Atlantic, cannot be followed. Even if a more efficient engine than the present one is installed, the fuel capacity cannot be increased sufficiently to eliminate the need of making use of the winds.

Seasons cannot be disregarded because in most latitudes the sea is too rough during the winter to make collecting work practicable. Near latitude 60° south, oceanographic stations seldom can be occupied even in January. Low temperature itself considerably decreases the efficiency of the entire personnel.

Although the itinerary of an expedition must be determined largely by weather conditions, and the number of stations occupied or the number of samples taken, determined by the time allotted for a day's run and by the number of men available for the scientific work, it usually will be possible to vary the program within certain relatively narrow limits, and this possibility should be taken advantage of to the fullest extent. For cruise VII of the Carnegie the courses, as well as the number of oceanographic stations, were determined in advance. The advisability of such an arrangement for a cruise intended primarily for oceanographic investigations was discussed with Captain Ault and he agreed that a flexible schedule would be much more productive of results than a rigid one, provided the men on board possess sufficient knowledge of oceanography to plan the work to best advantage as the cruise progresses.

A few conditions under which a flexible schedule would be an advantage may be mentioned. If an uncharted irregularity of the sea bottom is found, it should be developed even if a delay of several days were necessary. An area with unusual physical, chemical, or biological conditions should be more thoroughly investigated than one where conditions are normal. Where a marked current is encountered, the oceanographic stations should be located close together.

Comments on Ship's Equipment

The Main Engine.--The Carnegie engine has only one raison d'être, namely, that it is nonmagnetic. The main objection to it probably is that it is not powerful enough. The horsepower is 125 and it is capable of propelling the boat at the rate of about four knots. This speed is insufficient in many harbors and channels where the tidal current is often considerable. Consequently sometimes it is unsafe for the Carnegie to enter a harbor without being towed, which, of course, is expensive and often inconvenient. Nor is a speed of four knots sufficient when running against a strong wind, a fact which renders working or sailing near shore dangerous.

Another serious objection to the present engine is the cost of operation and maintenance. Because it is built entirely of bronze, it wears more rapidly than one made of steel and all parts for replacements must be made to order and of material more expensive than steel. Another considerable item of expense is fuel. In most foreign ports the price of gasoline is two or three times the domestic price.

The Anchor Winch.--The equipment for anchoring, utilizing nonmagnetic materials, is not the most satisfactory. The anchor lines are of hemp and consequently are easily cut by rocks or coral. For power, a fisherman's windlass is used and the labor involved in raising the anchor is so great that anchoring is avoided except when absolutely necessary. A small engine and anchor chains could well be substituted for the present equipment.

The Radio Equipment.--This consists of a long-wave receiver, which is used mainly for receiving time signals, and a short-wave transmitter and receiver. The latter equipment is used for communicating with short wave (amateur) stations on shore. Through such stations messages are sent and received.

It is obvious that the above equipment has various disadvantages. The Carnegie cannot communicate with commercial stations or ships, since these use a wave length of 600 meters. Consequently if a distress signal is to be sent, it is first necessary to make contact with an amateur station on shore. This is often difficult since amateur stations ordinarily operate only at night. If an amateur station is found, its operator must be asked to telephone the message to a commercial or navy station who, in turn, broadcasts the distress signal to ships at sea. Such a system is, of course, exceedingly uncertain, first because of the difficulty of being heard and second, because relayed information is likely to be inaccurate.

To correct the deficiency, however, introduces other difficulties. The cost of a standard wave-length transmitter is not considerable but an R.C.A. operator would be required. Such an operator probably would not assist with the scientific work. Also, it would be necessary to pay for messages forwarded by commercial stations. The short wave equipment also could be used, of course, but it is doubtful if the R.C.A. operator would be permitted to send messages over it.

The Sonic Depth Finder.--On the Coast and Geodetic Survey ships the sonic depth finder has been replaced by the Fathometer. The latter is much more convenient to operate and can be used in much shoaler water (about fifteen fathoms). Although the sonic depth finder is satisfactory, a Fathometer is the preferable device.

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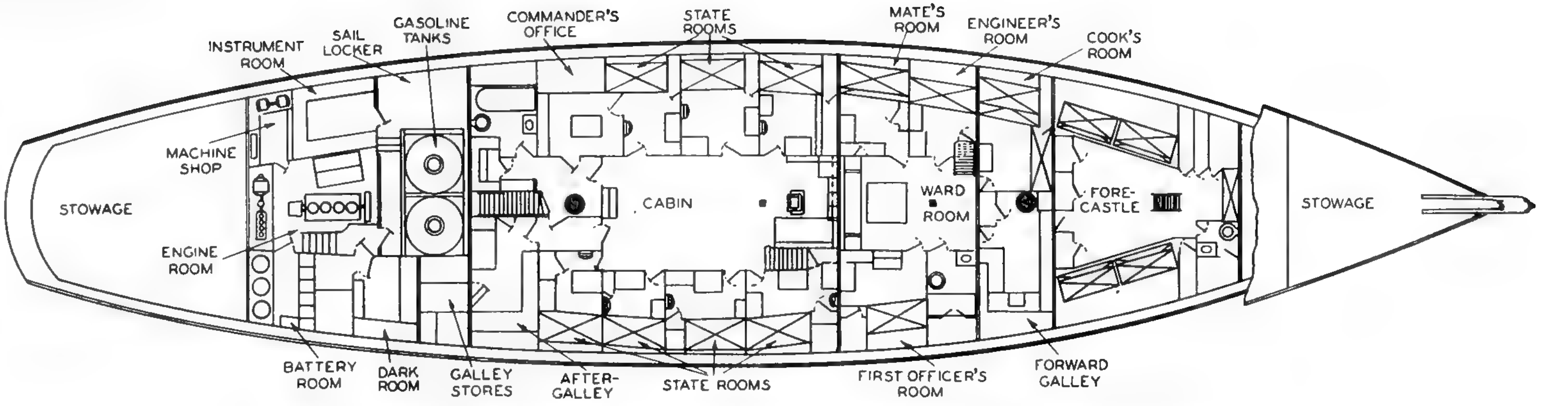

Fig. 1. View of the Carnegie below deck, showing arrangement of living quarters

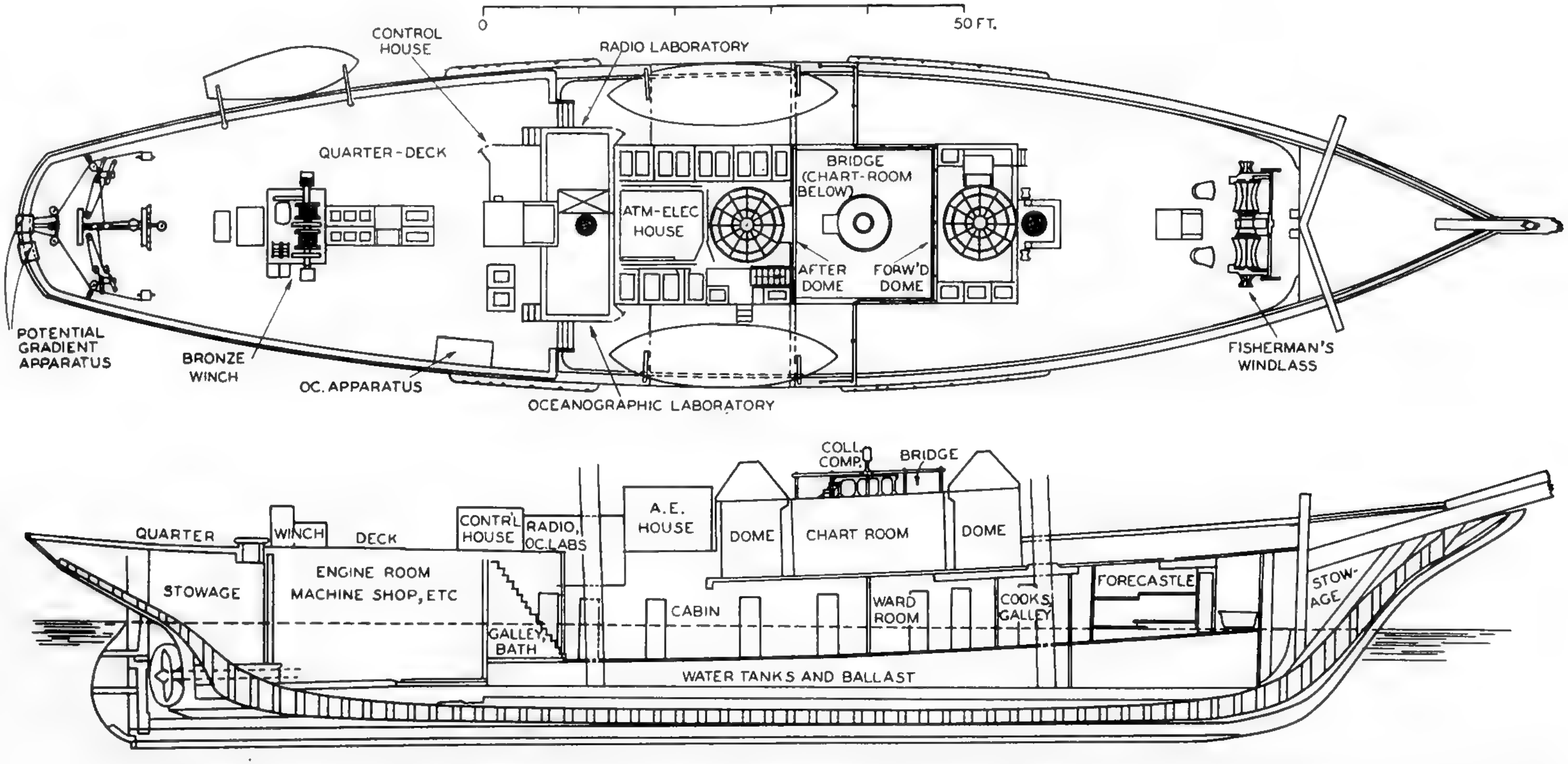

Fig. 2(A) and (B). Deck plan and vertical section showing arrangement of laboratories and deck space

V

GRAVITY DETERMINATIONS ON THE CARNEGIE

CONTENTS

GRAVITY DETERMINATIONS ON THE CARNEGIE

Early Gravity Observations at Sea

The importance of gravity measurements for determining the figure of the earth long has been realized and observations for this purpose have been in progress for at least a century. Within the last few decades the number of gravity stations has rapidly increased to several thousand. Most of these are located in Europe, Asia, and North America, and therefore are not well distributed geographically for the best determination of the figure of the earth. Likewise, since the land area comprises only twenty-eight per cent of the total surface of the earth, it is obvious that many observations over ocean areas are needed. Many of the values determined on islands cannot be used for this purpose because they are locally disturbed and are not representative for a greater area [see (1) of Literature Cited at the end of this paper].

The large number of gravity values determined for the purpose of deriving the accurate figure of the earth have been used in testing the isostatic condition of the earth's crust and the results obtained are found to agree completely with those obtained from studies of the deflections of the vertical as obtained from triangulation and astronomical data (2). The importance of gravity researches for studies of the stresses in the earth's crust, which must exist wherever there are deviations from isostatic equilibrium, has been pointed out (3).

The relation between these deviations from isostatic equilibrium and tectonic disturbances in the earth's crust has been demonstrated beautifully by a remarkable research done by Dr. F. A. Vening Meinesz, of the Netherlands Geodetic Commission, on "The gravity-anomalies of the East Indian Archipelago" (4). This research is based on the determination, on board a Dutch submarine, of gravity at nearly three hundred stations, practically all of which were made with the vessel submerged. A similar research, made in the West Indies in 1928 by Dr. Vening Meinesz in cooperation with the U. S. Navy and the Carnegie Institution of Washington (1), subsequently (1932) was extended through further observations by Dr. Vening Meinesz on a submarine placed, by the U. S. Navy, at the disposal of the International Expedition to the West Indies under the direction of Professor Richard M. Field, of Princeton University.

Until Dr. Vening Meinesz conceived the idea of swinging two practically identical and nearly isochronous pendulums in the same vertical plane and recording photographically the difference in their angles of elongation, no satisfactorily accurate method of making gravity observations at sea was available. This was owing principally to the fact that the horizontal accelerations on a ship at sea so disturb the motion of a single pendulum that it is not possible to obtain any accurate value of gravity by this means. If, however, the difference in the angles of elongation of two practically identical and nearly isochronous pendulums swinging in the same vertical plane be recorded, then this difference is, within limits, quite independent of horizontal accelerations of the apparatus, for the simple reason that however this horizontal acceleration may affect the angle of elongation of one of the pendulums, it will affect that of the other in the same way. This is the fundamental idea of the apparatus of Dr. Vening Meinesz and it is this principle which has made possible the success of several hundred observations which he has made on board submerged submarines.

The experience of Dr. Vening Meinesz with his apparatus on board the Dutch submarines, H. M. S. K XIII, K II, and K XI, and in particular on board the U. S. submarine S-21 (1), indicated that it might be possible to obtain gravity measurements on board surface vessels. In view of the character and extent of cruise VII of the Carnegie, of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, there seemed to be an ideal opportunity for obtaining gravity measurements at sea, in various harbors, and near several islands, which results would have been most desirable for a better determination of the figure of the earth and for further studies in isostasy.

Installation and Tests of Apparatus

Accordingly, it was decided to install a Meinesz gravity apparatus on the Carnegie at San Francisco, in August 1929, for this was the nearest port to Washington in the remainder of the cruise, and therefore required the least amount of transportation of apparatus and men to install it and to make the necessary adjustments and tests. Because of the great amount of detail and precision required in building such an apparatus and to the fact that the makers, Nederlandsche Seintoestellen Fabriek, at Hilversum, Holland, were dependent on other firms for special parts, it would have been impossible to complete the instrument in time to standardize it at the U. S. Coast and Geodetic Survey gravity base station and install it on the Carnegie at San Francisco, without the cooperation of interested persons and organizations as well as of the manufacturers.

Through the efforts of Dr. Vening Meinesz and the fine spirit of generous cooperation on the part of Dr. N. E. Nörlund, Director of the Geodetic Service of Denmark, it was arranged that the apparatus which had been ordered for the Geodetic Service and which was nearly completed, be delivered to Washington, although this meant no inconsiderable delay to the investigations of Dr. Nörlund in this direction. A set of invar pendulums kindly was loaned by the Netherlands Geodetic Commission. This cooperation made possible the delivery of an instrument in time for the standardization in Washington and the installation on the Carnegie in San Francisco (fig. 1).

The standardization at Washington and the preliminary records on the Carnegie at San Francisco were made under the supervision of Dr. F. E. Wright, of the Geophysical Laboratory at Washington. His experience in working with Dr. Meinesz on the gravity-measuring cruise of the U. S. submarine S-21 made his assistance invaluable. The instrument was placed in the main cabin of the Carnegie about seven feet abaft the chronometer cases. This was about as near to the center of oscillation of the ship as it was possible to determine that point.

The adjustments of the apparatus were completed before the end of August. They included an installation of a special time-signal amplifier, which had been used in Washington for the standardization, and which provided for the recording of wireless time signals automatically on the photographic record of the gravity instrument, in order to make for high precision in the corrections and rates of the chronometers used in the determinations of gravity. Provision also was made to obtain the chronometer corrections aurally by using coincident beats of a mean-time chronometer with rhythmic radio time signals, or by using the coincident beats of a fast-running chronometer with mean-time radio signals. When at sea on board the Carnegie the aural method was used entirely, for it was not necessary then to swing the pendulums and to develop the photographic trace, and, moreover, it was found that reliable aural comparisons could be made when radio reception was so poor that the signals could not be recorded automatically. The aural method, together with the calculations for the chronometer corrections, is described in "The gravity-measuring cruise of the U. S. submarine S-21" (1, pp. 37-38).

