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 – II

I. Marine Bottom Samples Collected in the Pacific Ocean by the Carnegie on Its Seventh Cruise

ROGER R. REVELLE

II. Radium Content of Ocean-Bottom Sediments

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PREFACE

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 field of chemistry, physics, and biology, including bottom samples and depth determinations. These observations were made at 162 stations, at an average distance apart of 300 nautical miles. The distribution of these stations is shown in the map, which delineates also the course followed by the vessel from Washington, May 1, 1928, to Apia, November 28, 1929. At each station, salinities and temperatures were obtained at depths of 0, 5, 25, 50, 75, 100, 200, 300, 400, 500, 700, 1000, 1500, etc., meters, down to the bottom or to a maximum of 6000 meters, and complete physical and chemical determinations were made. Biological samples to the number of 1014 were obtained both by net and by pump, usually at 0, 50, and 100 meters. Numerous physical and chemical data were obtained at the surface. Sonic depths were determined at 1500 points and bottom samples were obtained at 87 points. Since, in accordance with the established policy of the Department of Terrestrial Magnetism, all observational data and materials were forwarded regularly to Washington from each port of call, the records of only one observation were lost with the ship, namely, a depth determination on the short leg between Pago Pago and Apia.

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

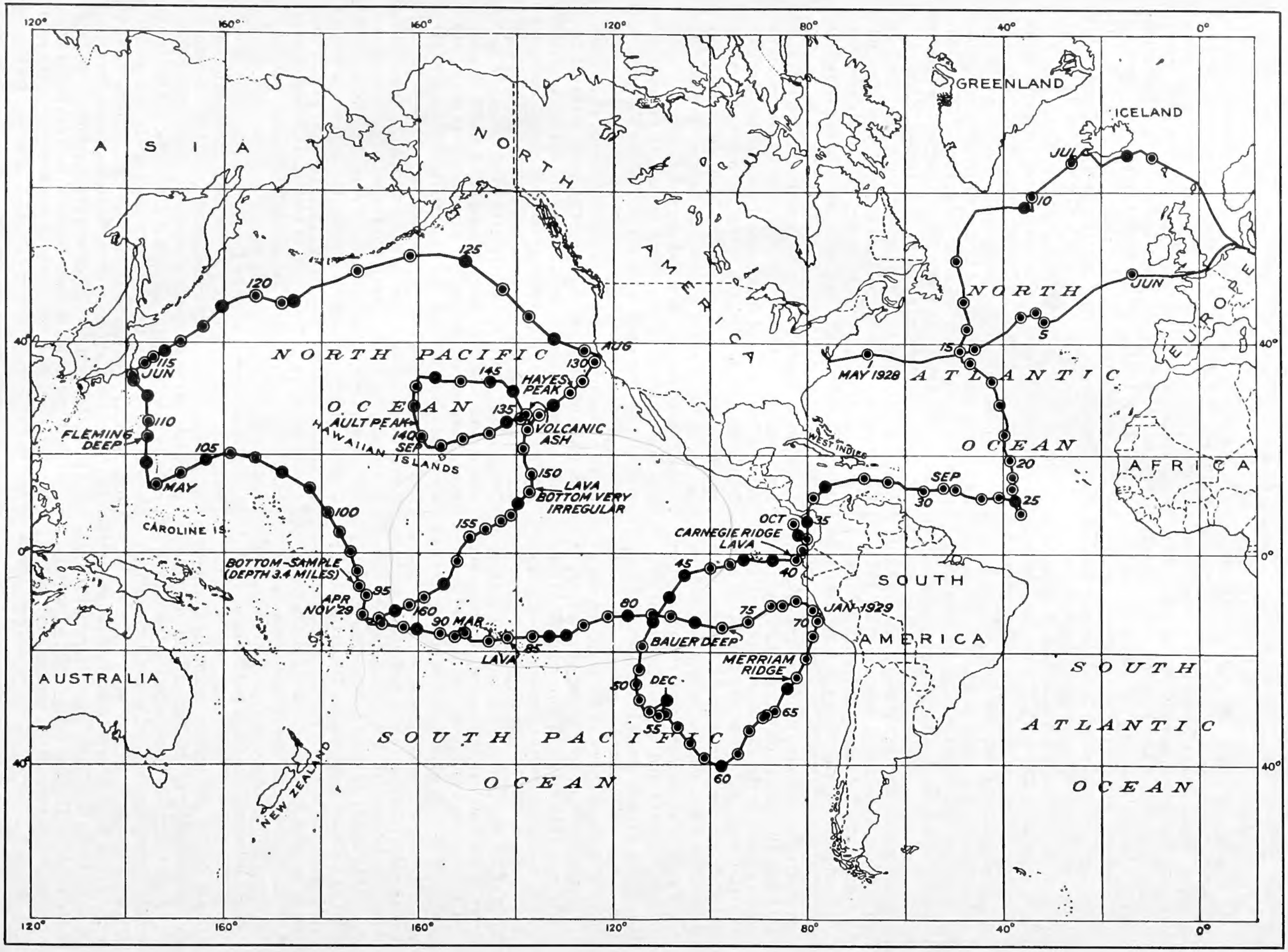
A general account of the expedition has been prepared and published by J. Harland Paul, ship's surgeon and observer, under the title The last cruise of the Carnegie, and contains a brief chapter on the previous cruises of the Carnegie, a description of the vessel and her equipment, and a full narrative of the cruise (Baltimore, Williams and Wilkins Company, 1932; xiii + 331 pages with 198 illustrations).

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 Zoölogy 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 Carlsberg Laboratorium, Bureau International pour l'Exploration de la Mer, and Laboratoire Hydrographique, Copenhagen, Denmark; 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 the 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."

The present report by Dr. R. R. Revelle, is one which will be recognized as a valuable contribution by all oceanographers. It contains an account of the general character of the deep-sea samples collected in the Pacific by the Carnegie, and of the distribution of the various deposit-types, together with the results of chemical, mechanical, X-ray, and other types of analyses. As indicated in the text, many of the analyses were carried out in whole or in part by other investigators.

When the samples were received in Washington from the Carnegie, they were divided and separate parts were sent to Dr. P. D. Trask and Dr. C. S. Piggot for analysis. Most of the remaining samples were sent to the Scripps Institution of Oceanography, La Jolla, California, where investigation was prosecuted with the active help of



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

Dr. T. Wayland Vaughan until the manuscript was ready for publication. After arrangements had been made for the carrying out of the chemical analyses, parts of the samples of sufficient size were sent to the Sharp-Schurtz Company of Lancaster, Ohio for analysis.

Although the number of samples examined is relatively small, they were collected from a very large area. Besides the seventy-five samples of Pacific deep-sea deposits, a few samples were collected in the Atlantic Ocean and in the shallow-water areas of the Pacific Ocean, but most of these are not described in this report.