The method is the same as for a coincidence determination between two chronometers; it requires the notation of the times indicated by the chronometer and by the radio time signal at the instant of coincidence. Since the method has seemed difficult to some observers, it will be described in more detail. It consists in putting the chronometer circuit, which is alternately open and closed for half-second intervals, in series with the phones through which the radio time signals are to be heard. Since the chronometer rate is altered so that it gains one mean-time second in about sixty-five, the purpose of which is to insure several coincidences with the radio time signals during the few minutes of their transmission and further to insure that these coincidences do not all occur in the silent intervals which are used to identify the minutes of the signal, the effect is a periodic "appearance" and "disappearance" of the radio signal. Some reflection shows that just when the time signal "disappears" there is a coincidence between the beginning of a radio time-signal impulse and one of the chronometer beats, and that the "appearance" marks a coincidence between the end of a particular time-signal impulse and a chronometer break. Since the corrections to time signals which are sent out by the transmitting observatory are for the beginnings of the impulses, it is clear that only the coincidences on "disappearance" should be used. If rhythmic radio time signals are used, then the coincidences may be obtained directly with the beats of a mean-time chronometer. The observer must be prepared at the instant of the coincidence to note both the chronometer time and the radio time. With some practice this can be done easily if the observer counts, from the beginning of an interval in which a coincidence is expected, the beats of the chronometer, which he can always hear in the phones. Suppose a coincidence is expected when the chronometer reads about thirty seconds. At fifteen seconds, for instance, the observer, by watching the chronometer, notes that beat in the phones which occurs just when the chronometer second-hand moves to fifteen; this beat he calls "fifteen," the next beat he calls "half," the following one "sixteen," and then successively "half," "seventeen," "half," "eighteen," etc., to the instant of coincidence. Thus the observer carries the fast-running chronometer time in his head without the necessity of continuously watching this chronometer; a glance at it at any instant tells him whether his counting is correct. To determine the radio signal time at the instant of coincidence, he notes visually the time, to the nearest half-second, indicated by a mean-time chronometer. Then he immediately writes down in seconds and half-seconds the time by each chronometer. After this is done he has plenty of time, nearly a minute, to note the number of hours and minutes indicated by each chronometer. To obtain the radio time of the coincidence it is necessary to know, only to the nearest half-second, the correction of the mean-time chronometer on the radio signal. Generally this can be obtained between coincidences by throwing a switch which will allow only the radio signals to be heard in the phones; the mean-time chronometer reading to the nearest half-second is then obtained visually at the beginning of a particular minute of the radio signal, or at the middle of the minute if this is identified by the signals.

The radio apparatus on the Carnegie was located in a cabin on the main deck; the gravity apparatus and the chronometers were below in the main cabin. Leads served to transmit the time signals from the radio receiver through a pair of phones worn by one observer near the chronometers. The circuit was so arranged that as soon as the radio operator had tuned in the time signal he could also hear the coincidences and by means of an auxiliary chronometer note the radio times of coincidences. These data, together with those obtained by the first observer, provided in effect two independent coincidence determinations. When the time signals were weak, this proved of great assistance and provided a good check. The two sets of coincidence determinations gave corrections to the chronometers which rarely differed by more than about 0.02 second.

In this connection must be mentioned the importance of obtaining corrections to the chronometers as frequently as possible, in order to minimize the effect of any diurnal variation in their rates. In any case, the daily rates as obtained between time-signal observations are the average rates for the interval between time signals. The duration of a gravity observation is about half an hour. If the actual rates of the chronometers during this half-hour differ from the average rates in the interval between time signals, then an error in the calculated value of gravity results. Data indicating this magnitude of variations in the difference in the daily rates of the two chronometers may be obtained in two ways. One consists in postulating that the difference between the two values of the period of either of the two pendulums in the gravity instrument as obtained from the two chronometers is owing to the difference in their daily rates. The second method consists of making an accurate comparison of the two chronometers near the beginning of the gravity record and again near the end. This can be accomplished by using the swing of the fictitious pendulum (to be described later) itself to measure the time interval between adjacent breaks of the two chronometers. The comparison, thus, is obtained with sufficient accuracy, particularly if the two chronometer breaks are not far apart, and further if they are on the same slope of the pendulum curve and near the center of the record as well.

The difference in the daily rates calculated by these two methods should be in good agreement and thus should provide some check on the determinations of the periods. The deviations between this difference in the daily rates and that obtained from the time signals give some indication of possible fluctuations in chronometer rates.

Theory of the Apparatus

The complete theory and description of the apparatus will be found in "Theory and practice of pendulum-observations at sea," by Dr. F. A. Vening Meinesz (5), and also in "The gravity-measuring cruise of the U. S. submarine S-21" (1). The theory and description of the apparatus will be considered, therefore, only in their essentials.

If all other disturbances except the horizontal accelerations are left out of consideration, the equations of motion of two pendulums may be written

$$d^2\theta_1/dt^2 + (g/\ell_1)\theta_1 + (1/\ell_1)\, d^2x/dt^2 = 0 \ldots (1)$$

$$d^2\theta_2/dt^2 + (g/\ell_2)\ell_2 + (1/\ell_2)\, d^2x/dt^2 = 0 \ldots (2)$$

in which θ_1 and θ_2 are the angles of elongation of the two two pendulums of length ℓ_1 and ℓ_2 respectively, g is the acceleration of gravity, and d^2x/dt^2 is the component in the plane of oscillation of the horizontal accelerations of the knife edges. If the two pendulums are isochronous, then $\ell_1 = \ell_2 = \ell$, say, and the result of subtracting (2) from (1) gives

$$(d^2\theta_1/dt^2 - d^2\theta_2/dt^2) + g/\ell\,(\theta_1 - \theta_2) = 0 \;\; .\,(3)$$

(3) is just the equation of motion of an undisturbed fictitious pendulum of length ℓ and angle of elongation $(\theta_1 - \theta_2)$, which is isochronous with each of the original pendulums. In the apparatus $(\theta_1 - \theta_2)$ is recorded photographically by means of mirrors attached to the tops of the pendulums. If it were possible to produce two pendulums which were isochronous within sufficiently small limits, the problem would be much simpler. Since this is not possible, the effect of any deviation in isochronism between the two original pendulums must be considered.

If this deviation from isochronism is sufficiently small, the only effect is to alter the period T of the fictitious pendulum from T_1, the period of the first original pendulum, by an amount δT where

$$T = T_1 + \delta T \ldots\ldots\ldots\ldots (4)$$

and

$$\delta T = -(T_2 - T_1)\,(a_2/a)\cos(\phi_2 - \phi) \ldots\ldots (5)$$

in which a_2 and a are, respectively, the amplitudes of the second original pendulum and of the fictitious pendulum, and ϕ_2 and ϕ their angles of elongation. $(T_2 - T_1)$ is the difference in the periods of the original pendulums at the temperature and air density during the observation. The apparatus records photographically ϕ_2 and ϕ, and since $a_2 \cos(\phi_2 - \phi)$ is the component of the pendulum-vector of the second pendulum in the direction of the fictitious pendulum-vector, the recording apparatus is arranged to facilitate, during most of the record, the measurement of $a_2 \cos(\phi_2 - \phi)$. This accounts for the change in appearance of the middle part of the records in figure 4.

Effect of Vertical Accelerations

The effect of vertical accelerations, during the observations throughout an interval t, on the resulting value of gravity will be simply the average value of those accelerations over the interval, that is,

$$1/t \int_0^t (d^2y/dt^2)\, dt \ldots\ldots\ldots\ldots (6)$$

which is equal to

$$1/t\,[(dy/dt)_t - (dy/dt)_o] \ldots\ldots\ldots (7)$$

This is to say that the effect of the vertical accelerations on the measured gravity is simply the difference in the vertical velocities at the beginning and end of the observation, divided by the time-interval t. This effect may be made as small as desired in two ways: first by making t large, and second by taking at the beginning and end of the observation the mean of the positions of the fictitious pendulum-vector for a great many seconds over which time the average value of the vertical velocity may be quite small. In this way observations of half an hour are more than sufficient to make this disturbance negligible.

Effect of Angular Movements

If β is the angle between the plane in which the pendulums swing and the vertical, the component of gravity in this plane is $g \cos \beta$. The angle β is made up partly of a constant quantity β_c and partly of a fluctuating quantity α, the period of which depends on the period of the apparatus in the gimbal suspension. The effects of accelerations introduced by rotations of the pendulum system about a horizontal and about a vertical axis in the plane of the pendulums must also be considered. The correction, δT, to the period of the fictitious pendulum for the latter effects may be combined with that due to the tilt of the swinging plane. It is given approximately by

$$\delta T = 1/4\, T_1\,[\beta_c{}^2 + C\alpha^2] \;\ldots\ldots\ldots (8)$$

in which

$$C = 1/2\,[1 - 2(T_1{}^2/T_f{}^2)] \ldots\ldots\ldots (9)$$

and T_1 = period of the first original pendulum, T_f = period of the fluctuating tilt, $\beta_c{}^2$ and α^2 are mean values during the observation. The approximation is accurate enough if no one of the periods of the fluctuating quantities is near that of the pendulums. This will be the case if the amplitude of the fictitious pendulums does not show any trace of fluctuations.

Other Corrections

The correction to the period because of the finite amplitudes of the pendulums is given by

$$\delta T = 1/16\, T_1\,[\{a + 1.5\, a_2 \cos(\phi_2 - \phi)\}^2 + a_2{}^2 - 1/4\, a_2{}^2 \cos^2(\phi_2 - \phi)] \;\ldots\ldots (10)$$

in which, as before, T_1 is the period of the first original pendulum, a is the amplitude of the fictitious pendulum, a_2 is the amplitude of the second original pendulum, ϕ_2 is the elongation angle of the second original pendulum, and ϕ is the elongation angle of the fictitious pendulum. As in the case of the ordinary pendulum, corrections must be applied for the temperature of the pendulums, for the density of the air surrounding them, and for rate of chronometer. These are as follows:

Temperature: $\delta T = c_1 t$ .... (11)
Density: $\delta T = d_1 D$ .... (12)
Rate of chronometer: $\delta T = -115.7\, rT \times 10^{-7}$ sec . . (13)

in which c_1 is the temperature constant of first original pendulum, d_1 is the density constant of first original pendulum, T is the period of the fictitious pendulum, and r is the daily rate in seconds of the chronometer used. The values of δT are the quantities which must be subtracted from the observed period of the fictitious pendulum in order to obtain the reduced period. The reduced period is the same as T_1, the period of the first original pendulum.

The Apparatus

The apparatus contains three principal quarter-meter pendulums, which are nearly isochronous and which swing in the same vertical plane. To facilitate description, the outer ones are designated as numbers 1 and 3, and the middle one as number 2. Their knife edges are about thirteen centimeters apart. By means of mirrors the following angles of elongation are recorded: $(\theta_1 - \theta_2)$, $(\theta_3 - \theta_2)$, and θ_2. The first two of these are the angles of elongation of two fictitious pendulums. The last provides the data to determine the corrections to the periods of the two fictitious pendulums which reduce them to T_1 and T_3, respectively. During the routine gravity observations the two outer pendulums are swung with equal amplitudes and opposite phases, whereas the middle pendulum is given as little amplitude as possible. It should be emphasized that the values of gravity are derived from each of the two fictitious pendulums.

The datum for recording θ_2 is a critically damped pendulum in the same plane as the other three. A second critically damped pendulum, in a plane at right-angles, records the tilt of the swinging plane.

Inside the apparatus there is also a dummy pendulum which contains a thermometer. There is also a hair hygrometer. Provision is made for mechanically lifting the pendulums off their knife edges and for firmly clutching and locking them when they are not in use, so they cannot be damaged during any rough weather at sea. Mechanical means also are provided for lowering the pendulums slowly so there will be no damage done to the agate knife edges or to the agate planes on which they rest. Further control is provided for giving the pendulums known amplitudes and phase relations at the beginning of an observation. These operations are carried out from the outside of a double-walled heat-insulated metal box, which contains the pendulums. Figure 2 shows the outward appearance of this part of the apparatus. The controls just described appear below the name plate on the front. Figure 3 is a top view of the apparatus after it has been removed from the box shown in figure 2. It shows the arrangement of the mirrors, prisms, and lenses for recording the pendulum movements. The top part of the apparatus, as shown in figure 1, contains the photographic paper for recording the pendulum movements. It also contains the source of light, the shutter mechanism which is operated by the two chronometers, the controls for altering the speed of the photographic paper, and a small window through which the movements of the light images on the paper may be observed during an observation without interrupting the recording.

The Record

Reading from bottom to top, figure 4 shows, on a reduced scale, three records obtained respectively in San Francisco, Honolulu, and Pago Pago (American Samoa). The actual width of each record is about 12 cm, and its duration is about thirty minutes. On each record the two upper curves, which have about the same width, are derived from the oscillations of the two fictitious pendulums, whereas the lower curve is derived from the oscillations of the middle pendulum alone. Its variable amplitude indicates how it is affected by the ship's movements. The regular amplitudes of the two fictitious pendulums show that these are quite unaffected by the ship's movements.

Superimposed on the trace of each fictitious pendulum are four sine curves. Two of these, which are 180° out of phase, are produced by a mean-time chronometer, whereas the other two are produced by a sidereal chronometer. Each chronometer, by means of an electrical circuit, causes a shutter to pass every half second in front of the beam of light, and interrupts the recording for about 0.01 second, thus producing the series of white marks which form the phase-lag curves. The period of each fictitious pendulum is obtained independently from each of the two chronometers by carefully measuring the time interval in which the phase-lag curve goes through a known number of cycles. In this way the uncorrected period of each fictitious pendulum can be determined from good records with an error not greater than about 5×10^{-7} second.

From the bottom curve on each record are obtained the corrections to each of the two fictitious pendulum periods, for deviation from isochronism, and also for reduction to infinitesimal amplitude. To facilitate the necessary measurements for these corrections, the shutter mechanism is changed so that the beam of light is interrupted for alternate half seconds, and to save paper and not make the record unnecessarily long, the speed of the paper is reduced. This explains the change in appearance of the middle part of each record. The observations are made by giving the two outer pendulums equal amplitudes and opposite phases, whereas the middle pendulum is given no amplitude, though, of course, its amplitude is soon increased by the ship's movements.

Behavior of Apparatus on Carnegie

No particular difficulty was experienced in obtaining gravity records on board the Carnegie while she was in port at San Francisco, Honolulu, and Pago Pago (American Samoa), although the amplitude of the middle pendulum in all but one of the records obtained at San Francisco always got quite large considering the small movements of the ship. This doubtless was owing, not so much to the amplitude of the ship's movements, as to the irregular movements caused by the "rubbing" of the ship against the pier.

Several attempts were made to obtain gravity determinations at sea during the seventeen-day voyage from San Francisco to Honolulu, and again during the forty-seven days from Honolulu to Pago Pago (American Samoa). Most of these were unsuccessful because the amplitudes of the pendulums got too large and in a few instances there was actual slipping of the knife edges. Figure 5 is a reproduction of three records obtained at sea. The upper record was obtained in the open sea between San Francisco and Honolulu, the middle one off West Passage, Penrhyn Island, and the lower one off Tauhunu Village, Manahiki Island. Because of the large amplitude of the middle pendulum, the lower curve on each record is indistinct. On the originals it was clear enough to insure a satisfactory reduction of the upper two records. The vertical blank spaces in the upper record are due to the observer's having momentarily thrown the recording spots, by means of a reflecting prism provided for the purpose, on a special ground-glass screen to insure that the apparatus was functioning properly. This in no way disturbs the record.

The sudden change in the amplitudes of the fictitious pendulums near the left end of the lower record indicates that the middle pendulum slipped on its knife edge. Other unsuccessful attempts to obtain gravity records at sea failed either for the same reason or because it was feared that slipping would occur.

Several factors may operate to increase the amplitudes of the pendulums to the point where slipping may occur. One is the unavoidable horizontal acceleration due to the rolling of the ship. Another, and this Dr. Vening Meinesz from his long experience with the apparatus considers quite important, is the effect of surface waves on the hull of the ship to produce horizontal accelerations apart from those due to rolling. Finally there are the elastic vibrations of parts of the apparatus or its support. If the period of such vibrations is near to the period of the pendulums, there will be a resonance effect which will cause the pendulum amplitudes to get large.

Some experiments were made in Honolulu harbor to determine whether the gimbal frame supporting the pendulum apparatus had a period which would produce large amplitudes in the pendulums. These experiments consisted in starting the pendulums swinging in the same way as for a gravity observation and then displacing the whole frame slightly and allowing it to vibrate. These vibrations, though small in amplitude, caused a large increase in the pendulum amplitudes. The frame then was temporarily braced so that it was impossible to cause the whole apparatus to vibrate in such a way that it would affect the pendulum amplitudes. With this same bracing further attempts at sea were made to obtain gravity records, but without any obvious improvement. Possibly the cause for the large effect on the pendulums originated not in the vibrations of the main supporting frame of the apparatus but in vibrations of one of the several subsidiary members necessary for the gimbal suspension. This must be taken into account when it is considered that the frame of the apparatus was made of brass, in order not to introduce unnecessary magnetic material on the Carnegie, and that the members were not of sufficient size to insure rigidity.

Dr. Wright, under whose direction the first observations were made on the Carnegie in San Francisco harbor, is of the opinion that the lack of rigidity in the platform on which the apparatus was mounted is a factor which should be strongly emphasized in attempting to explain just why the pendulum amplitudes got too large for the instrument to function properly.

This experience indicates the necessity of making experiments on land before installing such an apparatus on a ship to insure that no part of the apparatus has a period of vibration which can materially affect the pendulums. These experiments also should include tests to determine whether the period of the apparatus in the gimbals has any effect on the pendulums. In these tests it must be observed that any effect which causes a variation, apart from that due to damping, amplitude, and isochronism, of the amplitude of the fictitious pendulums will have an effect on their periods. The causes of any such variations then must be removed.

It seems also, from the writer's experience on board the Carnegie, that the friction in the bearing points of the gimbal suspension caused the movements of the apparatus to be somewhat jerky. This was overcome only partly by adjustments of the size of the damping vane which was attached to the apparatus and immersed in oil.

The Carnegie experience suggested, and the experiments of Dr. Vening Meinesz on board some passenger vessels confirm, that orienting the apparatus so that the plane of oscillation of the pendulums is parallel to the ship's keel instead of perpendicular to it, considerably increases the probability of obtaining a successful gravity determination. It now seems quite possible that, had the apparatus on the Carnegie been so oriented, a large number of successful determinations would have been obtained.

Remarks on Reductions

It should be borne in mind that the Meinesz gravity apparatus does not determine the absolute value of gravity at any station, but only the value at that station relative to a base station. The base station for Carnegie observations was that of the U. S. Coast and Geodetic Survey in Washington. Since the correction for deviation from isochronism depends on the difference in the periods of the middle pendulum and that outer pendulum from which the fictitious pendulum is derived (see equation 5), it is obvious that this difference must be known. Observations at the base station under somewhat special initial conditions (5, p. 28) are needed for determining this deviation of isochronism. Unfortunately, in the observations made at the base station in Washington, the phase relation between the pendulums was such that the deviation from isochronism in the two pendulum pairs could not be obtained. It was possible, however, to obtain approximate values of $(T_2 - T_1)$ and of $(T_2 - T_3)$ in another way. The rate of change of amplitude of each fictitious pendulum depends on the damping, the amplitude, and the deviation of isochronism. The following equations (taken from 5, p. 21) determine the effect of each factor:

$$\text{Damping:}\quad da/dt = -ka \quad \ldots\ldots\ldots (14)$$

$$\text{Amplitude:}\quad da/dt = (\pi/16T)\, a\, a_2 \sin(\phi_2 - \phi)\,[a + 2a_2 \cos(\phi_2 + \phi)] \quad \ldots\ldots\ldots (15)$$

$$\text{Deviation of isochronism:}\quad da/dt = -(\pi/T^2)\, U\, a_2 \sin(\phi_2 - \phi) \quad \ldots\ldots (16)$$

in which a is the amplitude of the fictitious pendulum; a_2 is the amplitude of the middle pendulum; T is the period of the fictitious pendulum; U is equal to $(T_2 - T_1)$, that is, the deviation from isochronism in pendulums 1 and 2; $a_2 \cos(\phi_2 - \phi)$ is the component of the pendulum-vector of the second pendulum in the direction of the fictitious pendulum-vector; and $a_2 \sin(\phi_2 - \phi)$ is the component perpendicular to this direction. The last two quantities can be measured directly from the record. The average total rate of change of amplitude of the fictitious pendulum is first measured over an interval chosen so that the average of $a_2 \sin(\phi_2 - \phi)$ is zero. Thus by virtue of equations (15) and (16), the effect of amplitude and isochronism is zero. This allows k in equation (14) to be computed. When this has been done, another interval is chosen (perhaps on a different record), so that the average of $a_2 \sin(\phi_2 - \phi)$ is as large as possible. For this interval the rate of change of amplitude due to damping and amplitude is calculated by equations (14) and (15). The average total rate of change of amplitude is measured from the record; the difference between this value and the sum of the effects due to damping and amplitude is owing to the deviation from isochronism and may, therefore, with the aid of equation (16), be calculated. A similar procedure gives $(T_2 - T_3)$, the lack of isochronism in the other pair.

In this way $(T_2 - T_1)$ was found to be about -250×10^{-7} second, whereas $(T_2 - T_3)$ was less than about 40×10^{-7} second. Considerable uncertainty in these values, particularly in the latter one, results from the errors in the actual measurements of the total rate of change of amplitude used in their determination. Unfortunately, in all the Carnegie records which were used in determining gravity, the second factor in the correction for deviation from isochronism was small [see equation (5)], so that the possible error in this correction due to the uncertainties in $(T_2 - T_1)$ and $(T_2 - T_3)$ probably is not greater than about 10×10^{-7} second even in the most unfavorable record. The deviation of isochronism in each pair, however, was known to be not greater than 50×10^{-7} second when the pendulums were adjusted in Europe. The large value of -250×10^{-7} second for $(T_2 - T_1)$ obtained at the base station in Washington indicates that some accident occurred to pendulum no. 1 before the base station observations were made. In view of this, it seems likely that T_1 might, with use, have been subject to further changes apart from changes due to variations in gravity.

If no change in either T_1 or T_3, apart from change due to variation in gravity, had occurred after the Washington observations, the values of $(T_1 - T_3)$ should have been constant. An inspection of the last column in table 1, however, indicates that they show variations which are much too large to be due to errors in their determination. These variations in $(T_1 - T_3)$ therefore have been attributed to changes in T_1 in view of its probable inconstancy.

Table 1. Gravity results on K XIII by Meinesz (1926) and on the Carnegie (1929)

Station	K XIII	Carnegie		Carnegie difference $(T_1 - T_3)$
		T_3 only	T_1 only	
	cm/sec^2	cm/sec^2	cm/sec^2	sec $\times 10^{-7}$
San Francisco	979.998	979.999	980.015	+216
		980.009	980.024	+218
Honolulu	978.942	978.940	978.968	+188
Pago Pago	....	978.662	978.671	+234
		978.673	978.671	+261
		978.669	978.676	+238
Penrhyn	....	978.453	978.450	+264
At sea	....	979.197	979.191	+274

For this reason those values of gravity derived from T_1 are given no weight except to provide some check on the values derived from T_3. A glance at table 1, which gives the values of gravity in centimeters per second for each separate determination, shows that the values of gravity obtained in San Francisco and Honolulu are in much better agreement with those previously determined there by Dr. Vening Meinesz when T_3 is used for the calculation than when T_1 is used. This seems to indicate further that T_1 was subject to erratic changes. The values in the second column were obtained by Dr. Vening Meinesz on board the Dutch submarine K XIII during a cruise from Holland to Java in 1926.

A further inspection of table 1 shows that for the last three stations, which are the only new ones determined on the Carnegie, the values of gravity derived from T_1 and from T_3 are in fairly good agreement. Practically then, it is not important whether the values derived from T_1 are rejected or not as far as the new stations are concerned.

Table 2 gives the latitude and longitude for each of the five stations.

Table 2. Geographical positions, Carnegie gravity stations

Station	Latitude (ϕ)	Longitude (λ)
San Francisco	37 47.6 N	122 23.4 W
Honolulu	21 18.5 N	157 52.0 W
Pago Pago	14 16.6 S	170 41.0 W
Penrhyn	8 59.7 S	158 03.8 W
At sea	27 44.8 N	135 22.1 W

The results of the computations for the isotatic reductions of the last three stations as made by the U.S. Coast and Geodetic Survey are given in tables 3 and 4. The methods used in calculating the reductions were those elaborated by Hayford and Bowie (6 and 7).

Remarks on Anomalies

The last line in table 3 gives the values of the isostatic anomalies, according to the Bowie formula of 1917, at the three Carnegie stations. The first of these stations, marked "at sea," has a positive anomaly according to the Bowie formula of 1917 of 0.036 cm/sec^2. This value agrees with the average anomalies obtained by Dr. Vening Meinesz for stations in this approximate neighborhood of the Pacific. The positive anomaly of 0.040 cm/sec^2 at Penrhyn is not unusual. Dr. Vening Meinesz is of the opinion that the large positive anomaly at Pago Pago--0.110 cm/sec^2 according to the Bowie formula of 1917--probably has some connection with the neighboring Tonga Deep, since up to the present practically all the deeps where observations have been made, show a strip of negative anomalies over or near the deep, bordered on both sides by fields of positive anomalies which in several instances attain rather large values. He considers quite unlikely the possibility that this anomaly is owing to the fact that the island is composed largely of a heavy basalt or to the fact that the station, although made in the harbor of Pago Pago effectively was not far from the center of the island. A detailed

Table 3. Principal facts at Carnegie gravity stations

Values are based on Potsdam System

Element	Station		
	At sea	Penrhyn	Pago Pago
Latitude (ϕ)	27° 44'.8 N	8° 59'.7 S	14° 16'.6 S
Longitude (λ)	135° 22'.1 W	158° 03'.8 W	170° 41'.0 W
Depth, fathoms	2465	130	10
Observed gravity (g), cm/sec^2	979.197	978.453	978.668
Corrections, cm/sec^2			
Elevation	0.000	0.000	0.000
Topography and compensation	+0.004	+0.248	+0.205
Computed values, cm/sec^2			
Helmert[a], theoretical $\gamma_0 = \gamma_0''$ [b]	979.149	978.156	978.344
computed gravity (g_c)	979.153	978.404	978.549
Bowie[c], theoretical $\gamma_0 = \gamma_0''$ [b]	979.157	978.165	978.353
computed gravity (g_c)	979.161	978.413	978.558
Anomalies, cm/sec^2			
Free air ($g - \gamma_0''$), Helmert[a]	+0.048	+0.297	+0.324
Bowie[c]	+0.040	+0.288	+0.315
Isostatic ($g - g_c$), Helmert[a]	+0.044	+0.049	+0.119
Bowie[c]	+0.036	+0.040	+0.110

[a] Using Helmert formula of 1901, $\gamma_0 = 978.030\ (1 + 0.005302 \sin^2 \phi - 0.000007 \sin^2 2\phi)$. [b] Stations being at sea level with no correction for elevation. [c] Using Bowie formula of 1917, $\gamma_0 = 978.039$ $(1 + 0.005294 \sin^2 \phi - 0.000007 \sin^2 2\phi)$.

investigation of the gravity field in the region of the Tonga Deep doubtless would prove of great interest, especially since there is a great deal of volcanic activity in this area.

Thus the contribution in number of new gravity stations determined on board the Carnegie during the last few months of her cruise is not great. It has been the aim of this report of the first attempt to make accurate determinations of gravity on board a sailing ship at sea, to show that in spite of the difficulties inevitably encountered in any first attempt, and in spite of the writer's lack of any previous experience with the apparatus, together with the fact that because of numerous other duties he could devote only a small amount of his time to this research, a few successful observations were obtained.

It is hoped that this report may succeed first in stimulating further researches in gravity determinations at sea, either aboard surface ships or aboard submarines, and second in being of some assistance in their success.

Acknowledgments

Grateful appreciation is expressed to Dr. F. A. Vening Meinesz, whose personal interest and assistance have made it possible to complete the Carnegie gravity reductions, and to Captain R. S. Patton, Director of the U. S. Coast and Geodetic Survey, through whose interest and cooperation the isostatic reductions for the three new Carnegie gravity stations were made by that bureau.

Table 4. Corrections for topography and compensation for *Carnegie* gravity stations

Zone	Elevation	Correction for			Zone	Correction for topography and compensation	
		Topography	Compensation	Topography and compensation			
				Station at sea			
	feet	cm/sec^2	cm/sec^2	cm/sec^2		cm/sec^2	
A	- 9096	-0.0001	....	-0.0001	18	+0.0093	
B	- 9096	-0.0046	+0.0002	-0.0044	17	+0.0092	
C	- 9225	-0.0109	+0.0005	-0.0104	16	+0.0092	
D	- 9225	-0.0227	+0.0011	-0.0216	15	+0.0092	
E	- 9225	-0.0382	+0.0022	-0.0360	14	+0.0094	
F	- 9225	-0.0448	+0.0028	-0.0420	13	+0.0156	
G	- 9225	-0.0405	+0.0033	-0.0372	12	+0.0095	
H	- 9225	-0.0372	+0.0044	-0.0328	11	+0.0078	
I	- 9225	-0.0374	+0.0074	-0.0300	10	+0.0059	
J	- 9225	-0.0247	+0.0103	-0.0144	9	+0.0036	
K	- 9225	-0.0178	+0.0148	-0.0030	8	+0.0031	
L	- 9225	-0.0125	+0.0221	+0.0096	7	+0.0013	
M	- 9225	-0.0136	+0.0542	+0.0406	6	+0.0013	a
N	- 9179	-0.0040	+0.0470	+0.0430	5	+0.0010	
O	- 9185	-0.0003	+0.0463	+0.0460	4	+0.0007	
...	....	....	....	....	3	+0.0004	
...	....	....	....	....	2	+0.0004	
...	....	....	....	....	1	0.0000	
Total (all zones, lettered and numbered)						+0.0042	
				Station at Penrhyn			
	feet	cm/sec^2	cm/sec^2	cm/sec^2		cm/sec^2	
A	- 480	-0.0001	....	-0.0001	18	+0.0113	
B	- 480	-0.0040	0.0000	-0.0040	17	+0.0113	
C	- 461	-0.0050	0.0000	-0.0050	16	+0.0116	
D	- 323	-0.0022	0.0000	-0.0022	15	+0.0116	
E	- 321	-0.0012	+0.0001	-0.0011	14	+0.0115	
F	- 448	-0.0011	+0.0001	-0.0010	13	+0.0170	
G	- 550	-0.0009	+0.0002	-0.0007	12	+0.0102	
H	- 750	-0.0008	+0.0004	-0.0004	11	+0.0078	
I	- 1369	-0.0020	+0.0011	-0.0009	10	+0.0057	
J	- 2379	-0.0026	+0.0027	+0.0001	9	+0.0037	
K	- 3401	-0.0037	+0.0054	+0.0017	8	+0.0036	
L	- 5996	-0.0057	+0.0144	+0.0087	7	+0.0019	
M	- 9225	-0.0136	+0.0542	+0.0406	6	+0.0016	
N	-10332	-0.0049	+0.0529	+0.0480	5	+0.0012	
O	-11070	-0.0026	+0.0558	+0.0532	4	+0.0007	
...	....	....	....	....	3	+0.0003	
...	....	....	....	....	2	+0.0003	
...	....	....	....	....	1	0.0000	
Total (all zones, lettered and numbered)						+0.2482	
				Station at Pago Pago			
	feet	cm/sec^2	cm/sec^2	cm/sec^2		cm/sec^2	
A	- 37	-0.0001	....	-0.0001	18	+0.0095	
B	- 39	-0.0009	0.0000	-0.0009	17	+0.0095	
C	- 40	-0.0002	0.0000	-0.0002	16	+0.0100	
D	+ 30	-0.0004	0.0000	-0.0004	15	+0.0101	
E	+ 239	-0.0003	-0.0001	-0.0004	14	+0.0101	
F	+ 458	-0.0008	-0.0001	-0.0009	13	+0.0144	
G	+ 452	+0.0002	-0.0002	0.0000	12	+0.0078	
H	+ 118	+0.0001	-0.0001	0.0000	11	+0.0064	
I	- 307	-0.0002	+0.0002	0.0000	10	+0.0052	
J	- 936	0.0000	+0.0010	+0.0010	9	+0.0034	
K	- 2242	-0.0020	+0.0036	+0.0016	8	+0.0034	
L	- 3767	-0.0029	+0.0090	+0.0061	7	+0.0017	
M	- 6642	-0.0073	+0.0391	+0.0318	6	+0.0013	a
N	- 6665	-0.0020	+0.0341	+0.0321	5	+0.0012	
O	- 8080	-0.0008	+0.0407	+0.0399	4	+0.0007	
...	....	....	....	....	3	+0.0003	
...	....	....	....	....	2	+0.0002	
...	....	....	....	....	1	0.0000	
Total (all zones, lettered and numbered)						+0.2048	