Few determinations have been made on the radium content of materials comprising ocean-bottom sediments. Dr. C. S. Piggot made twenty-eight determinations on samples secured by the Carnegie on her last cruise. The results of his investigations are presented in the second report of the present volume. When the vast areas covered by ocean-bottom sediments, and the high radium content of these sediments is considered, it is evident that additional measurements of this kind should be made.

Dr. Revelle, because of the demands on his time as a commissioned officer of the U. S. Navy, has been unable to give his personal attention to the final reading of the master copy as prepared for publication. The material, however, has been carefully read by the members of the staff of the Department of Terrestrial Magnetism.

The present volume is the ninth in the series of "Scientific results of cruise VII of the Carnegie during 1928-1929 under command of Captain J. P. Ault." It is the second of the Oceanographical Reports.

J. A. Fleming
Director, Department of Terrestrial Magnetism

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I. MARINE BOTTOM SAMPLES COLLECTED IN THE PACIFIC OCEAN BY THE CARNEGIE ON ITS SEVENTH CRUISE

ROGER R. REVELLE

CONTENTS

MARINE BOTTOM SAMPLES COLLECTED IN THE PACIFIC OCEAN BY THE CARNEGIE ON ITS SEVENTH CRUISE

INTRODUCTION

The Carnegie, on its seventh cruise, collected seventy-five samples of deep-sea deposits in the southeastern and the north Pacific. In 1930 these samples were sent to Dr. T. Wayland Vaughan, Director of the Scripps Institution of Oceanography, University of California. He immediately arranged for the making of certain mechanical analyses by a member of the Institution's staff, and he arranged with Dr. John A. Fleming of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, to have chemical analyses of forty-five of the samples carried out by the Sharp-Schurtz Company of Lancaster, Ohio. In the fall of 1931 Dr. Vaughan offered the writer the opportunity of making an extended study of the samples. It was expected that this report would be completed at the end of about a year, but the demands of other problems and the increasingly widened scope of the study have combined to cause a delay of several years in the completion of the work.

Seiwell has a preliminary report on the samples collected in the southeast Pacific, and Ault and Soule (1929) have described the sounding methods used in that area. Piggot (1933) has published a discussion of the determinations of radium in many of the samples, and Trask (1932) has determined and published in tabular form the nitrogen content of nearly fifty of them. The methods of collecting and storing the samples have been described elsewhere in this volume.

Scope and Nature of this Report

This report contains an account of the general character of the deep-sea samples collected in the Pacific by the Carnegie, and of the distribution of the various deposit types, together with the results of chemical, mechanical, X-ray, and other types of analyses. As indicated in the text, many of the analyses were carried out in whole or in part by other investigators.

Although the number of samples examined is relatively small, they were collected from a large area, and therefore afford an opportunity to re-examine many problems of deep-sea sedimentation in the light of modern methods of sedimentational and soil analysis. The questions which must be considered in such a study are (1) the determination of the various constituents of the samples with the view of ascertaining their physical and chemical nature, origin, and history before and after deposition; and (2) the classification of the samples from the point of view of the causes of the variation in bottom deposits with depth and location. In so far as these questions are answered, they may contribute to the solution of such larger problems as the time rate of deposition in the deep sea (see Twenhofel, 1929), the geologic history of the ocean basins, and the nature of the changes which the continental masses have undergone by reason of their continuing contributions to the sea and the sea floor.

Only fragmentary and speculative answers to the foregoing questions have resulted from the present study. Several modifications of the usual classification of deep-sea deposits are suggested. An attempt has been made to determine something of the nature and origin of the fine materials which form a predominant part of the noncalcareous parts of the samples. In addition, the possible factors affecting the distribution of calcium carbonate in the bottom deposits of the southeastern and of the north Pacific are evaluated.

Specific or generic identifications of many of the organic remains in certain representative samples were made by various experts, but complete faunal lists for all the samples are not given. Owing to the fact that cores were not collected, except in one case, it has been impossible to employ the method used so successfully by Wolfgang Schott (1935) of estimating the rate of deposition of deep-sea deposits from the vertical distribution of pelagic foraminifera. Similarly, although the presence of abundant or significant mineral grains and rock fragments of sufficient size to be identifiable by ordinary optical methods has been recorded, complete lists of such mineral and rock species in the samples are not given. These relatively large grains are usually minor constituents of deep-sea deposits and may be of little significance in explaining the origin of the fine materials in the samples. Besides the seventy-five samples of Pacific deep-sea deposits, a few samples were collected in the Atlantic and in shallow-water areas of the Pacific.

Acknowledgments

The writer wishes to express his thanks to Dr. John A. Fleming, Director of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, for the privilege of examining the collection, for his generous cooperation in the allocation of funds, and for the assistance given by him and the staff of the Department in the study of the samples and in the preparation of this report.

The author is greatly indebted to Dr. T. W. Vaughan for the opportunity to make these studies, for his constant aid in the preparation of the manuscript and in enlisting the assistance of others, and for his encouragement. It is a pleasure also to acknowledge indebtedness to Mr. George Steiger, of the United States Geological Survey, for making the spectrographic analyses; to Dr. P. G. Nutting, of the United States Geological Survey, for his report on the mean grain densities, weight humidity, and weight temperature relations of certain of the samples; to Professor W. P. Kelley, of the University of California, College of Agriculture, for determinations of the base-exchange capacities and replaceable bases of certain of the samples, and for advice with respect to soil colloids; to Dr. Parker D. Trask, formerly of the American Petroleum Institute and now of the United States Geological Survey, and Mr. Harald Hammar, of the American Petroleum Institute, for determinations.

of the amounts of nitrogen in the samples and of the percentages of calcium carbonate in certain of them; to Dr. J. A. Cushman, of the Cushman Laboratory for Foraminiferal Research, for identifications of the foraminifera separated from sixteen samples; to Dr. M. W. de Laubenfels, of the Department of Zoology and Museum, Pasadena High School, for a report on the sponge spicules found in the samples; to Mr. Austin H. Clark, of the United States National Museum, for his examination of echinoid spines; to Dr. R. S. Bassler, of the United States National Museum, for examination of bryozoan and other remains; to Dr. C. I. Alexander for the generic identification of ostracod shells; and to Dr. C. S. Ross, of the United States Geological Survey, for his optical identification of beidellite in a sample of red clay. Chemical analyses of thirty samples collected by the United States Coast and Geodetic Survey ship Surveyor, had previously been made at the request of Dr. Vaughan by Mr. J. H. Fairchild, of the United States Geological Survey, and the author is grateful for permission to use these as supplementary material. Mr. W. H. Dore, of the University of California, Department of Agriculture, kindly supervised the making of the X-ray powder diagrams, and to him the author is also grateful for much previously unpublished data and for personal discussions of the results of the X-ray analyses. Professors Adolf Pabst and N. L. Taliaferro, of the Department of Geology of the University of California, generously gave valuable assistance in the X-ray studies. The author is greatly indebted to Dr. G. F. McEwen, of the Scripps Institution of Oceanography, for his advice and assistance with regard to statistical problems. Miss Esther C. Allen assisted in the determination of total carbon dioxide in certain of the samples; Dr. Eaton MacKay and Mr. Richard Barnes, of the Scripps Metabolic Clinic in La Jolla, kindly made certain calcium determinations; Dr. E. M. Thorp, of the Scripps Institution of Oceanography, made the original photographs of the sand grades of the samples on which the illustrations in plates I to XII are based. The writer is also grateful to Dr. Thorp for advice with regard to the identification of organic remains and for a study of sample 89, a calcareous beach sand from Easter Island. The charts and figures in the text were made by Mr. E. C. LaFond, and the writer is grateful for his ingenuity and conscientiousness. Dr. R. H. Fleming, of the Scripps Institution of Oceanography, gave much assistance and encouragement in the preparation of the report, and the writer thanks both him and Miss Ruth Ragan, without whose constant assistance the manuscript would not have been completed. To Professor A. O. Woodford, of Pomona College, the writer owes thanks for thoughtful criticism of the manuscript. The writer is greatly indebted to his wife, Ellen C. Revelle, for her help in many ways, and particularly in the preparation of the tables. For some of these, such as those on the color and physical characteristics of the samples, and on the distribution of calcium carbonate in Pacific deep-sea sediments, she is largely responsible.