[a] Values interpolated

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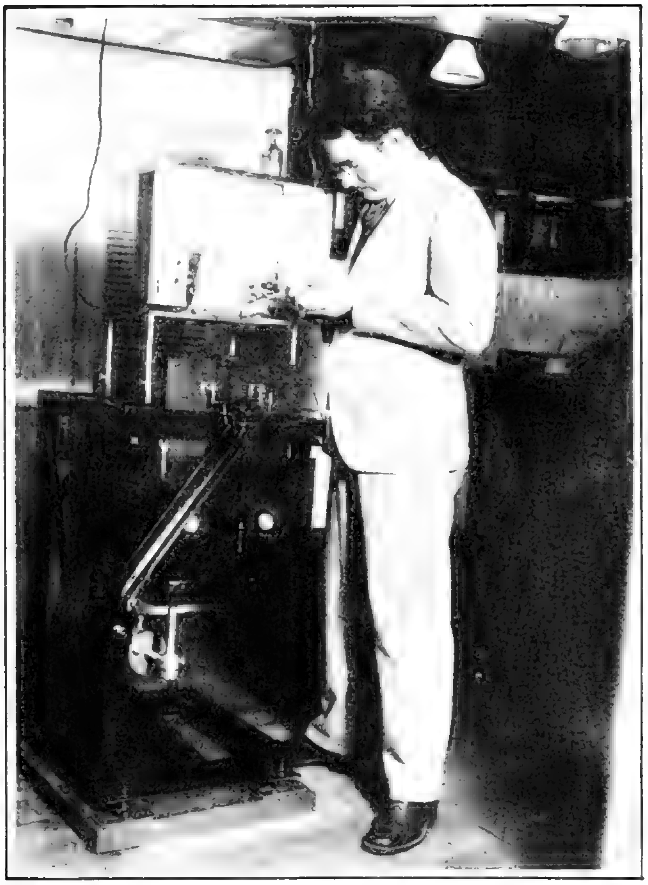

Fig. 1. Vening-Meinesz gravity instrument installed in the main cabin of the Carnegie

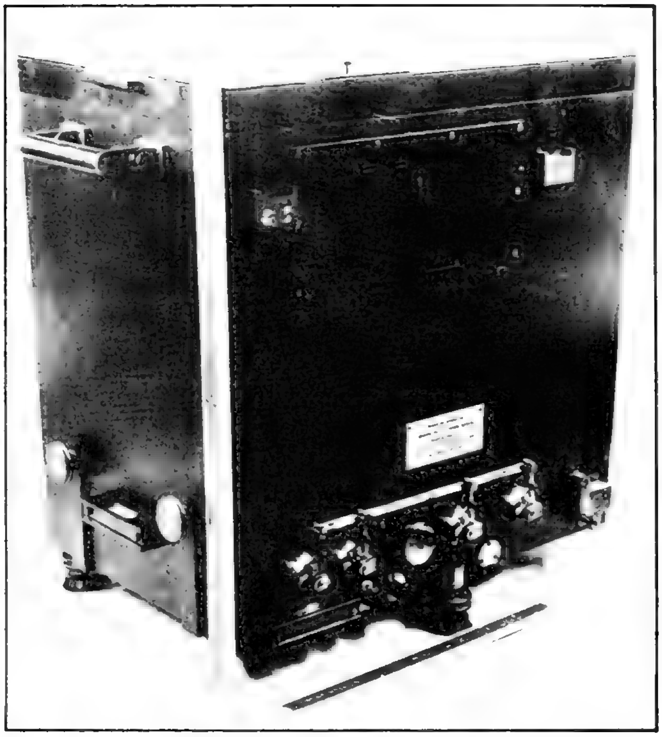

Fig. 2. Pendulum case of the gravity apparatus

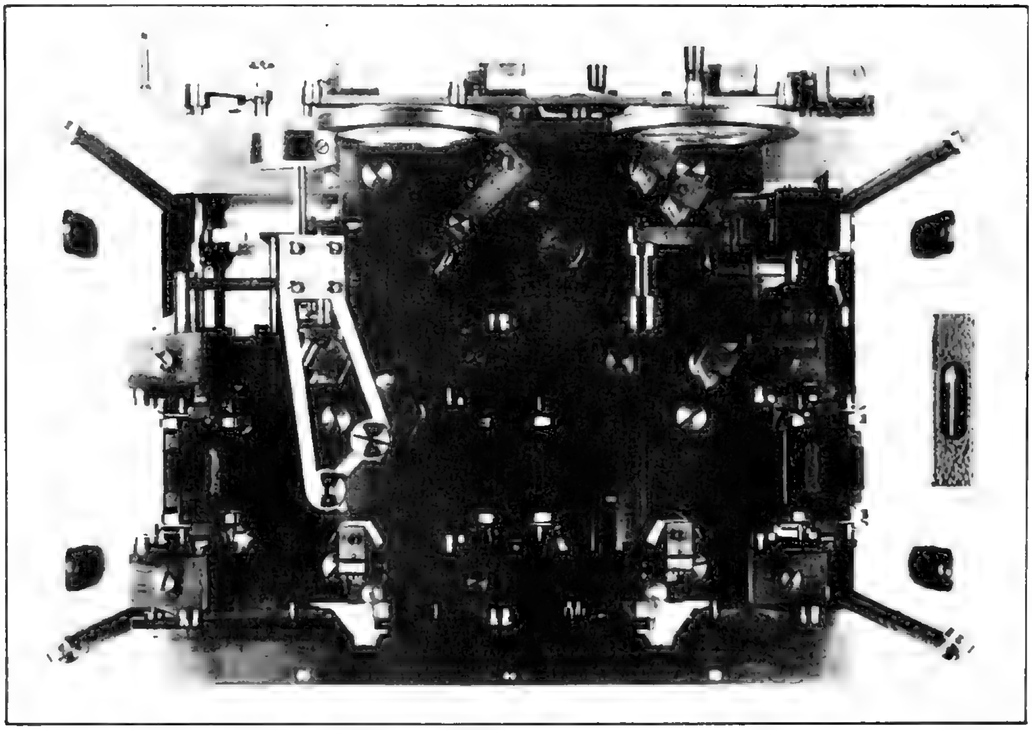

Fig. 3. Top view of the pendulum apparatus

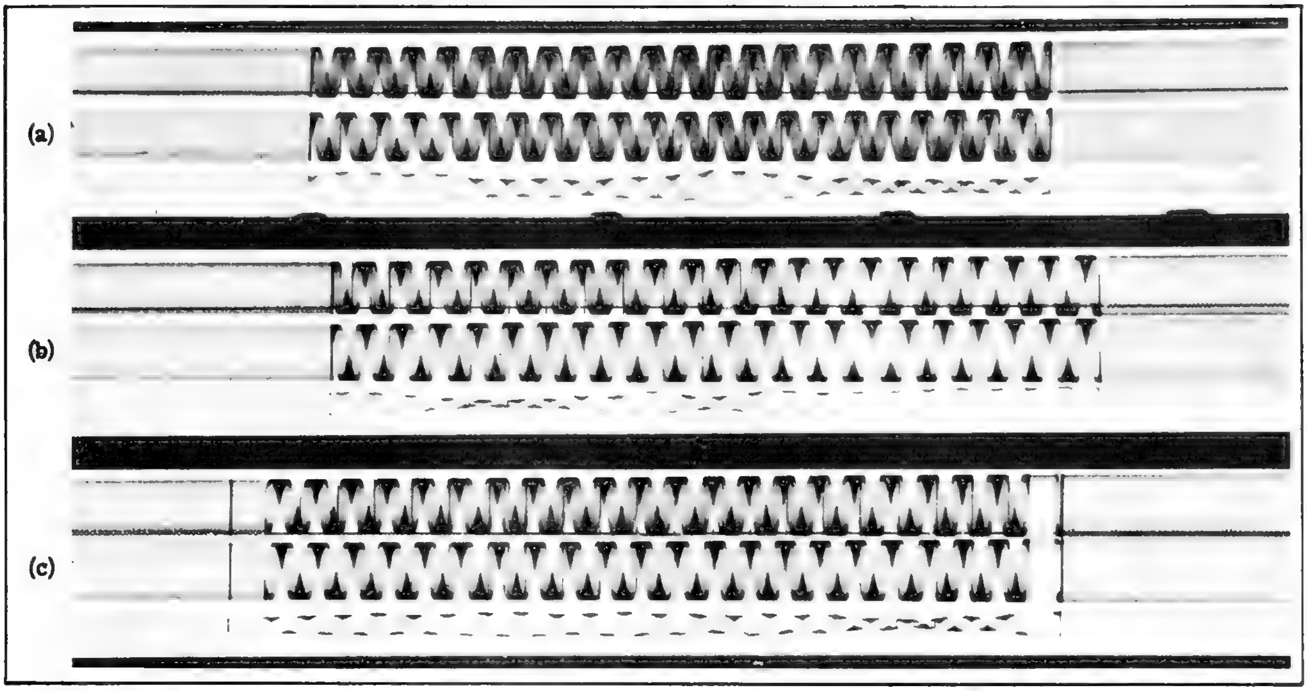

Fig. 4. Gravity records obtained in (a) Pago Pago, (b) Honolulu, and (c) San Francisco harbors

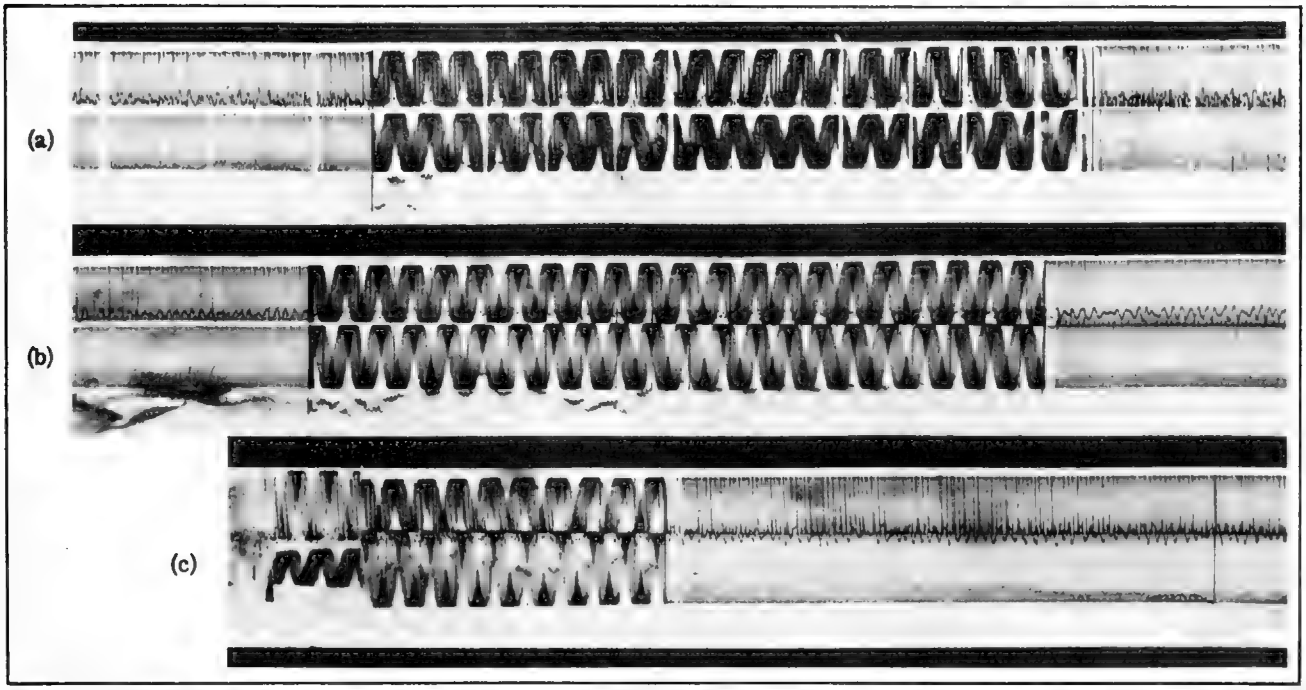

Fig. 5. Gravity records obtained at sea on the Carnegie, (a) open sea in 27° 44ʹ.8 north and 135° 22ʹ.1 west, (b) off West Passage, Penrhyn Island, and (c) off Tauhunu Village, Manahiki Island

WORK OF THE CARNEGIE AND SUGGESTIONS FOR FUTURE SCIENTIFIC CRUISES

VI

NOTE ON THE FLUORINE CONTENT OF ROCKS AND OCEAN-BOTTOM SAMPLES

CONTENTS

NOTE ON THE FLUORINE CONTENT OF ROCKS AND OCEAN-BOTTOM SAMPLES

Until recently little information has been available concerning the amount of fluorine present in rocks, the lack of data being due to the unreliable analytical methods in use. The Willard and Winter procedure, published in 1933 (1), furnishes an easy and surprisingly accurate method of fluorine determination. Recent work shows that instead of being a very minor constituent of rocks, fluorine is present in about the same amount as chlorine and must be considered in rock analyses. A tentative average value of about 0.04 per cent is suggested and some indications point to regional concentrations. Ocean-bottom samples are found to contain about the same quantities as the rock.

On the seventh cruise of the Carnegie ocean-bottom samples were collected at many of the one hundred and sixty-two oceanographic stations occupied. Representative samples were examined for fluorine content, with the results shown in table 1. In the table the type of bottom material has been included. The fluorine content of all the specimens averages 0.047 per cent. With the exception of no. 6, these are all from the Pacific Ocean. The type of bottom evidently is important. Thus, globigerina ooze, being largely calcium carbonate, might be expected to hold some excess of fluorine, but obviously calcium fluoride is too soluble in sea water to permit this. On the other hand, the aluminous clays retain larger amounts.

In figure 1 has been plotted geographically the fluorine concentration of the ocean-bottom samples. The fluorine concentration is proportional to the diameter of the circles. With so few data one notes only trends, but some of these are suggestive. It appears that there is a notable concentration of fluorine between the west coast of North America and the Hawaiian Islands. In view of Zies's (2) observations on the great quantity of fluorine given off by volcanoes in the Alaskan area, and assuming that in the long continuance of Japanese volcanicity similar amounts must have been evolved in that region, we should expect the ocean bottom to have received much of this fluorine and the samples to show a high content all along this northern arc. Instead we find low, or average, fluorine off the Japanese Islands and the northern arc, and a notable concentration east of Hawaii. It is possible that this concentration is related to the turn of the ocean currents at this point, but no similar richness appears off the South American coast where somewhat similar conditions prevail.

One definite fact has been established by recent studies of ocean-bottom samples and rock samples: fluorine is not an insignificant constituent of the earth's crust, as had been supposed. It evidently is present in quantities as great as, and sometimes greater than, chlorine, and this poses a question for which at present there is no satisfying answer. The question is: What becomes of this fluorine? Zies has discussed this matter and summarized the answers thus far. It is true that great deposits of fluorine as well as chlorine exist, but it is far from clear how the fluorine that is being released all over the earth finds its way into such deposits. The ocean-bottom data shed some light on this, as do the few sedimentary rocks tested. Since 1933 much work has been and is being done on the fluorine content of inland waters, and this work indicates again the spotty character of such concentrations in various geological formations. As this work continues we shall be able to trace the vagaries of this elusive element. It seems to the writer that when account is taken of all the known loci of fluorine, there still remains a large amount unaccounted for, or else the fluorine present in the outer parts of the earth did not all derive from the rocks.