REVIEW OF OTHER INVESTIGATIONS[1]

It is said that the first attempted deep-sea sounding in the Pacific was made in 1521 by the explorer Magellan. Using a sounding line less than 200 fathoms in length he failed to reach bottom and concluded, according to Murray and Hjort (1912), that he had arrived at the deepest part of the ocean. Over three hundred years later, in 1839 to 1842, the first successful deep-sea soundings in the Pacific were made by the United States exploring expedition, of which J. D. Dana (1849) was a member. Not until 1855 was an actual sample of the bottom of the deep sea in this ocean obtained by Lieutenant Brooke, U.S.N., on board the U.S.S. Vincennes in the Coral Sea, west of the New Hebrides, at a depth of 2150 fathoms. This sample (probably a red clay) was examined by Bailey, who says in a letter to Maury (1859), "The sounding from 2150 fathoms, although small in quantity, is not bad in quality, yielding representatives of most of the great groups of microscopic organisms usually found in marine sediments. The predominant forms are siliceous spicules of sponges . . . . the diatoms are very few in number . . . . the foraminifera are very rare."

Later in the year 1855 three specimens of the "ooze and bottom of the sea" were obtained by Brooke in depths of 900 to 2700 fathoms in the Kamtchatka Sea. These were also described by Bailey (1856), who notes the predominance of siliceous shells of diatoms in the deposits and the absence of foraminifera. He remarks that "all the specimens contain some mineral matter, which diminishes in proportion to the depth and which consists of minute angular particles of quartz, hornblende, feldspar and mica."

Ehrenberg (1860) also described samples collected by Brooke in the Pacific on this expedition, at depths of 3300 and 2600 fathoms, the latter sounding being between California and the Hawaiian Islands.

The next successful attempt to collect deep-sea bottom samples in the Pacific was carried out by Seidenburg (1861) on the Dutch ship Z. M. Cachelot in 1858 in the Banda Sea. Five of these samples, collected at depths between 1782 and 4860 meters, were examined and described by Harting (1864). He noted the presence of many species of foraminifera, radiolaria, diatoms, and sponges, and pointed out the absence of foraminifera, at great depths, which he rightly believed to be surface dwelling.

The broad foundations of the study of marine bottom deposits, as of nearly all other aspects of modern oceanography, were laid by the circumnavigating voyage of H.M.S. Challenger during the years 1872 to 1876. The report on the specimens of bottom deposits collected by this expedition was published in a classic volume by Murray and Rénard (1891), who, in addition to detailed study of the deposit samples collected by the expedition, also examined over 12,000 samples from all parts of the world. Murray, in 1876, had published a preliminary report on the Challenger samples. The route of the Challenger in the area investigated by the Carnegie is shown on chart 1. Starting with a point north of the Admiralty Islands, the Challenger sailed north to Japan, thence westward approximately along the 36th parallel to a point

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[1] For a list of all ships which have carried on oceanographic work in the Pacific since 1800, see H. Bencker (1930) and R. de Buen (1930 and 1934).

north of the Hawaiian Islands, and southward to Tubuai Island, and eastward to Valparaiso. About eighty bottom samples were collected during this part of the voyage.

Other trips made at about the same period as that of the Challenger were those of the U.S.S. Tuscarora, under Commander Belknap (1874) in 1873 to 1878 throughout the basins of the Pacific. Piano wire was first used for deep-sea sounding work during these expeditions, although previous experiments with it had been undertaken by Sir William Thomson (Lord Kelvin). Only one detailed description of any of the Tuscarora samples has been published--a Globigerina ooze, collected in the central Pacific just south of the equator, which was described by Murray in 1906. All the samples collected by this ship, however, were examined by Murray and Rénard, and the first knowledge of the belt of diatom ooze which extends across the north Pacific was the result of the Tuscarora work.

Another expedition contemporaneous with that of the Challenger was the voyage of circumnavigation of the German ship Gazelle in 1874 to 1876. The bottom deposits were described in some detail by von Gümbel (1888), who gives many chemical analyses and lists of the species of organic remains and of the minerals in the samples. The course of the Gazelle in the southeastern Pacific, shown in chart 1, lay to the south of that of the Carnegie.

During the next decade the U.S.S. Enterprise (1883-1886), on a cruise that included all the oceans, made an important collection of bottom deposits from the south central Pacific some of which were described in detail later by Murray (1906). The samples described by him, however, were collected to the southwest of the area investigated by the Carnegie and are not considered in this report. The Russian ship Vitiaz, under Makaroff, made a voyage around the world between 1886 and 1889. Some bottom samples were collected in the shallow waters of the northwestern Pacific. The organisms which these samples contained are described in Makaroff's account of the voyage (1894). Between 1882 and 1885 the Italian ship Vettor Pisani carried out observations in the central Pacific. Picaglia (1893) listed the foraminifera obtained in dredgings at three stations, but the writer has found no reference to descriptions of the bottom samples.

During this time the British surveying ships H.M.S. Egeria (1887-1889), Rambler (1888-1904), Dart (1888-1902), Alert (1880), and the S.S. Britannia (1888-1907) and other cable ships also began a long period of soundings in the Pacific. Later H.M.S. Waterwitch (1894-1901) and Penguin (1890-1906) carried out deep-sea soundings in the Pacific. The earlier samples collected by these expeditions were examined by Murray and Rénard in their preparation of the Challenger report and some of the later samples collected by the survey ships were described by Murray in 1906. Peake directed the work of the Britannia during the year 1901; 597 samples collected by Peake in the southwestern Pacific were studied by Murray, and some of them were described by him in 1902. Those samples described by Murray in 1902 and 1906, which were collected from the area traversed by the Carnegie, are indicated on chart 1. In 1891 the U.S.S. Alert, under Wainwright, made soundings and collected bottom samples in the Bering Sea and in the northwestern Pacific. Cushman (1910-1916) has described the foraminifera from these samples.