Table 1. Ocean-bottom samples collected by the Carnegie

Station no.	Type of sediment	Fluorine per cent
6	terrigenous	0.053
43	globigerina ooze	0.028
44	globigerina ooze	0.033
51	globigerina ooze	0.054
60	globigerina ooze	0.035
62	globigerina ooze	0.033
67	globigerina ooze	0.032
113	terrigenous	0.029
116	terrigenous	0.020
117	red clay	0.033
119	diatom-terrigenous	0.032
127	blue mud	0.072
131	red clay	0.071
132	red clay	0.069
133	red clay	0.071
136	red clay	0.086
137	red clay	0.033
151	red clay	0.114
156	red clay	0.050
157	globigerina ooze	0.010
160	globigerina ooze	0.038
Average		0.047

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*The present note is an abstract of a paper entitled: "Note on the fluorine content of rocks and ocean-bottom samples," by E. S. Shepherd, of the Geophysical Laboratory, Carnegie Institution of Washington, Washington, D. C., published in the American Journal of Science, vol. 238, pages 117-128. 1940.

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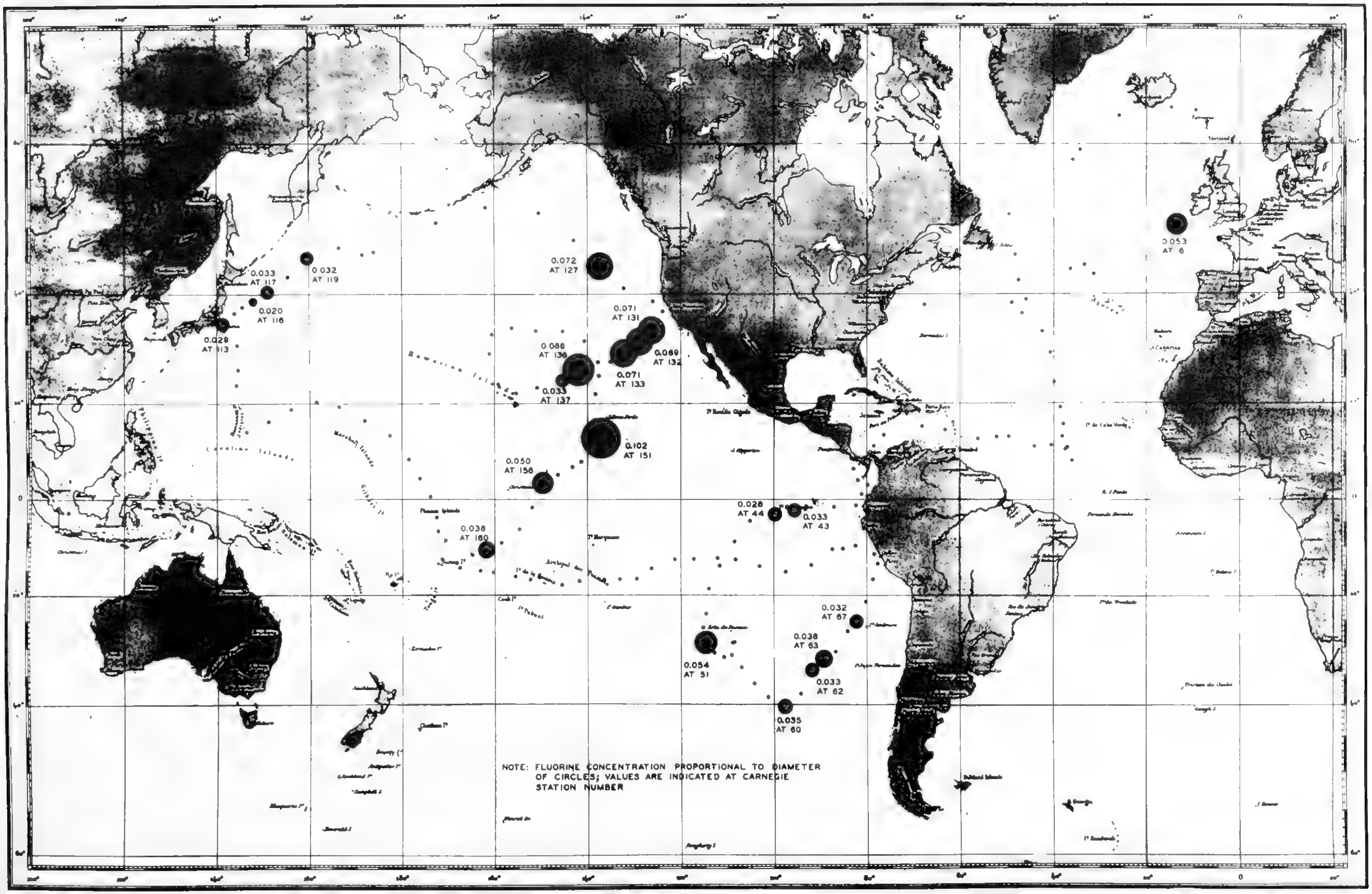

NOTE: FLUORINE CONCENTRATION PROPORTIONAL TO DIAMETER OF CIRCLES; VALUES ARE INDICATED AT CARNEGIE STATION NUMBER

Fig. 1. Fluorine content of sea bottom samples collected by the Carnegie (analyses by E. S. Shepherd, Geophysical Laboratory, Carnegie Institution of Washington)

WORK OF THE CARNEGIE AND SUGGESTIONS FOR FUTURE SCIENTIFIC CRUISES

VII

FUTURE OCEAN MAGNETIC, ELECTRIC, AND OCEANOGRAPHIC SURVEYS

CONTENTS*

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*Memoranda discussing the scientific equipment and programs of the Galilee and Carnegie based on personal experiences of staff-members, and incorporating suggestions for improvements in instruments, observational procedures, ship's equipment, and comments on any other matters on which constructive suggestions might be of benefit to investigators planning future ocean work. These were prepared in 1930 and given limited circulation at that time. In the present volume the papers are presented essentially as written in 1930, only a few deletions having been made of suggestions and comments no longer applicable, and a few statements corrected on the basis of more up-to-date information. The papers represent an important series of reports on practices and procedures on board the Carnegie, particularly because the seventh and last cruise was the only one on which a very diversified program, including magnetic, electric, meteorological, and oceanographic measurements, was carried through.

A PRELIMINARY REPORT ON REQUIREMENTS FOR A VESSEL SUITABLE FOR INVESTIGATIONS IN MAGNETISM, ELECTRICITY, AND OCEANOGRAPHY

The following report is submitted by the committee consisting of Messrs. Peters, Soule, and Torreson, appointed by Dr. Fleming to make a study of ways in which the Carnegie Institution might be helpful in the development of a plan for construction of a ship primarily for oceanographic researches but also for occasional magnetic and electric observations.

This report reviews certain general requirements that should govern the selection of the type of vessel. Various suggestions for improvement in instruments and equipment, in the operations, and in the scope of the investigations, based on experience on the *Carnegie*, will be the subjects of other reports.

The requirements in the construction and in the method of propulsion, especially in the maneuvering of the ship for trawling and for securing bottom and deep-sea samples, are quite at variance with the requirements for the precision sought in magnetic observations. For one, the essential is power for executing the various operations of the investigations and power to maneuver the ship during these operations; for the other, freedom from effects of iron masses is the most essential, economy in supplying power being more desirable than facility of maneuvering.

Other investigations at sea in general do not demand such very contradictory requirements. Atmospheric-electric observations, gravity determinations, pilot-balloon observations, and other meteorological observations can be made with equal facility on any vessel of the same approximate dimensions regardless of the general construction and propulsion. There are, however, details in construction and propulsion that should not be overlooked. For example, atmospheric-electric operations require installation to windward of gas and smoke exhausts, temperature gradients of the atmosphere require lofty installations, gravity determinations require freedom from engine vibrations--all of which could be provided for on a steamer if they were considered well in advance of construction or alterations. Convenience in the collection of water samples in any sort of weather and ready accessibility to ample storage space may also require attention to details in construction in any type of vessel.

For securing oceanographic deep-sea and bottom samples a twin-screw vessel driven by steam, gas, or electricity is preferable to a sailing vessel. The loss of sounding wire with its expensive collection of bottles, thermometers, and snappers might be averted on occasions if the ship could be maneuvered more easily and quickly than could the *Carnegie*. A larger vessel would also be more steady, and thus might facilitate the operations, but the maneuvering of a very much larger vessel would be slower. Twin screws, however, imply a steel hull in usual construction, which also has advantages in the greater space it provides and possibly in more economical upkeep and in the installation of subsurface acoustic apparatus. In building a special twin-screw vessel, or even more in the purchase of one ready built, one should beware of in-turning screws, which practically destroy the maneuvering power of twin screws (1). Masts and sail, even if only as auxiliary on a steamer, might be useful in maneuvering at sea during deep-sea work; also in keeping course with engines stopped in gravity work and affording lofty positions for meteorological work. Other power than steam might be considered with advantage, as the diesel-electric drive on the U. S. Coast and Geodetic Survey *Hydrographer.*

A steel hull, however, is fatal to the precision required in magnetic observations. For example, the iron-built *Clyde* and the *City of Sydney* of the British Mercantile Marine had deviations of which the constant part during a swing amounted to $0.^\circ7$ and $1.^\circ4$ in declination, 10° or 11° in inclination (British Channel) and about 25 per cent of horizontal intensity in the determination of this element (2). The values of the constant part of the deviation during a swing are difficult to control, since they must be determined from swings surrounded by land stations. Such swings must be made in many ports where the dip and intensity are quite different and even then they are not always satisfactory.

The advantage of nonmagnetic construction is the elimination of long and often unsatisfactory computations of the deviation corrections, thereby permitting: (1) facility in securing a dense distribution of observations over the seas for the improvement of navigational charts and for use in theoretical investigations of the earth's magnetism; (2) rapid determinations of secular change far from land; (3) detailed surveys of ocean areas known to be or suspected of being locally disturbed; (4) experimental work at sea for the improvement in magnetic ininstruments otherwise not possible because deviations might obscure the results of experiment. In view of the work already done on the *Carnegie*, the work described in (1) may be regarded as accomplished. The most suitable vessel for (2), (3), and (4) would be a schooner constructed to a large extent, though not necessarily entirely, of nonmagnetic material. Schooners are manned by less than half the crew of the *Carnegie*, and the cost and upkeep of masts, spars, rigging, and sails would be reduced correspondingly. Auxiliary power would be needed only occasionally. A vessel fitting these specifications, with small alterations, might be found for sale at an insignificant sum (3). Such a vessel, however, would not serve for deep-sea sounding work, although she would be suitable or adaptable for other oceanic investigations besides magnetic.

For both magnetic and deep-sea oceanographic work the best practical compromise appears to be a vessel as large as or even somewhat larger than the *Carnegie*, with sails in addition to steam or some other dependable power for propulsion. The construction would be wood as far as practical. It might be noted here that for ice navigation, wooden construction suitably reinforced generally has been preferred to steel. Wooden construction also would be less objectionable in radio experimental work. A location for magnetic instruments should be selected after a preliminary plan had been drawn or a survey made showing the location of engine, chain lockers, tanks, and other large masses of iron, and magnetic material should be excluded within a space of eight meters radius surrounding the selected position. This limitation was used on the German Steamer Gauss and the so-called "constant" part of the deviations that is difficult to control usually was less than 1° for both declination and inclination. Details regarding location of laboratories needed for atmospheric electricity, for chemical analysis, and for biological work in the designing of a vessel would be arranged best after the architect's preliminary plan had been drawn in which the locations had been made in conformity with requirements herein stated. The accommodations for scientific personnel should be planned in anticipation of future increases after mature consideration of a possible future expansion in oceanographic work. Subsequent additions to quarters rarely can be made without sacrifice of ventilation, light, or comfort.

Plans of other vessels which have been engaged in oceanographic work would supply many ideas of details of arrangement that might be overlooked without such guides. Among these are the plans of the Carnegie, the German steamers Gauss and Meteor, the Discovery II (4), and some of the U. S. Coast and Geodetic Survey vessels.

The U. S. Shipping Board publishes a monthly periodical list of its vessels for sale. These are all steel and of several thousand tons dead-weight, too large for economic operation. Yacht brokers of New York at one time published a list of yachts for sale, but this has been discontinued and each broker supplies the information on request. The foreign edition of Fairplay (3), a weekly published in London, gives list of sales consummated in English and foreign ports, also advertisements of vessels for sale. It might be worth while noting that a secondhand wood hull, if in sound condition, is less liable to dry rot than new construction.

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NOTES ON THE POSSIBILITY OF USING AVAILABLE VESSELS FOR DETERMINING MAGNETIC SECULAR-VARIATION

In view of the improbability of building a nonmagnetic vessel, at least in the near future, it becomes important to consider the possibilities of magnetic work on vessels not especially constructed for the purpose.

The principal object in building the *Carnegie* was to eliminate ship-deviations so that observations could be made frequently without the necessity of computing corrections that require an immense amount of office work, that occasion delays in publication, and that are not very satisfactory after all is done.

The mathematical theory of ship-deviations assumes that the ship may be magnetic from two sources, that is, from transient magnetism induced in the soft iron of the ship by the earth's field, and from permanent magnetism in the hard iron. It assumes that the transient magnetism at any instant corresponds with changes in orientation of the iron or changes in the earth's field and that the permanent magnetism is constant. Experience indicates, however, that neither assumption is strictly true. Changes due to time, buffeting of the seas, and holding one course for many days in succession are factors in the problem. Their effects cannot always be controlled to the required degree of accuracy.

Since the observations already made by the *Galilee* and the *Carnegie* are fairly well distributed over large ocean areas, the principal desiderata now in magnetic surveys at sea are secular variation observations, which are essential for keeping the magnetic charts up to date and for theoretical studies. It might be noted here that the errors found in the magnetic data on charts by the *Galilee* and *Carnegie* appear to be largely the result of imperfect knowledge of secular change. Since secular stations may be rather widely spaced over the oceans, sufficient data could be obtained, say, once a week, depending on the progress of the cruise.

In accordance with these ideas, it is now proposed to utilize the opportunities offered by the ship of any scientific expedition provided she is not too magnetic, and to eliminate the harmonic part of the deviations due to her magnetic character by swinging her at every station and to reduce the nonharmonic part by installing the instruments at the most favorable location on board.

The practical limits admissible in future work at sea for the magnitude of the nonharmonic part of the deviations may be inferred from the parameters (see table 1) of the *Erebus*, *Challenger*, *Gazelle*, *Gauss*, *Terra Nova*, and *Discovery*. These were all sailing vessels with auxiliary steam or steamers with auxiliary sail, having wooden hulls iron-fastened. On the *Challenger* and *Gauss* there was no iron within about thirty feet of the magnetic instruments, other than the hull fastenings.

In table 1 A, D, E represent so-called deviation-coefficients for the magnetic elements, the parameters c, f, g, h, k depend on the amount, arrangement and inductive capacity of the soft iron of the ship, and P, Q, R are parameters depending on the amount, arrangement,

Table 1. Parameters of some wooden vessels

Vessel and date	λ	A	D	E	g	h	c	f	k	P	Q	R
		°	°	°						cgs	cgs	cgs
Erebus (1) 1839-1842	0.991	0.0	+0.4	small	+0.027	small	+0.026	small	+0.003	small	small	small
Challenger (1) 1873-1876	0.999	+0.1	+0.3	0.0	0.000	0.000	+0.008	0.000	-0.033	+0.013	0.000	-0.040
Gazelle (1) 1874-1876	0.980	+0.3	+0.6	-0.1	+0.013	+0.009	+0.021	-0.007	-0.021	+0.008	-0.003	-0.002
Gauss (1) 1901-1903	1.003	+0.3	+1.2	0.0	-0.005	0.000	-0.012	+0.001	-0.013	+0.002	0.000	-0.002
Terra Nova (2) 1913	1.000	......	......	.....	+0.037	....	....	....	+0.009	....	....	+0.007
Discovery (3) 1904	0.973	0.0	+1.1	0.0	....	....	+0.003	0.000	-0.022	+0.003	0.000	+0.004
Galilee (4) 1905-1908	1.000	0.0	0.0	0.0	-0.001	-0.006	0.000	+0.001	-0.008	0.000	-0.001	-0.001

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and permanent or subpermanent magnetism of the hard iron of the ship. The term λ is defined and discussed in a later paragraph. The equations of the mathematical theory of ship-deviation in which these parameters are found are discussed in detail in reference (4) at the end of the table.

The mean A_D for each ship, that is the nonharmonic part of the declination-deviations, does not exceed 0.3 in this list of vessels. It is constant according to the mathematical theory. Practically it has been found to vary within a range of about 1°, but some part of such changes probably has been due to changes in the instrument corrections. Experience with the declination compasses on the *Galilee* has revealed possibilities of changes in the instrument corrections alone of more than 1° (1). For future work it might be noted that the instrumental constants of the marine collimator lost with the *Carnegie* were remarkably stable (2). A similar instrument might show that the ship's constant part of the declination-deviations indeed is more stable than has been found when using the ordinary compass.

The nonharmonic part of the horizontal-intensity deviations A_H theoretically is equal to a constant fraction of the horizontal intensity H of the earth's undisturbed field expressed by $(\lambda - 1)H$ in which λ represents the ratio of the horizontal component of the earth's undisturbed field to that of the ship's and earth's combined. The value of λ differs little from unity in wooden hulls. Excepting the values for the *Discovery* and the *Gazelle*, the greatest difference from unity occurs in the value 0.991 for the *Erebus* which would give about three in the third decimal place of H for the nonharmonic part of the deviations in H in a region of high H. It would seem that even a mediocre control of the changes in λ should make the values of the correction dependable at least to within a unit in the third place.

The nonharmonic part of the deviations in dip or inclination, I, is more complicated. It depends on the vertical components of the ship's magnetism at the point of observations and on the inclination. On the *Challenger* it amounted to 6° or 7° in some parts of her cruise. On the *Gauss* and *Gazelle* apparently it did not exceed 0°.3 to 0°.6.

To calculate the probable magnitude for any given inclination and vertical force, the parameters for the vertical components of soft and hard iron magnetization at the instrument would have to be determined. Their combined effect can be determined very readily with a vertical-force instrument, but to separate the effects of soft from hard iron, which would be necessary to enable some estimate to be made of the probable values of the nonharmonic part of the dip-deviations, observations would be required in localities with widely different values of the vertical component of the earth's field.

All the vessels above referred to, except the *Galilee* and *Carnegie*, had steam boilers with long funnels. The funnels have been regarded in some cases as contributing the major portions of the vertical components of the disturbances and the irregular changes in these components have been ascribed to changes in funnel temperatures. The nonharmonic part of the dip-deviations is given by

$$A_I = 2 \sin I/2(2 - \mu)$$

and

$$\mu = 1 + k + R/Z$$

in which R represents the vertical magnetization of hard iron and k the coefficient for soft iron magnetized by the vertical component Z of the earth's field.

Data for modern steel hulls usually do not contain values for the vertical parameters. There are, however, published values for early English warships (3) giving μ by which the nonharmonic part of deviations in dip may be computed for the localities in which the given μ has been determined. These values are found to range from a few tenths of a degree up to 10°. It is inferred that steel hulls also would give values of the same order of magnitude and it is reasonably certain that magnitudes of this order could not be controlled to the required degree of accuracy.

Details in the methods of observing by swinging ship, etc., at every station belong to specific instructions but it might be well to note some of the departures from former practice that would be permissible. As it is proposed to eliminate the harmonic part of deviations by swinging, it is not necessary to determine the coefficients. Four headings are sufficient to eliminate the harmonic part for declination, horizontal intensity, and dip. Two are sufficient to eliminate the harmonic part in vertical intensity. For the same reason the headings need not be restricted to cardinal or intercardinal points. It is necessary, however, and it is sufficient that they be equally spaced around the compass points. This is worth considering especially when swinging under sail only. The time taken to make a swing probably can be reduced still more by the adoption of electrical methods for determining inclination and intensity. Experience on the *Carnegie* confirms both the practicability and the rapidity of electrical methods for determining inclination and the method for horizontal intensity had reached a very promising stage of development.

It appears from these considerations that satisfactory determinations for secular variation can be made on a vessel not especially constructed for magnetic work and that the reduction need not involve so much labor in observing and computing as was required for such vessels on past expeditions. But trial is necessary to substantiate these conclusions. Some vessels, even of wooden construction, may be too highly magnetic for reliable work. After one has been found that is suitable, every precaution should be taken against large changes in her magnetic condition.

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NOTES ON THE PROGRAM FOR FUTURE MAGNETIC MEASUREMENTS AT SEA

In considering the possibilities of measurements of the magnetic elements at sea in the future, approach must be made from one of two angles; the ship either shall be specially constructed so as to be nonmagnetic, or shall have only certain modifications which will make it available for magnetic work. At present it appears that the second arrangement--modifying a ship not essentially nonmagnetic--will offer, perhaps, the earlier opportunity for the resumption of measurements at sea, and this paper will be devoted to considering what kind of program will be required on such a ship.

In accordance with the suggestions of the first report of this section, the major requirements of a wooden hull and of a region eight meters in radius free from magnetic materials around the proposed site of the magnetic instruments will be considered as having been arranged for, since the work would prove of little value unless that were the case.

The special construction of the Carnegie made it possible to make a series of magnetic observations which could be accepted as correct, without the need for additional observations to eliminate the deviations introduced by magnetic materials. A ship not specially constructed, but modified as indicated in the preceding paragraph, will require swinging ship for each set of magnetic observations. For the Carnegie magnetic work, swinging ship was carried out at comparatively infrequent intervals and practically always in port, and thus did not constitute a very large part of the work.

On cruises I to VI of the Carnegie, declination observations were made twice each day if weather permitted, and measurements of horizontal intensity and inclination at least once each day. On cruise VII this program was reduced, horizontal intensity and inclination measurements being made only on alternate days, though declination measurements were made twice each day as previously. On cruise VII, declination observations made with the marine collimating compass (1) required twenty to thirty minutes each morning and evening, with three observers; horizontal intensity and inclination required fifteen to thirty minutes and thirty to sixty minutes, respectively, with the earth inductor (2) and three observers; horizontal intensity with the deflector (3) and two observers required sixty to one hundred and twenty minutes. The earth inductor and deflector observations always were carried on simultaneously on the Carnegie. For all these measurements the ship was put on some cardinal or intercardinal heading and was kept there throughout the work on each element.

When swinging ship on cruise VII, the various measurements were curtailed on each heading, the periods being five minutes for declination, twenty minutes for horizontal intensity (simultaneously with deflector and earth inductor), and twenty minutes for inclination. Repeating the measurements on eight headings made the time for a declination swing forty minutes, for horizontal intensity two hours and forty minutes, and for inclination two hours and forty minutes. The declination swing was taken either at sunrise or sunset, the five-hour period for the other two elements being arranged to occupy either morning or afternoon.

Since every set of magnetic measurements on a modified ship will require swinging ship and since such observations will consume at least one-half day's time, it is realized that the work probably could not be done oftener than once a week. In addition to the time required for observation, time needed for computation will amount perhaps to two or three hours with two men engaged. In attempting to fit magnetic work into the program of an expedition, probably it would be well to estimate that the time of three men would be required for one entire day each week.

The measurements of horizontal intensity with the earth inductor on cruise VII of the Carnegie indicate that the degree of accuracy that may be obtained with that instrument is sufficient for marine measurements, and it is possible that deflector observations can be omitted in future work. If deflector observations are not discontinued, but are to be taken simultaneously with earth inductor measurements, five men would be needed for the work instead of three as mentioned above, although the time required for swinging ship would be about the same.

The marine collimating compass, the earth inductor, the deflector, and the many pieces of apparatus used with these instruments, all destroyed with the Carnegie, would have to be duplicated in the instrument shop of the Department and would have to be requested very considerably in advance of the date set for the beginning of an expedition as the work would be a large item.

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THE DETERMINATION OF GEOGRAPHICAL POSITION FOR SCIENTIFIC OBSERVATIONS AT SEA

The value of scientific observations at sea may be enhanced or diminished according as the determinations of geographical position of the different observations are good or poor. For the best determinations of position there must exist the closest cooperation between the ship's officers and scientific staff, and this cooperation is best attained when each group has a fairly good understanding and appreciation of the problems of the other. Perhaps the best results are obtained when the members of one group participate regularly and rather extensively in the activities of the other. On the Carnegie this latter arrangement always existed. Two or more members of the scientific staff always participated in the navigational work, making the customary astronomical observations, computing dead reckoning, and making the necessary adjustments of navigational data in its application to all the scientific observations. The ship's officers, on the other hand, took active part in the scientific work and were thus made aware of the need for effective notes on unusual features of meteorological conditions, ship's operation, or scientific work. The result to both groups was greater appreciation of the demands for highest accuracy in all phases of the work.

On all cruises of the Carnegie the accuracy required in navigation was secured by having three observers--two members of the scientific staff and the first watch officer--make all the astronomical observations. Furthermore, six altitudes of a celestial body were taken, weather permitting, in rapid succession for longitude sights, the computations being based on the mean of the six altitudes. Chronometer corrections were known to tenths of seconds with the aid of the radio and were used to that degree of accuracy, and watch corrections were taken to fifths of seconds. The results of the three independent computations usually ranged over approximately one mile, making the mean probably only a few tenths of a mile in error. Observations of latitude at noon likewise usually ranged over about one mile.

The accuracy of the dead reckoning was limited by the correctness of assumptions as to drift when hove to, to leeway when sailing, and to current. The judgment of the sailing officers on these details was based not only on their long experience at sea, but on their appreciation of the importance of navigational details in relation to the scientific work, and therefore was accepted for the dead reckoning computations.

On the Carnegie between ten and twenty geographical positions were required each day for the various scientific observations and the dead reckoning had to be adjusted back over varying intervals, from each of the astronomical observations, for each of the positions. It is believed that the positions as determined were accurate to within less than a mile under good sailing and navigating conditions.

On any future expedition it is possible that echo soundings alone may greatly increase the number of geographical positions to be determined each day, the total becoming perhaps as much as forty and fifty, or more. Some of the observations, among them the magnetic measurements, will require more accurate positions than others. The program outlined for magnetic measurements on a ship that has been adapted and not specially constructed for the purpose (see second paper of this section) will require star sights to precede the swing for declination observations if the latter are made in the morning, or to follow if the observations are made at sunset. Sun sights will provide the position of the swing for the other magnetic measurements during the day.

It is not intended here to specify any particular method of navigation or to insist that the scientific staff should participate in that work, but it does seem desirable to emphasize the fact that the determination of positions is, in reality, part of the scientific work and requires more detailed attention than is given to it in ordinary navigation.

NOTES ON THE PROGRAM FOR FUTURE ATMOSPHERIC-ELECTRIC MEASUREMENTS AT SEA

Atmospheric-electric elements to be observed.--(1) Pressure or "potential;" (2) conductivity; (3) number of small ions; (4) number of large ions; (5) penetrating radiation; (6) space charge; (7) diminution constant for small ions; (8) radioactive content of sea air; (9) radioactive content of sea water; and (10) "nuclei" count.

For items (1) to (6) recording instruments would be desirable, whereas eye readings would be made for the remaining items. For the experiments and tests which would precede the selection of the final design for some of the apparatus, and for the construction of all the apparatus, a period of from two to three years would be required. The experimental period would require the greater part of the time of three or four members of the Department's atmospheric-electric staff and there would be required a very considerable part of the time of the staff of the instrument shop for the construction of the apparatus.

Location and size of laboratory.--Excepting in the case of items (1) and (10) above, the apparatus would be permanently mounted in the laboratory on board. Suitable openings would have to be provided, some overhead through the ceiling and some through the sides of the laboratory, to permit mounting the air-flow tubes which would convey the outer air into the measuring apparatus. To accommodate the apparatus, with all the accessories, and also provide deck space for the observers, a laboratory fifteen feet square would be the minimum requirement. Although one large laboratory would be preferable, two adjacent, communicating rooms could be used.

The location of the laboratory should be selected so as to avoid the region of atmospheric pollution on the ship, in case the ship is to be operated by a power plant rather than by sails. The site therefore would lie well forward and, in order to provide the necessary unobstructed area overhead through which the air-flow tubes would rise, would have to be one of the highest parts of the ship's superstructure.

The potential gradient apparatus on a steam or on a motor vessel probably would have to be mounted forward and well away from any of the ship's superstructure or gear that would create an abnormally low field.

Personnel.-- For the program indicated above, a staff of three scientists, all familiar with atmospheric-electric observations, would be the minimum requirement if no clerical aid were to be furnished. If two clerks could be provided to do the scalings, computations, and tabulations, however, two observers could operate instruments and carry out observations. Thus, accommodations would have to be provided in the quarters of the scientific staff for at least three and probably four men who would do the atmospheric-electric work.

Although the above program might seem to be very ambitious and to require too large a personnel, it should be remembered that, to secure the material from a complete program, such as has been outlined, for a period of perhaps one year, would be infinitely more valuable than to obtain the more limited observations which one man could carry out over a period of several years.

NOTES REGARDING OCEANOGRAPHY

In discussing the details of oceanographic work such as that included in the program of the seventh cruise of the Carnegie, a major item to be mentioned is the taking of water samples at various depths from the surface down to 10,000 meters. This operation requires, as equipment, bronze cable, preferably graduated in size, and ample power to handle it, along with maximum manueverability of the vessel. It also demands a large supply of reversing water bottles, deep-sea reversing thermometers, and messengers. Another operation of importance is bottom sampling. An innovation, which was to have been tried by the Carnegie and which seems worth recommending to others, was to be the use of a light and small water bottle on the bottom sampling line a short distance above the bottom sampler. The water bottle was to be reversed by a propeller arrangement similar to that of the Sigsbee thermometer reversing frames. A few such bottles had been made for the Carnegie but, as they were received the day before the ship was destroyed, there was no opportunity to try them out. A separate winch equipped with piano wire is desirable for getting bottom samples.

A third operation is trawling, which is necessary in connection with the biological work. This requires a winch of considerable power. Even so, the size of trawls and dredges must be limited to fairly small units when this work is carried on in great depths. Plankton and the smaller forms of marine life are caught with silk townets. Vertical and horizontal tows are made, and in the latter case several nets can be attached to the same line at various levels. The Pettersson plankton pump is used for quantitative studies, but, aside from its other mechanical defects, it has the disadvantages that the volume of water pumped is more or less uncertain and that the more rapidly moving organisms are not caught by it. The U. S. Coast and Geodetic Survey sounding tube works very well for determining net depths in plankton work. While the vessel is under way, small nets are used for diatom tows at the surface; while in port or in shallow water, the small Mann bucket is useful for diatom dredging. The ordinary dip net is a very handy device at all times and for a variety of purposes.

Experience indicates that it is very desirable that a hard and fast schedule be avoided, that is, it should be sufficiently flexible to allow the vessel to be stopped to develop more fully an interesting or unusual section and to verify unusual results. This applies with equal force to the physical, chemical, and biological fields. In biological work, night stations are fully as important as day stations, and probably more valuable than either would be a twenty-four-hour station.