Between 1888 and 1897 the United States Fish Commission steamer Albatross made a very large number of soundings and collected samples from the sea bottom off the west coast of North and South America, in the Gulf of Alaska, in the Bering Sea and the Sea of Okhotsk, and between California and Hawaii. Alexander Agassiz directed the work of this vessel during the exploration of the Panamic region in 1891 and published a brief description of the nature of the bottom in his report (1892). Later, in 1899 to 1900, the Albatross conducted oceanographic observations from San Francisco to Tahiti and thence to the Fiji, Gilbert, Marshall, and Caroline archipelagoes, and to Japan. In 1904 the Albatross again undertook explorations in the southeast Pacific. Murray and Lee (1909) reported in detail on the 343 bottom deposits collected during the latter two expeditions, although Agassiz (1906) had previously described the general character of the bottom and the nature, extent, and amount of the bottom faunas. These two cruises of the Albatross resulted in a great extension of knowledge concerning many aspects of the southeast Pacific. An example is the development of the widespread Globigerina ooze area of this region which previously had been supposed to be underlain largely by red clays. As will be shown in a subsequent section, the area of Globigerina ooze was even further enlarged by the work of the Carnegie. Agassiz also pointed out the close correlation between the quantity of surface plankton as it is affected by marine currents and the amount of the benthonic fauna. The routes of the expeditions of the Albatross from 1899 to 1900 and in 1904 are shown on chart 1.

In 1899 the U.S.S. Nero, under Belknap and Hodges, while engaged in the survey of a route for a transpacific cable, made soundings at average intervals of 10 miles between Honolulu, the Philippine Islands, and Japan. Many soundings were made in very deep water, including one at 5269 fathoms which was the deepest cast that had been made up to that time. About 150 of the samples collected were briefly described by Flint (1905). He designated some of the samples as diatom oozes, stating that they contain abundance of the frustules of the large Coscinodiscus rex. Murray (see Murray and Hjort, 1912), who later examined these samples, declared them to be identical with what he considered radiolarian ooze. On the other hand, as will be shown later, even the deposits from the Pacific north of Japan, which were called diatom oozes by Murray and Rénard, contain a large proportion of radiolaria. The route traversed by the Nero in the area covered by the Carnegie is shown in chart 1.

During the years 1899 to 1900 the Dutch steamer Siboga (see Weber, 1902) collected many bottom samples in the seas surrounding the Dutch East Indies; these were later described by Bõggild (1916) and the results discussed by Molengraaff (1916, 1922, 1930). The German ships Edi, Stephan (1905-1911), and Planet (1906-1914), during the course of expeditions throughout the great oceanic basins, collected bottom samples from the western Pacific between the Philippine Islands and Japan. Several of these samples were collected from the great foredeeps of the island arcs of the region and, according to Andrée (1920), were found by Horn to be of terrigenous type in spite of the immense depths. This fact is not surprising when it is considered that the slope from land to the bottom of these deeps is often as much as 1 in 6. Andrée believes that submarine landsliding has played a considerable role in the formation of the deposits of the great abysses.

The explorational work of the Albatross was continued during the first part of this century: in the vicinity of the Hawaiian Islands in 1902; in Alaskan waters in 1903; off the North American coast from 1904 to 1905; in Alaskan waters, the Bering Sea, the Sea of Okhotsk, and in the vicinity of Japan and in the Inland Sea in 1906; in the vicinity of the Philippines from 1907 to 1910, off the southern and lower California coasts and in the Gulf of California in 1911; in the Gulf of Alaska in 1911; and off the coasts of Washington and Oregon from 1914 to 1915.[1] Except those collected under the direction of Agassiz, most of the Albatross samples have not been described fully. Trask, however, (1932) has determined the contents of $CaCO_3$ and of organic matter in many of them.

The surveying work of the United States Coast and Geodetic Survey ships Guide, Surveyor, Pioneer, Discoverer, and others along the North American coast from Panama to Alaska has similarly resulted in the collection of hundreds of fairly large samples of which there are no published descriptions, although Trask (1932) has published the results of determinations of the $CaCO_3$ and organic matter contents and of mechanical analyses of many of them. Most of these samples are in the collections of the Scripps Institution, whereas others are in the United States National Museum. Chemical analyses of thirty samples collected by the Surveyor were made at the request of Dr. T. W. Vaughan by J. G. Fairchild, of the United States Geological Survey. The results of these analyses are given in the present report and have been taken into account in drawing the maps, given below, of the distribution of deposit types and of $CaCO_3$ content in the area investigated.

On the western side of the north Pacific the surveying ships of the Japanese Navy, according to Yabe (in Hanzawa, 1928), were engaged actively over a long period of years in observing the nature of the bottom and in collecting deposit samples. Unfortunately, most of the earlier samples were destroyed by the earthquake and fire of 1923. About 700 samples, however, were collected between 1925 and 1928 in the southwestern north Pacific by the surveying ship Mansyu (1933). Hanzawa has published general descriptions of the deposit types represented and lists of the foraminifera, as well as a map showing the distribution of marine deposits in the Pacific between 120° and 180° east, and from the equator to 37° north, based partly on the Mansyu samples in addition to all other available information. It is stated that more detailed descriptions and mechanical analyses will be given in a future publication.

During recent years, in addition to the seventh cruise of the Carnegie, several other oceanographic expeditions have collected bottom samples in the Pacific; namely, the Willebrord Snellius expedition in the Dutch East Indies, the expeditions of the William Scoresby and the Discovery II in the Antarctic and along the South American coast, and of the U.S.S. Hannibal in the waters of the Gulf of Panama and off the coast of Costa Rica. The deposits collected by the Willebrord Snellius have been commented on briefly by van Riel (1932), the leader of the expedition, and are being studied by Dr. Ph. H. Kuenen of Grōningen.

Neaverson (1934) has published a general description of the samples collected in the Pacific by the Discovery II and the William Scoresby, Earland (1934) has described the foraminifera collected by these ships in the Antarctic south of the Falkland Islands and South America, and Moore (1933) has described certain coprolitic pellets from the bottom samples. Neaverson introduces the term "diatomaceous mud" to designate those sediments occurring along the South American coast and in certain parts of the south Atlantic which contain large amounts of both diatom frustules and detrital mineral grains, and which were called diatom ooze by Murray and Lee (1909). He also states that the characteristic green color of many terrigenous deposits is owing to the presence of chlorophyll.

Approximately 130 samples, collected by the U.S.S. Hannibal, are at present in the collections of the Scripps Institution and it is hoped that these will be described in the near future. Captain Allan Hancock on the Yacht Velero III has also collected bottom samples from the eastern tropical Pacific, particularly in the region of the Galápagos Islands.