Inasmuch as the details and technique of management of a sailing vessel when hove to for the collection of deep-sea samples are of interest to those contemplating an oceanographic expedition in such a vessel, and as published data covering the experience of previous expeditions are rare, it seems advisable to note here, even if briefly, some of the problems encountered and practices resorted to on the nonmagnetic ship Carnegie. The Carnegie was a wooden auxiliary brigantine of about 568 tons displacement, carrying fore course, lower and upper topsails, gallant, and royal on the foremast; a single club-mainsail on the mainmast; main, middle, and upper staysails; and fore-topmast staysail, inner, outer, and flying jibs forward. Her auxiliary power was small and was furnished by a 100-horsepower gasoline engine driving a single screw, and capable of producing a speed of six knots under conditions of dead calm, smooth sea, and no swell. A single winch powered all lines and was located on the quarter-deck. This winch carried two reels of aluminum bronze cable, a reel of steel piano wire, and two gypsyheads. The piano wire led directly to a sounding davit at the stern and was used for bottom sampling. The bronze cables led through blocks at the mainmast to sounding davits on either side of the quarter-deck somewhat forward of the winch. One line was used for reversing water bottles and the other for the plankton pump. Silk nets were put out forward and their line brought aft through suitable blocks and manipulated by means of one of the gypsyheads. Thus it will be seen that a maximum of four lines were out at one time, two of them shallow and two deep. The problem was to keep the lines as nearly vertical as possible and to prevent their fouling one another. Three elements had to be considered, namely, wind drift, current drift, and the vessel falling off and coming up. In general, the Carnegie was hove to under mainsail and backed lower topsail. Depending on conditions, more of the fore-and-aft sails were set or more of the square sails were backed as required. The water-bottle line ordinarily was led to the windward davit to insure the line leading away from the vessel instead of leading under it, although in some cases of unusual currents the use of the leeward davit was necessary to obtain the desired result. Because of the difference in loading of the various lines and because of their differing resistances to motion through the water, the different lines had different wire angles. Of the three lines put over from the quarter-deck, generally the piano wire had the greatest angle, the plankton-pump line had the next greatest, and the water-bottle line had the least. The pump line, however, was sometimes more nearly vertical than the water-bottle line. This variation was due largely to the fact that the pump line was always confined to the upper one hundred and fifty meters and hence was subjected, for the most part, to only the surface current, whereas the water-bottle line extended down below the surface current in most cases. The relative angles of the two lines consequently were dependent on the velocity and direction of the surface current with respect to the wind. Often the surface current is moving with the wind; under this condition the wire angle can be expected to increase with the depth to which the line extends after the end of the line has penetrated below the surface current. This, if for no other reason, is because the deeper the line beyond the limit of the surface current, the greater the anchoring effect or resistance to horizontal motion afforded by the subsurface layers. It will be seen, then, that the wire angle changes both in paying out and hauling in, and that, consequently, care and judgment must be exercised if the lines are to be kept from fouling one another during such operations. Economy of time would require that all lines be out simultaneously and this was the practice on the Carnegie during the early part of the cruise. Later the program was changed, at the expense of time, for greater economy of equipment. The greatest amount of time was consumed, of course, by the bottom sampling and the deep water-bottle series. The final program in general was as follows. The bottom sampler was started down, and when about 1000 meters of the piano wire were out, the wire angle was noted and an estimate formed of the expected wire angle for the water-bottle line. Then the shallow water-bottle series was payed out and allowed to come to equilibrium in temperature and the reversing messenger released. After the sampler had struck bottom, hauling in on both lines was begun. The deep water-bottle series was not started down until the hauling in of the bottom sampler had been completed. The plankton pump and nets were payed out and hauled in at convenient times during the other operations. Under this arrangement the time required for the occupation of an oceanographic station generally was that required for the bottom sampling and the deep water-bottle series. This usually was from three to four hours.

An attempt was made to check the drift of the vessel with a sea anchor, but it had little effect because of the low drift velocity. Also an attempt was made to improve the verticality of the wires by the use of the auxiliary engine. This was very nearly disastrous to the lines which were out, and had to be abandoned.

Under adverse conditions of wind and current the wire angle was large and, with the original messenger equipment, a station could not be occupied successfully when the angle was greater than about 45° because of the uncertainty as to whether or not the messenger would slide down the wire. This limiting wire angle was increased about 10° through loading the brass messengers by filling drill holes with lead. The dimensions of the messengers remained as before but the weight was increased from seven to thirteen ounces. The use of too heavy a messenger must be guarded against because of the possibility of damage to the water bottle.

In the biological work, some difficulty was experienced at first because of the silk nets being torn by their rapid motions caused by the roll and pitch of the vessel. Considerable improvement was effected by attaching the net line to a twenty-foot length of rubber airplane rope. Some idea of the strains to which the nets were subjected may be gained from the statement that at times the surge of the vessel elongated the rope to twenty-eight feet.

A feature of design or arrangement of an expedition ship that may be lost sight of easily is the matter of storage space for collected specimens. This becomes of even greater importance if the field is not limited to plankton and small marine life. Not only should such storage space be ample, but also it should be accessible.

It is recommended that on oceanographic expeditions of the future the chemical and biological work be separated both as regards personnel and laboratory space, if at all possible. It is recommended also that the chemists and biologists be relieved of such time-consuming labor as cleaning glassware and keeping the laboratories in order.

Provision should be made on future research vessels for a water-bottle rack on which bottles of the Nansen type could be placed after being brought up. This rack should be of convenient height for drawing off the samples and should be sheltered from the weather, yet reasonably convenient to the davits. If the rack is properly sheltered, the thermometers need not be removed from the bottles but may be left in place to come to temperature equilibrium. It would be desirable to carry equipment suitable for the calibration of the deep-sea thermometers, at least such equipment as would be necessary for determining the ice point.

A diving outfit suitable for shallow depths is not only useful for the study of marine life and coral formations near shore but was found to be of service in the repair of the sheathing on the Carnegie and once was used for helping untangle fouled lines in oceanographic work. It would be well to include such equipment on another expedition ship.

Routine measurements of salinity were made on the Carnegie by physical rather than chemical means. A Wenner salinity bridge was used and was checked against silver nitrate titrations.

If the program permits, measurements of submarine illumination might be included on future expeditions. Comparative measurements can be made by means of Secchi's disc, and Poole and Atkins (1) have used a photoelectric cell to advantage. This field has not been thoroughly investigated and the adoption of any method of measurement should be the result of careful consideration.

For obtaining profiles of the ocean bottom, sonic methods of sounding are necessary for rapid work. It would be desirable to have several different types of sonic depth finders on a new vessel, completely to cover the range of depths encountered and as an occasional check on the accuracy of the instruments. The better directional qualities of shorter sound waves make it desirable to include a supersonic machine in the equipment. In addition to the Navy type of instrument, a Fathometer and a supersonic should be installed as a minimum of equipment. A more intensive program than was carried out on the Carnegie is recommended. An unsatisfactory arrangement on the Carnegie was the installation of the motor generator control panel in a different part of the vessel from the location of the depth finder. These ordinarily would be closely adjacent. For ease and accuracy of sonic sounding, the quietest and most vibrationless propelling machinery should be installed. For this reason, as well as for flexibility and economy, electric drive is recommended.

Whether the prime mover for the generator is to be a Diesel engine or a steam turbine is another matter. Bothersome vibration may be less with a steam turbine than with a Diesel, but more space would be required. If steam is used, it is recommended that the boiler furnace be an oil burner both for comfort and reduction of labor, and because of the lesser interference with atmospheric-electric work. An item to be remembered is the fact that a new vessel should be designed with both tropical and cold weather in mind. In hot climates the Diesel has the advantage, but if such a power plant is selected a small steam heating plant should be installed for use in cold weather.

As meteorology is so closely related to certain phases of oceanography, work in this field would be done in any case on an oceanographic vessel. It would be most unfortunate if the meteorological program were not of such scope as to make the fullest possible use of such an opportunity. The program should include measurements by sea-water and air thermographs, wet- and dry-bulb thermometers distributed at various heights, evaporimeters, and rain gages. Measurements of barometric pressure by a number of types of instruments should be made. Wind velocity and direction might be measured at various levels from the water surface to the masthead to supplement pilot-balloon observations. It has been suggested that a small hydroplane possibly might be used in getting temperature and humidity lapse rates at higher altitudes and also in following pilot balloons farther than would be possible from the deck, but it is unknown how far sea conditions and expense would render such an arrangement impractical. It is understood that the Meteor obtained some of its most valuable meteorological data with kites carrying barographs, thermographs, and hygrographs. Frequent observations of amount and type of clouds probably will prove of value. Work on solar radiation also might be carried on.

Another subject which should be included in any new program is the measurement of the acceleration due to gravity. This subject, although ordinarily not considered a branch of oceanography inasmuch as it is a part of geodesy, is nevertheless related to it in a larger sense. The gravity apparatus of Meinesz, with certain modifications (the necessity for which was indicated by the experience on the Carnegie), might give valuable information on gravitational anomalies and isostasy over the practically unexplored ocean areas. For this work the smaller the ship's motions, the better are the observing conditions. Machinery must be stopped so that if the vessel is power-driven, she should have sufficient sail to keep headway during gravity measurements.

It should be understood that the above suggestions represent a maximum program. Probably all the subjects suggested for study could not be undertaken by one expedition. To carry on such a program as outlined, it is estimated that the vessel should be about 200 feet long, with a displacement of about 1000 tons. It should have a cruising radius of about 10,000 miles. The total ship's company, including a scientific staff of not less than ten, would be about fifty. Her power plant should be capable of a cruising speed of about 10 knots, and it would be very desirable that she carry a power launch 30 or 35 feet in length.

To supplement the ship's operations, a shore office naturally would be maintained for administration, checking and computing, and publishing of data. The ship should be continuously in commission, and active collection of data should be continued with but short intervals of interruption. It seems possible that the running expenses for such a combination, including salaries, upkeep, and ship's fuel could be met with from $200,000 to $250,000 per year. It would be desirable that there be a sufficient endowment to provide for these maintenance operations. A vessel already built possibly may be found suitable, thus lessening the initial cost. In any case, careful consideration should be given to the selection of the type of vessel best suited to the contemplated program; that is, whether it should be power, sail, or auxiliary, and whether of wood or steel. The final decision probably will be a compromise between economy and the extent of the desired program, and between the contradictory requirements of the various parts of the selected program.

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THE BIOLOGICAL AND CHEMICAL PROGRAM

The biological and chemical program of the Carnegie consisted chiefly of marine microbiology, the study of planktonic organisms, and the nature of their environment; but dredgings in shallow water and shore collections of a general biological nature were made when the opportunity afforded. Owing to the lack of time and of space for dredging equipment, the collections at sea necessarily were restricted to planktonic organisms. Efforts were made to obtain a vertical section of the plankton population at each station and to obtain the necessary physical and chemical data for the study of the many factors which govern the distribution of the plankton throughout the seas. Plankton samples of the upper 100-meter layer were taken at each station at depths approximately 0, 50, and 100 meters.

Samples were collected for both systematic and quantitative studies; the qualitative samples with silk townets, and the quantitative with a Pettersson plankton pump. The nets were made of silk bolting-cloth constructed as described by Seiwell (1), in two sizes, namely, one meter, and one-half meter in diameter. The nets originally were towed astern during an oceanographic station; but because of frequent fouling with other wires that were run astern, later they were lowered from the bow where entanglement with other wires was not so likely. The nets were towed with stranded 6-mm aluminum bronze wire payed out from a hand reel on the quarter-deck and snubbed around the after bit. They were hauled in with the electric winch by taking a few turns of the wire around a revolving gypsyhead. In lowering the nets, a lead weighing about seventy pounds was attached to the end of the wire and lowered below the surface. Nets were placed at various intervals along this line by tying the bridles to the wire above split and hinged brass balls clamped to the wire. It was customary to take samples at the surface and at depths of 50 and 100 meters, with an occasional vertical haul from a depth of 150 meters. A table was compiled, giving the lengths of line necessary to lower the nets to the desired depths with different wire angles. Before lowering the nets, the angle on some other line--the pump line, for example--was measured and the expected angle on the net line was judged. From the table, the length of tow line required could be obtained which would lower the nets to the approximate depths. The surface net was towed from a separate line. The meter nets were used only in good weather since they offered so much resistance to the water that the strain produced by the pitching of the vessel was sufficient to tear them in rough seas. Half-meter nets were used in bad weather, although these, too, often were torn by severe surging of the vessel in heavy seas. Much of this trouble was obviated and the life of the nets increased by the use of airplane shock-absorber cord on the net bridles of the surface net and on the end of the wire of the other nets after the latter had been lowered to their proper levels. At the beginning of the cruise, closing nets were used to eliminate contamination from upper layers, but these were abandoned owing to trouble with the closing devices and to the fact that quantitative samples were being secured with the pump.

The Pettersson plankton pump was used regularly for collecting quantitative samples. It was operated at the same depths at which the net tows were made so that a check on the two hauls was obtained and a picture of the life at those levels might be more easily drawn. Trouble with the operation of the pump was experienced because of its complicated mechanism and a great many adjustments had to be made. When these difficulties were overcome (temporarily on each occasion) the results were quite satisfactory, but several important changes in design should be made to secure a consistently practical piece of equipment.

Quantitative samples also were obtained by collecting water in an Allen bottle as well as in a Meteor bottle and straining the water through a silk filter net. The results so obtained were compared with those of the pump and it was found that where the water is as scantily populated as it usually is far out at sea, a greater quantity of water than is collected in these bottles must be strained. The advantage of the Pettersson pump lies in the larger quantity of water filtered. During the latter part of the cruise some surface samples for phytoplankton were taken after the method of W. E. Allen, by passing twenty liters of water through a filter net, the water being collected in a draw bucket over the side of the vessel while under way.

For collecting larger floating organisms a dip net, equipped with a handle five meters long, was used. To facilitate the use of this net and of the surface tow nets while the vessel was under way, a special boom walk was installed on the starboard forward side where the collector might walk nine meters out from the side of the ship and drag the nets well beyond the wash of the vessel. This walk, however, was seldom used because it was impractical when the vessel was rolling appreciably and townets could not be used when the vessel was making much headway.

The oceanographic laboratory had complete microscopic equipment so that an examination of the plankton samples could be made at the time of collecting. Time did not permit of a critical study on board but examinations were made to determine the general characteristics of the region being traversed and to compare results obtained by different collecting methods.

The plankton samples were preserved in 8-ounce and 16-ounce wide-mouthed bottles as used by the U.S. Bureau of Fisheries. Formaldehyde was the preservative used, borax sometimes being added for the preservation of calcareous specimens as described by Atkins (2). Flemming fluid was used also.

Every two or three months (the intervals being governed by the shipping facilities of ports) the samples accumulated on board were shipped back to the office of the Department of Terrestrial Magnetism, at Washington, to await further study. Before shipping, each bottle was tightly corked and the tops sealed over with viscose or cellulose self-fixing caps (3) which prevented any evaporation of the fixative during transit or while in storage at the office.

In shallow waters (usually when the ship was in port and work was done with the launch) dredgings were made for bottom-living diatoms and foraminifera. A Mann diatom bucket dredge was used for this purpose. For the collection and study of living forms as they exist in shallow waters and near reefs below the surface, a diving hood was used which enabled an observer to walk about freely and comfortably.

When there was an opportunity, while in ports, land collections were made of the plants, insects, and birds, with a view to enriching already existing collections and to further our knowledge of the geographical distribution of plants and animals over the world.

The chemical program was designed to obtain data concerning the factors governing the distribution of marine organisms. No attempt was made to determine more fully the exact composition of sea water. An analysis was made of some constituents dissolved in the oceanic waters which are known vitally to affect the life in the water. Inorganic phosphate determinations were made as possible indications of the fertility of the water, a factor which is known to have a direct bearing on the phytoplankton. Silicate determinations were made to study the dependence of diatoms on this constituent in sea water. Of the gases dissolved in oceanic waters, oxygen and carbon dioxide are the most closely interrelated with the occurrent organisms. It was not possible to include determinations of the carbon dioxide tension in the Carnegie program but analyses for dissolved oxygen were made regularly during the last part of the cruise. The hydrogen-ion concentration which is such an important ecological factor in any environment, was determined regularly for all samples collected. Salinities, which have a more hydrographic significance, were determined regularly for all depths by electrometric means with a Wenner salinity bridge, the results occasionally being checked by titrations. Following the policy set at the beginning of the cruise, all the determinations were made on board at sea.

An oceanographic station was occupied regularly every second day, making the stations about two to three hundred miles apart. The vessel was hove to and a series of observations and specimens were taken which included the collection of sea-water samples from the surface down to great depths. These samples were collected in Nansen deep-sea, reversing water bottles to which were attached thermometers for recording the temperatures at which the samples were taken. Bottles were lowered in two series. The first, the shallow series, collected samples at the surface, 5, 25, 50, 75, 100, 150, 200, 300, 400, and 500 meters. The second, the deep series, collected samples at 500, 700, 1000, 1500, 2000, 2500, 3000, 3500, and 4000 meters. Conditions of current and sea sometimes prevented the obtaining of the samples at the greater depths in the deep series.

As the series was hauled in, the bottles were detached and placed in a rack on the gear box and samples were immediately drawn from these into glass bottles to be taken to the laboratory. Three samples were drawn from the Nansen bottles which were of a capacity of 1.25 liters. First, the sample for oxygen determination, which was immediately fixed to prevent any gas exchange with the atmosphere, was drawn into a 100-cc pressure-stoppered bottle. Then a sample was run into a citrate-of-magnesia bottle for other chemical determinations. Lastly a magnesia bottle was filled for salinity determinations.