Tyler (1931) has reported the results of a study of certain bottom samples from the Gulf of Alaska, most of which were collected by the United States Coast and Geodetic Survey ship Surveyor. Although the majority of these samples are shallow-water, near-shore types, several were collected at depths greater than 100 fathoms and one was collected at a depth of nearly 2200 fathoms, about 400 miles from land. The results of chemical analyses, rough mechanical separations, and detailed determinations of the heavy and light minerals show, according to Tyler, that a considerable part of the clay fraction cannot be considered as kaolinite. Hypersthene, often euhedral, and minerals of continental type, were found to be the most abundant heavy constituents. The presence of hypersthene is of interest in connection with its corresponding abundance in the Carnegie deposits collected off the coast of Japan. The locations of the samples studied by Tyler are shown on chart 1.

Galliher (1932) has published mechanical and partial chemical analyses of sediments from Monterey Bay; Trask (1931) has given the results of mechanical analyses of samples collected at depths down to 2000 meters in the region of the Channel Islands off the southern California coast. In a following section the mechanical analyses by Galliher and Trask of the finer sediments will be compared with those of the red clays collected by the Carnegie.

In the above review most of the papers cited are those in which deep-sea bottom samples collected by various exploring expeditions in the Pacific are partially or completely described. No account has been given of other papers on certain aspects of the samples by such investigators as Gümbel (1878), Murray and Rénard (1883-1884), Brady (1884), Buchanan (1891), Murray and Irvine (1891 and 1894), Hōgbom (1894), Harrison and Jukes-Brown (1895), Thoulet (1901, 1902, 1931), East-

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[1] For lists of the soundings, dredgings, and other records of the Albatross from 1883 to 1920, see the reports with appendices of the United States Fish Commission, particularly C. H. Townsend, Dredging and other Records of the United States Fish Commission's steamer Albatross, with bibliography relative to the work of the vessel, in United States Fish Commissioner's Report for 1900, pp. 387-562, 1901; the appendices to the reports for 1902, pp. 397-432; 1903, pp. 123-138; 1905 (U. S. Fish Commission Document 603); 1906 (U. S. F. C. Document 621); 1910 (U. S. F. C. Document 741); 1920 (U. S. F. C. Document 897).

man (1903), Collet and Lee (1906), Clarke (1907), Joly (1908), Caspari (1910), Cushman (1910-1916), Clarke and Steiger (1914), Odén (1916), Heim (1924), Pettersson (1930), and others. They will be referred to in connection with the later discussions of this paper.

Likewise, no account has been given of those expeditions and voyages on which deep-sea soundings were made but bottom samples either were not collected or not reported. For example, the Danish ship Dana (Dana Report no. 1, 1934), and the U.S.S. Ramapo (see Hydrographic Office no. 210a and c, 1932, 1934) together with the U.S.S. Milwaukee and other ships of the United States Navy, have carried out extensive series of echo soundings in the south and the north Pacific, which have added greatly to our knowledge of the hydrography of the Pacific, and therefore to our understanding of the relations between the various types of sediments on the bottom. Owing to the method of soundings, however, no bottom samples were collected.

CLASSIFICATION OF RECENT DEEP-SEA SEDIMENTS

Principles of Classification

The purposes of a scientific classification of natural objects should be (1) to summarize the significance of the similarities and differences between the objects and to suggest ways in which their relations may be studied; and (2) to systematize the nomenclature of the objects through the setting up of an orderly series of criteria or diagnostic characters by which they may be distinguished from each other. A true classification should be genetic, that is, the relations expressed by it should be in terms of the origin and history of the objects classified.

Since the conditions of formation and the origins of the materials of deep-sea sediments are extremely complex and often unknown or doubtful, it is desirable that certain qualities of the sediments themselves, which may be presumed to reflect their genesis, should be selected as the basis of classification. Moreover, one of the purposes of the study of deep-sea sediments is to determine the significance of such factors as geographical location, depth, bottom configuration, distance from shore, and the biological, physical, and chemical conditions of the overlying water. Therefore, although a genetic classification must take such variables into account, it is desirable to express the effects of these factors in terms of the physical characters and composition of the sediments. A further requisite of the qualities selected is that they should be clear-cut and easily ascertainable in order that they may be readily employed as criteria for distinction between the various types of deposits.

Physical Characters and Composition of Recent Sediments

Let us now consider the nature and significance of certain of the physical and chemical characters of recent sediments, namely color, texture, chemical composition, and physical composition.

Color. The colors of most deep-sea deposits vary between reddish-brown to white on the one hand, and grayish-blue, green, or black to white on the other. A red-brown color indicates the presence of ferric hydroxide or oxide either as separate particles or as a constituent of clay minerals and, therefore, an oxidizing potential as far as ferrous iron is concerned. A grayish-blue or black color usually indicates the presence of hydrotroilite (ferrous sulphide) together with finely divided organic matter, therefore a reducing potential as far as ferric iron is concerned. A greenish color may be owing to the presence of much finely divided organic matter or to that of glauconite and related minerals and, therefore, most probably indicates a slightly reducing potential, according to Hadding (1932). When an oxidizing potential, as shown by a red or brown color, exists below the surface of a deposit, it implies that decomposition of the organic matter in the sediments has taken place under aerobic conditions (therefore presumably at or near the surface) either completely to CO_2 and water or, as claimed by Waksman (1933), to relatively undecomposable components, such as lignins. Other things being equal, this must mean either a relatively slow rate of deposition of the organic matter or of the sediment as a whole. On the other hand, a reducing potential, indicated by a grayish-blue, green, or black color, beneath the surface of a sediment means that the decomposition of organic matter is taking place under anaerobic conditions. This usually implies a relatively rapid rate of deposition of both organic and inorganic constituents.

Somewhat similar ideas as to the significance of color were long ago advanced by Bõggild (1906), who says, with reference to certain clays collected by the Fram expedition in the North Polar Sea off the Siberian coast, that the color of the clay is "a tolerably pure gray near the coast, while further out in deep water it acquires an increasingly brown tone and in the deepest places is almost pure brown . . . . the color of each species of clay depends as a rule exclusively upon the color of the clayey matter itself and is due to the precipitation of hydrated peroxide of iron on the separate clay particles." Furthermore, "it seems necessary to assume that the transformation of the gray clay to brown can only take place in the very uppermost, extremely thin layer, that is in immediate contact with the sea water, for otherwise all the mud upon the bottom could not but acquire the same brown color . . . . the only possible explanation appears to be that the gray clay is deposited so much more rapidly than the brown that the uppermost layer has not time to be changed before it is covered with new sediment . . . . this circumstance is very important in estimating the relative rapidity with which the various sea bottom deposits are formed. Thus, where the conditions in the main are uniform, and where there is no great variation in the composition of the sediments that are carried out into the sea, we may assume that the rapidity with which the deposition takes place is about (inversely) proportional to the amount of brown in the color of the sample. It is not impossible, however, that several different factors, such as temperature, currents, etc., may modify the conditions to some extent. The amount of lime it contains does not seem to influence the color of the clay in any way, except in giving it a lighter shade."

A division of the sea floor on the basis of the prevailing conditions of oxidation or reduction has been suggested by Murray and Hjort (1912) who state: "We may indeed divide the floor of the sea, according to the relative abundance or paucity of dissolved oxygen in the bottom waters, into oxidizing and reducing areas. Reducing conditions will prevail wherever there is a larger excess of putrifiable organic matter than can be coped with by whatever supply of oxygen (depending on the circulation of the area) may be available. In general, therefore, the coast-lines of continents are girdled by reducing areas, and it is here that blue muds characteristically occur. Oxidation of the organic matter is here effected at the expense of ferric iron, probably by bacterial agency."

In areas near shore, where there is a large amount of deposition of organic matter, the surface layers of fine-grained sediments may be light colored, brown, or black, depending on the amount of destruction of organic matter by scavengers and bacteria (see Twenhofel, 1932) and on the circulation and oxygenation of the water. For example, Petersen and Jensen (1911) found that the sea bottom off the coast of Denmark is covered by two different types of organic mud, a brown layer and a black one. Both originate from the breaking up of the seaweeds and Zostera along the shore. The brown layer forms in the open sea where there is sufficient circulation and oxygenation of the water. It is the most important source of bottom life. The black, foul-smelling bottom layer is most common in the inner fjords and represents an early stage of the condition which, in its extreme development, is found in the Black Sea. Likewise, Hadding (1932) finds that the change in fossil sediments from bituminous muds carrying graptolites and brachiopods with phosphatic shells, but without glauconite (that is, extremely reducing muds), to glauconitic sands with autochthonous glauconite, formed according to this author under nearly neutral conditions, does not indicate an alteration of depth or other general conditions, but merely the admission of a stronger, probably cold, ocean current to the sheltered inlets and embayments where fine mud is being deposited with its planktogenous organic material.

On the other hand, Zenkewitch (1931) believes that the brown deposits high in ferric iron and manganese dioxide and low in organic matter and bottom fauna which have been described by Gorshkova (1931) from the centers of the White, Barents, and Kara seas owe their existence to prolonged periods of stagnation and oxygen depletion during which the benthonic fauna is reduced or killed, carbonic acid is developed, and conditions are favorable for the development of iron bacteria. A more likely explanation seems to be that there is a very small benthonic fauna because there is little accumulation of edible organic material, and that the small amounts of organic material allow the maintenance of an oxidizing potential.

That in some areas near continental margins the relative rate of accumulation of easily decomposable organic matter is slow compared with that of ferric hydroxide and clay minerals containing Fe_2O_3 is shown by the existence of red muds of perhaps considerable thickness, such as those described by the Challenger from off the Brazilian coast. Somewhat similar deposits found by the Siboga expedition in the Dutch East Indies (Bøggild, 1916) were found to be bluish in color at a depth 15 cm below the surface. Certain sediments also, notably volcanic muds, owe their colors in part to the presence of unaltered colored materials, such as dark colored volcanic glass, pyroxenes, amphiboles, and olivine.

In general, however, the colors of deep-sea sediments are an index of the relative rates of deposition of their components and thus of the sum total of conditions under which they are formed; furthermore color is a more or less quantitative, easily determinable property.

Texture. In comparison with color the texture of deep-sea sediments is often a complicated and misleading quality, since it is the result either of mechanical sorting, by currents and otherwise, of clastic particles, or of the building up of authigenic mineral grains, or of the varying sizes of the skeletal remains and coprolitic or other agglomerations of organisms (see Buchanan, 1890; Murray and Philippi, 1908; Vaughan, 1924; Thorp, 1931; Takahashi and Yagi, 1929; Moore, 1931, 1933). In consequence, Thoulet's (1894) attempted size classification of deep-sea sediments on the basis of grain size yields such anomalies as the designation of a Globigerina ooze as a calcareous sand.

Nevertheless, the grain sizes of the individual detrital or volcanic mineral particles in deep-sea sediments can usually at least roughly be determined, if only by microscopic examination, and are of fundamental importance in classification.

Chemical Composition. Certain of the chemical characters of sediments may be of use in classification. For example, the calcium carbonate content, as will be shown in a subsequent section, reflects many of the conditions of formation. Likewise, sediments might be separated on the basis of their silica sesquioxide ratios into ferruginous or basic, argillaceous, and siliceous types. Similarly, according to Caspari (1910), sediments of low silica-base ratio contain large amounts of unweathered materials, whereas those in which the ratio is high consist of products of weathering, such as quartz and clay minerals. Gripenberg (1934) has recently shown that the sediments of the north Baltic Sea may be satisfactorily classified on the basis of their content of organic matter, and use might be made of this quality in the classification of deep-sea sediments. The role of organic matter, however, perhaps depends as much on its composition--particularly the nature and amount of decomposable constituents--as on the actual total amount present in the sediments.

Physical Composition. The chief materials which constitute marine sediments may be classified according to origin as follows:

I. Substances of terrigenous origin
  A. Relatively unaltered minerals and rock fragments
    1. Detrital materials. The products largely of mechanical weathering of continental land; transported by wind, water, ice, and organic agencies
    2. Volcanic ejecta. The explosive products of vulcanism; transported by the initial force of the explosion, by wind, and by marine currents
  B. The ultimate products of the chemical weathering of rocks on land. These include certain clay minerals, iron and aluminium hydroxides, and free silica, either as quartz or as colloidal silica; transported from land chiefly in suspension by marine currents
II. Substances precipitated from solution in the sea, either by organisms or otherwise

- A. Carbonates and phosphates, mostly of calcium but with some magnesium
    - 1. Skeletons of marine organisms, either pelagic, such as Coccolithophoridae and certain foraminifera and mollusca, or benthonic and neritic, including corals, and certain calcareous algae, mollusca, and foraminifera
    - 2. Inorganic calcium carbonate not formed directly by organisms
- B. Hydrated silica, usually as the test of radiolaria, frustules of diatoms, and skeletal fragments of other organisms, but possibly also deposited inorganically

III. Authigenic substances. The products of submarine weathering and diagenesis; including glauconite, phillipsite, ferrous sulphide, iron manganese concretions, probably certain clay minerals, and iron and aluminium hydroxides, together with other substances formed in place on the sea bottom

IV. Organic matter. The carbonaceous and nitrogenous remains of organisms (terrigenous in part)

In any particular sediment, of course, a given component may have originated in different ways. For example, glauconite and calcium carbonate are often detrital, whereas some ordinarily detrital minerals, such as feldspar, occasionally may be authigenic. Furthermore, the clay minerals and other products of subaerial weathering may be indistinguishable from those possibly resulting from submarine weathering. The colors of sediments largely depend on the colors of the constituents listed under divisions I A, III, and IV, although the presence of volcanic ejecta sometimes lends a dark color to a deposit.