Glass-stoppered bottles were used for storing the samples during part of the cruise but pressure-stoppered bottles were found to be more convenient, as with the latter there was less danger of the samples coming in contact with the atmosphere owing to the displacement of the stoppers. The bottles used for the oxygen samples were of 100-cc capacity with rubber-washered, enameled, pressure stoppers as furnished by Richter and Wiese. Four-ounce "juice bottles," procurable from any large bottle maker, fitted with magnesia-bottle stoppers will do as well and are obtainable in this country. If larger samples had been available, larger bottles would have been used, as a larger sample reduces the experimental error of the determination. The samples were drawn from the Nansen bottles through a straight piece of glass tubing long enough to reach to the bottom of the collecting bottles and attached to the valve of the Nansen bottle by a short piece of rubber tubing. The oxygen and magnesia bottles were carried about in compartment trays. These and the rack for the Nansen bottles were covered with a temporary canvas shelter on rainy or bright sunny days to prevent dilution of the samples with rain water during the filling of the bottles or to prevent undue decomposition or photosynthetic activity on the part of entrapped organisms. As soon as the samples were drawn from the Nansen bottles they were removed to the oceanographic laboratory and kept in a dark place. The determinations were begun immediately.

Four chemical determinations were run on the samples regularly for each station, namely, of hydrogen-ion concentration, of phosphates, of silicates, and of dissolved oxygen. The hydrogen-ion concentration was determined first so that there would be no change in the pH value of the samples due to interchange of atmospheric carbon dioxide when the bottles were opened for the running of other determinations. For determining the hydrogen-ion concentration, a double-wedge comparator was used as designed by Seiwell (4), constructed according to the principle used in the apparatus designed by Barnett and Barnett (5) and modified by Moberg (6), using cresol red as indicator. With this apparatus, readings were made accurately within 0.02 pH. Determinations of phosphates were made following the method of Denigés (7) and of the dissolved silicates after Dienert (8). For these two determinations a colorimeter was designed which permitted a comparison of color intensities of the samples against a standard in long, graduated tubes in which the columns of liquids could be varied until a match in intensity was obtained. Determinations of the dissolved oxygen were made according to the method of Winkler (9). Although salinities were determined regularly with the Wenner salinity bridge, the bridge frequently was checked by chemical determinations. The latter chemical determinations were done by titrating the chlorides in the water with silver nitrate, using a Knudsen burette and computing the total salinity with the use of Knudsen's hydrographical tables.

A great deal of trouble was encountered in the silicate determinations owing to the leaching of silicates from the glass of the magnesia bottles. Some bottles showed very evident leaching in less than one day's storage. The experience on the Carnegie indicated the great desirability of having some hard glass or other type of container for storing the silicate samples.

Distilled water for the chemical laboratory was carried in five-gallon carboys which were filled at each port. There always was difficulty in getting water sufficiently pure to be used for making the phosphate standards for the delicate Denigés test. Sufficient quantities for this purpose often were obtainable only at hospital laboratories. In many ports it is impossible to get even ordinary commercially distilled water. The experience on the Carnegie showed that a water still is a necessary part of the oceanographic equipment and should be included in the laboratory equipment to eliminate all the uncertainties connected with obtaining a supply of water.

When the chemical and physical results were obtained for a station, the vertical distribution curves were drawn in order that the changes at various depths might be seen graphically and, if unusual gradations were found, additional samples were taken at following stations in the region, at the depths in question.

The biological and chemical program on the Carnegie was as extensive as the whole general plan of the expedition would permit, but on future expeditions, primarily concerned with an oceanographic program, it would be desirable that the biological and chemical work be somewhat more elaborate than that on the Carnegie. Even if the collecting is to be confined to pelagic life, and deep-sea trawling omitted, the work should be of a broader scope than conditions would permit on the Carnegie. The personnel should be increased so that one man could devote his entire time to the biological work which could be materially expanded.

Surface catches for phytoplankton should be made hourly throughout the day and night to obtain more frequent samples for a more intensive study of plankton distributions. Townets could be used at much greater depths than was done on the Carnegie, which investigated only the photosynthetic zone. Stations might be occupied at different hours of the day and plankton collected at various levels for a study of the diurnal migrations of the plankton. It is highly desirable that nets of different mesh be used at each level fished, in order that a separation of the organisms be made at the time of collecting, thus greatly facilitating the study of the samples later. More work should be done on the quantity of plankton in the sea. A centrifuge should be employed for quantitative studies of the nannoplankton.

The chemical program might be expanded to include determinations of nitrates and carbon dioxide, but this depends on the perfection of methods that will determine minute quantities of these substances in the water.

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Instruments

Instruments and apparatus used on cruise VII of the Carnegie are described below. Through the courtesy and cooperation of the Division of Aeronautics, U. S. Navy Department, practically everything used in the pilot-balloon work on the Carnegie was loaned for the duration of the cruise. Since it might be desirable to procure the equipment through manufacturers, however, information which might prove helpful in the matter has been included in the notes below.

Theodolite.--Keuffel and Esser theodolite no. 54005, manufactured according to plans and designs furnished by the Navy Department, was used on board the Carnegie. Supplied in August 1929, this instrument represented the latest development in aero-theodolites. It was hung in gimbals, with a counterweight, to minimize the effect of the ship's motion. In the work on the Carnegie two features were noted in which improvement might be made. The first was the need for a clamping screw on the lower horizontal plate of the azimuth circle. Such a clamp was part of the equipment of older types of theodolites and would seem to be a permanently desirable feature, since it would permit the "zero" setting to be made on true north and would result in azimuth observations which would be true as read and would not require correction. The second somewhat unsatisfactory feature was the ring constituting the top of the tripod. The diameter of this ring was so small that, for a rolling of the ship of ten degrees or more, the counterweight shaft would strike the ring, sometimes causing the displacement of the instrument in azimuth. On some other ship than the Carnegie the motion might not be great enough to cause the counterweight shaft to strike the ring.

Sextant.--On board the Carnegie the motion very frequently was great enough to make difficult the reading of both altitude and azimuth with the theodolite. To distribute the work, a sextant was utilized for accurate readings of altitude. The theodolite then, was set only roughly on altitude, the major effort being devoted to accurate setting of azimuth. The sextant used on board the Carnegie was made by Plath, of Hamburg, Germany, type no. 17, serial no. 11730. Type no. 17 is an instrument with very large field and an endless drum-vernier which can be read with ease and rapidity. The combination of theodolite and sextant proved a very satisfactory arrangement as the motion of the ship did not interfere with the sextant readings nearly as much as with the theodolite readings. Therefore, though the balloon might be lost by the theodolite during a period of heavy rolling, the sextant would retain it and, by setting the observed sextant altitude on the theodolite, the balloon often could be picked up again by the latter instrument and the series of observations extended considerably.

Balloons.--Six-inch and nine-inch balloons in cream or tan-colored pure gum and in black, were furnished to the Carnegie. The six-inch pure gum variety were used almost exclusively. Only when there was a high, white, uniform cirrus formation of clouds could the black balloons be used to advantage. Six-inch balloons were used rather than nine-inch, chiefly for economy in the hydrogen supply. The ascensional rate of 180 meters-per-minute, generally used at the land stations in the United States, was used on the Carnegie. There were occasions when a higher rate of ascent would have been desirable, as when large clouds were traveling rapidly or the cloud formations changing rapidly. For such occasions the nine-inch balloons, which could be inflated to have an ascensional rate of 250 meters-per-minute, would be preferable. In order that the amount of hydrogen put into a balloon might be weighed accurately, the inflation had to be performed in one of the laboratories where air currents could not reach the balloon. The laboatory door was just sufficiently wide to permit removal of the six-inch balloons, which became 65 centimeters in diameter when inflated, but would not let out the 75 to 80 centimeter nine-inch. Future plans would have to take into consideration the need for an inflation room with adequate opening for removing the balloons. Balloons were procured from Faultless Rubber Company, Ashland, Ohio, the price for the six-inch being approximately fifty cents each.

Inflation balance.--The balance is a small device which serves as a valve for admitting hydrogen to the balloon and also serves as a weight for determining the "free lift" of the inflated balloon. Information as to where this might be obtained doubtless could be secured from the Navy Department. The price probably is not great.

Hydrogen.--The Carnegie was most fortunate in having the cooperation of the Navy Department in the matter of furnishing the hydrogen. One large tank (200 cubic feet) is sufficient to inflate only twenty to twenty-five balloons of the six-inch size and twelve to fifteen of the nine-inch, so that for an intensive program of observations and an extended cruise, a comparatively large number of tanks must be carried. The Carnegie carried six tanks and was able to keep a supply of hydrogen on hand by replenishment at U. S. Naval bases. It was found that some of the larger seaports in the Pacific had no commercial establishments furnishing hydrogen and it would appear, therefore, that unless official cooperation were secured, the problem of maintaining a supply of hydrogen on an expedition would be an important one and would require considerable advance planning.

Record forms, plotting board, etc.--Forms for recording observations (Aero 474) and the equipment used for plotting the results were furnished to the Carnegie by the Navy Department. The Navy Department probably would be pleased to furnish information as to where these items could be obtained. Also the book of instructions used by observers on Naval vessels doubtless would be furnished on request.

Observing Station and Personnel

Station.--The station should be located on some well-exposed area on the deck where the least restricted view of the full horizon may be had. Also, the location should be such that the base line may be easily and quickly sighted along for the zero azimuth setting. Two stations were used on the Carnegie, close to the rail, on each side of the quarter-deck. It was possible to sight forward a distance of seventy-five feet from these stations, and no other positions could give greater distance. The seams in the deck assisted greatly, first in laying out the base lines, and, subsequently, in orienting the theodolite during observations.

When the base lines were laid out, the quarter-deck theodolite stations were chosen so that the instrument would be centered over a particular seam; the seam then was followed forward and, as it happened, the vertical edge of a supply bin was found to coincide with the seam. Supply bins being identically located on both sides of the forward deck, two parallel base lines were readily obtained which were in turn parallel with the ship's keel.

When the instrument was set up for a period of observation, one tripod foot was pointed forward and set on a seam; the other feet were set on a line at right angles to the seams and spread over a certain number of seams to make the tripod head level. The tripod feet were prevented from spreading beyond a certain amount by being wired together, near the ends, with wires radiating from a central ring, all the wires lying close to the deck when the instrument was in use. After the initial choosing of the proper seams, it was but a brief task to repeat a set up when desired. Speed in setting-up and in other preliminary preparations, was essential when rapid variations in cloud formations allowed only short intervals for observations.

Personnel.--The preliminary preparations on the Carnegie required the presence of two men for about ten minutes; the observations (by sextant and theodolite) required the presence of three men for a few minutes to more than an hour, according to conditions of cloud and weather; the subsequent computations and reductions required the time of one man (for an average series of twenty minutes) for about two hours, or more if the series of observations were longer.

If morning and afternoon observations were to be carried out by future expeditions, in conformity with land stations in the United States, the entire time of one man would have to be devoted to the work and the assistance of two, or possibly three, men would be required for an hour or so each morning and each afternoon.

The importance of pilot-balloon observations over the oceans is generally recognized and a full program of this work should be carried out by any and every ship having sufficient personnel. Though the full program has been emphasized, just one series each day would be highly valuable and the demands on personnel would be reduced considerably.

Transmitter.--The Carnegie's transmitter consisted of a one-quarter kilowatt, crystal-controlled, master oscillator, power amplifier outfit using a Western Electric 50-watt tube as crystal oscillator, a 250-watt first amplifier, and a 250-watt second amplifier. The frequency range of the transmitter was from 3000 to 18,000 kilocycles.

Power supply to transmitter.--The power supply to this transmitter was taken from a 3-kilowatt, 500-cycle motor generator run by the ship's batteries. The output from the generator was run through suitable transformers for filament, plate, and bias supplies. In the case of the negative bias for the grids of the amplifier tubes and in the case of the plate supply to the master oscillator, the transformer output was in each case rectified by two UV217-A rectifier tubes and the rectified output then filtered.

Transmitting antenna.--The antenna used for transmitting had a vertical part 130 feet long and a horizontal top part 35 feet long, making a total of 165 feet. This antenna was used with a ground, and the lead from the transmitter to ground was about 12 feet, making a total antenna ground length of 177 feet. A counterpoise also was used on 18,000 kilocycles only and its length was about 12 feet.

Main receiver.--The receiver used for 3000- to 50,000-kilocycle reception was of U. S. Navy design and consisted of a push-pull, screen-grid, radio-frequency amplifier followed by a push-pull detector, the output from which was put through a two-stage, audio-frequency amplifier.

Other receivers.--A receiver made by the Radio Engineering Laboratory was used as an emergency in case of failure of the main set. This was a regenerative detector, two-stage, audio-amplifier outfit that tuned from 3000 to 20,000 kilocycles.

A honeycomb-coil type receiver was used for long-wave press and also for receiving broadcast programs.

Special amplifier.--A two-stage, audio-frequency amplifier provided with extra high negative bias on the grids was used to work a 600-ohm relay for recording time-signal beats on a photographic record.

Operation of the transmitter.--The transmitter operated well over its entire frequency range. The daylight communication range was found to be about 4000 miles; the night range seemed to be not much over 8000 miles. These ranges are based on ability to handle message traffic in a satisfactory manner with a signal strength of at least 4 on a scale of 10. The daylight frequencies were between 14,000 and 18,000 kilocycles; the night frequencies were between 14,000 and 7000. The night range was limited to 8000 miles by virtue of the power available, but the daylight range of 4000 miles was limited by power, frequency, and possibly the antenna system.

Operation of the receivers.--The main receiver functioned very well, except for failure of audio-frequency amplifying transformers, and this difficulty was remedied by filling the transformer bases with a special compound protecting them from moist sea air. The emergency receiver, except for calibration, exceeded expectations. The honeycomb-coil receiver was not satisfactory on broadcast programs but worked well on the long-wave code-reception.

Operators.--One operator carried on all the radio work but had other work also, one-half of his time being spent in other than radio work.

Recommendations for Future Work

Transmitter.--The same type of transmitter could well be used with the addition of another amplifier having an output of at least one kilowatt.

The frequency range of the transmitter should be increased to include the 500-kilocycle ship standby frequency for distress calls and to include, as a high-frequency limit 50,000 kilocycles.

Receiver.--The receiver as used was satisfactory, with the exception of transformers, as already mentioned, and microphonic noises on the higher frequencies. Both these faults should be taken care of in a future receiver. Also a receiver covering the 500-kilocycle ship standby frequency should be provided.

Operators.--On a fully staffed expedition at least three full-time operators should be employed, the reason for this provision being that it is impossible for one or two men to be sure of life and health over an extended period, and in case of urgent need the presence of three operators materially increases the chances of survival of the whole expedition. Furthermore, to augment knowledge of the behavior of high frequencies at sea a continuous watch should be kept to make full use of the opportunities offered.

Lifeboat equipment.--A low-powered transmitter should be provided in each large lifeboat, with directions for operating. This set should be foolproof, rugged, and efficient.

Routine of observations.--An entry in the radio log should be made every hour for signal intensity on frequencies such as 7000, 8000, 9000, 10,000, on up to 80,000 kilocycles; in other words, run through the spectrum from 80,000 to about 7000 kilocycles, making a note of signals and their strengths about every 1000 kilocyles. If two-way communication with experimental stations is possible, additional data should be secured every hour in this way on 7000, 14,000, and 28,000 kilocycles.

At least every hour, for about ten minutes, a watch should be kept on 500 kilocycles, the ship's distress frequency. While yachts are not required to keep such a watch, one should be kept as often as possible as a matter of cooperation with other ships. It is often the case than an expedition is in a part of the ocean not frequented by other ships on their regular courses and, because of this unique position, may be able to lend valuable assistance to a vessel driven from her course by storm or accident.

Special apparatus.--An oscillograph record of echo signals at sea, together with a record of the direction of arrival, would be a most valuable piece of research to undertake. To do this an oscillograph, additional amplifier equipment, and a directional receiving antenna would be necessary.

VIII

COMPLETE BIBLIOGRAPHY OF CRUISE VII OF THE CARNEGIE

COMPLETE BIBLIOGRAPHY OF CRUISE VII OF THE CARNEGIE

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