Some sediments consist of only one or two of the above groups of components and may be classified easily according to the agents responsible for the origin of the materials which they contain, as proposed by Grabau (1904) and Holmes (1920). The majority of sediments, however, contain many components, each of different origin, and are accordingly difficult to classify on this basis. Furthermore, two sediments whose major components are similar but which differ in their minor components may have been formed under quite different conditions. Nevertheless, the conditions of formation are in part reflected by the relative proportions of the components and by the presence of certain constituents, so that the mineralogical or modal composition of sediments is of importance in classification.

Previous Classification. The first attempt at classification of recent marine sediments was made by Murray and Rénard (1884) primarily from the geographical point of view although subdivisions were made according to grain size, the preponderance of different groups of organisms and different kinds of inorganic materials, and color and calcium carbonate content. Murray and Rénard designate as deep-sea deposits all those beyond the 100-fathom line and they divide these into two groups, namely: terrigenous deposits formed in deep and shallow water close to land masses, and pelagic deposits formed in deep water far removed from land, that is, in the great central oceanic basins. Pelagic deposits, in turn, are subdivided according to whether they consist largely of the remains of organisms or of inorganic materials, the organic deposits being called oozes, and the inorganic deposits being the red clay. The terrigenous deep-sea deposits, called muds[1] are subdivided on the basis of color and physical composition. In outline, the classification used by these authors is as given below.

Subsequent authors, including Krümmel (1907), Andrée (1920), and Johnstone (1923, following Herdman), have modified in various ways the original grouping of deep-sea sediments into pelagic and terrigenous deposits. All these writers, however, have retained essentially the same deposit types as those proposed by Murray and Rénard.

Classification of deposits

Deep-sea deposits (beyond 200-meter line)	Red clay Radiolarian ooze Diatom ooze Globigerina ooze Pteropod ooze	Pelagic deposits (formed in deep water far from land)
	Blue mud Red mud Green mud Volcanic mud Coral sand and mud	Terrigenous deposits (formed in deep and shallow-water close to land masses)
Shallow-water deposits (between low water mark and 200-meter line)	Gravel, sand, muds, etc.	
Littoral deposits (on the strand between high and low water marks)	Stones, gravels, sands, muds, etc.	

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[1] Gripenberg (1934) has recently discussed the usage of the term "mud" which, she says, is analogous to the term "gyttja" employed by limnologists, and should be used to refer to the color and consistency of fine-grained sediments regardless of their grain size. Typical muds of the Baltic, for example, are loose and flocculent in structure and black in color, as contrasted with clays of the same region which are firm and gray.

Types of Marine Deposits

The limiting characteristics of the types of deep-sea marine deposits as they were distinguished by Murray and his co-workers are summarized in the accompanying table (table A). For each deposit type, the $CaCO_3$ content, per cent of pelagic and benthonic foraminifera and other calcareous remains, per cent of siliceous remains, and texture and composition of inorganic constituents are listed. These have been taken from the summaries given by Murray and Rénard for the Challenger samples, by Murray and Philippi (1908) for the Valdivia expedition, and by Murray and Chumley (1924) for over 1400 deposits of the Atlantic Ocean. The actual $CaCO_3$ content of a sample was chemically determined by these authors, whereas the relative proportions in the whole sample of pelagic and benthonic foraminifera and of calcareous remains other than foraminifera were estimated by inspection chiefly of those parts of the sample greater than 0.05 mm in size. This procedure has been questioned by Heim (1924), who points out that samples listed by Murray and his co-workers as containing from 40 to 70 per cent pelagic foraminifera actually often contain only 1 to 5 per cent of recognizable tests of foraminifera. In the Challenger report, the percentage of remains of siliceous organisms included only those greater than 0.05 mm in size. Later, the procedure for estimating the proportion of siliceous remains was revised, and the estimated amounts in the finer fractions were included in the total percentage of siliceous remains by Murray and Chumley.

Following is a list of the various types of deep-sea marine deposits of Murray and Rénard, arranged alphabetically, together with a discussion of the origin of the terms used and of names applied to similar deposits by other workers. Later it will be shown that certain revisions of the existing terminology may be desirable in order to obtain greater precision in the classification and separation of deep-sea sediments.

1. Blue mud (French, Boue bleue; German, Blauer Schlick). This name was employed by Murray in 1876 to designate the deposits most frequently met with in the deeper waters surrounding continental land and in all enclosed or partially enclosed seas more or less cut off from free communication with the open ocean. The terms "gray mud" (for noncalcareous samples) and "transition mud" (for samples containing appreciable amounts of lime) were suggested by Schmelck (1882) and later employed by Böggild (1906). The blue muds are characteristically slatey or bluish in color when wet, passing in most cases into a more or less thin layer of a reddish color at the upper surface. In some of the samples collected by the Siboga expedition this layer was 15 cm in thickness (Böggild, 1916). When dry, the great majority of Atlantic samples are gray, sometimes with a brown, green, or blue tinge, and sometimes brown or reddish rather than gray. The structure is rarely plastic and compact, but instead is usually only moderately coherent and granular. In blue muds of glacial origin the proportion of clay minerals in the finer fractions may be quite small, and these deposits were designated as glacial marine sediments by Philippi. Coprolitic pellets are common, and phosphate nodules rare, constituents of blue muds. When the former are abundant, the term coprolitic mud employed by Buchanan (1890) may be used (see Murray and Philippi [1908], Andrée [1920], and Thorp [1931]).

2. The terms coral mud and coral sand were employed by Murray and Rénard in 1884 to designate the calcareous sediments found in the vicinity of coral reefs and islands, and consisting largely of the fragments of neritic and benthonic organisms. Since the remains of corals are usually not predominant constituents of such sediments, Murray and Philippi (1908) later suggested the use of the term "Detritogene Kalkablagerungen," and Vaughan (1924) used the terms "calcareous muds and sands." These deposits are usually white or dirty white in color. The large amount of fine-grained calcareous matter in calcareous muds gives them a sticky and chalky character, according to Murray and Rénard, whereas calcareous sands, which, as the name implies, are sandy in texture, are incoherent and granular in structure. (For more detailed descriptions of these deposits, see Goldman [1926], Bramlette [1926], and Thorp [1935]).

3. Diatom ooze (French, Vase à diatomée; German, Diatomeenschlamm). This term was introduced by Murray in 1876 to distinguish those deposits first described by Hooker (1847) from the Antarctic in which diatom frustules are exceptionally abundant. Such deposits are characteristic of the cold waters of the Southern Ocean at a distance from the Antarctic Continent and are found also along the northern border of the Pacific. They are characteristically yellowish, straw or cream colored when wet, and dirty white when dry, although according to Murray and Rénard near land they may assume a bluish tinge from the admixture of land detritus.[1] When dry, the deposits are pulverulent, soft, and gritty in structure.

4. Globigerina ooze (French, Vase à Globigérines; German, Globigerinenschlamm). Globigerina ooze was described first by Bailey in 1853 (see Maury, 1859) and by Ehrenberg (1854) from specimens collected by Lee and Berryman of the United States Navy in the north Atlantic. This deposit covers most of the great central oceanic basins at depths less than 2500 fathoms, and is second in areal distribution only to red clay. The color of Globigerina oozes far from land is said to be milky white, rose, yellow, or brown and of that near land dirty white, blue, or gray. The structure is usually pulverulent-granular to coherent, and the deposits are usually fine-grained and homogeneous, though in the tropics many of the foraminifera shells present in the deposits are macroscopic in size. As stated above, proportions of the various calcareous organisms given in the table were estimated from the coarser fractions of the sediments which were assumed to be representative of the finer fractions as well. On the other hand, Lohmann (1903) describes a sample from the Atlantic which contained 70 per cent of coccoliths and Andrée points out that this should be designated as coccolith ooze. Certain of the Challenger samples redescribed by Heim in which "die Hauptmasse besteht aus mehr oder weniger tonreichem dichtem Kalkschlamm, der die grösste Ähnlichkeit mit Seekreide hat" (Pia, 1933, p. 339) might logically be called simply calcium carbonate oozes, since it is often impossible to determine what organisms, if any, were responsible for the deposition of the larger proportion

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[1] Since this was written, a paper by Neaverson (1934) on the bottom deposits collected by the Discovery II and William Scoresby has appeared in which the term diatomaceous mud is suggested for diatomaceous sediments which contain considerable amounts of detrital mineral grains and of decomposable organic matter.

of the calcium carbonate. Phosphate and manganese nodules are not abundant in Globigerina ooze according to Murray and Rénard, but in the southeast Pacific the Globigerina oozes are often very high in manganese. The inorganic residue of pelagic oozes was thought by Murray and Rénard to be nothing more than red clay. On the other hand, as will be shown subsequently, there is, in the south Pacific at least, a marked distinction between the noncalcareous parts of certain of the Globigerina oozes and red clays from the same region, the residue from the Globigerina oozes having a much lower silica sesquioxide ratio than any red clays which have been collected hitherto.

5. Green mud and sand (French, Boue et sable vert; German, Grün-Sande-und Schlicke). Recent green sands were described first by Bailey (1851) and Pourtàles (1853) from off the Atlantic coast of the United States. The term "green mud" was used by the Challenger workers for the finer-grained equivalent of green sand. These deposits are said to be found most characteristically on continental slopes off high and bold coasts, where the rate of deposition is slow. The seventeen Atlantic samples described by Murray and Chumley are said usually to be gray rather than green when dry, although often with a green tinge. They have sometimes a brown tinge and are rarely bluish. The structure is only slightly coherent and is granular, owing to the presence of glauconite grains. Glauconite is, by definition, present in all samples. There are many green-colored sediments, however, in which the presence of glauconite is doubtful. These were called blue muds by Murray and Rénard, although a more logical system of designation would be the naming of all fine-grained green-colored sediments as green muds, separating those containing glauconite as glauconitic muds.[1]

6. Pteropod ooze (French, Vase à ptéropodes; German, Pteropodenschlamm). This name was employed by Murray in 1876 to distinguish those deposits formed in warm waters of moderate depth, on oceanic ridges and cones usually far from continental land, which are characterized by the presence of a great number and variety of pelagic organisms, notably pteropod and heteropod shells. The Atlantic pteropod oozes are usually light brown or almost white in color when dry, often with a gray, reddish, pink, or yellow tinge. They are only slightly coherent and usually are coarsely granular, many of the pteropod shells being macroscopic in size. This deposit is perhaps best regarded as a variety of Globigerina ooze.

7. Radiolarian ooze (French, Vase à radiolaires; German, Radiolarienschlamm). This name was used by Murray in 1876 to designate those deposits found in the central Pacific and later in the Indian Ocean which, "while resembling red clays in most respects, differ from them in containing a much larger number of radiolarian shells, skeletons, and spicules, together with sponge spicules and the frustules of diatoms." These sediments are red, chocolate, or occasionally straw colored, and less plastic than the red clay. Argillaceous matter is always present, and is often formed into irregular agglomerations which do not break up under the action of acid, and may be cemented by colloidal silica. "Peculiar white-colored aggregations composed of minute rhombohedral crystals," believed to be calcite or dolomite, are usually present.

8. Red clay (French, Argile rouge; German, Roter Tief-See Ton). This deposit was first discovered by the Challenger between Teneriffe and the West Indies, and was described in 1874 by Wyville Thomson, who believed that it was primarily of organic origin, being "essentially the insoluble residue, the ash, as it were, of calcareous organisms." Murray, in 1877, claimed that the clay was derived from the decomposition of volcanic ejecta, but he admitted that "colloid clayey matter coming in suspension from the land may play some part in the formation of this deposit." The red clay is spread over the greater depths of the ocean far from land and is the most widely distributed of all deep-sea deposits. In the north Atlantic and some other regions the color is brick red from the presence of ferric hydroxide, intimately mixed with the clay. In the south Pacific and the Indian oceans the color is often chocolate brown from the presence of minute grains of manganese dioxide. Some of the samples collected relatively near shore and described as red clays had a bluish rather than red tinge owing to the presence of ferrous sulphide and organic matter. Similarly, certain gray Albatross samples collected near the South American coast were called red clays by Murray and Lee (1909). The red clay is plastic and greasy to the touch when wet. When dry it is very coherent.

9. Red mud (French, Boue rouge; German, Roter Schlick). Red mud was described first in 1876 by Murray, who regarded it as a local variety of blue mud found in certain regions, such as the Yellow Sea and off the coast of Brazil, where great rivers bring down "large quantities of ochreous matter" and in which the rate of accumulation of organic matter is not sufficient to reduce the large amounts of ferric oxide. Ten samples described by the Challenger from the Brazilian coast were all red brown in color. The mineral assemblage is said by Murray and Rénard to be similar to that of other terrigenous deposits along the continental shores, except that glauconite is never present.

10. Volcanic mud and sand (French: Boue et sable volcanique; German, Vulkanische Schlicke und Sande). This name was given by Murray in 1876 to the muds and sands found around volcanic islands which contain large amounts of volcanic material. The color is usually brownish gray or grayish brown, occasionally with a green or blue tinge. The structure is ordinarily only slightly coherent. Glauconite is usually absent.

From a study of the above descriptions and of the values given in the tabular summary for the characteristics and composition of the various deposit types, it will be seen that it is usually possible to express the Murray classification of recent deep-sea sediments (which is based on assumed origin of the sediments and geographical location) in terms of the physical and chemical composition and characters of these sediments themselves, even though the maximum and minimum values given for several of the deposit types overlap.

The criteria for the recognition of pelagic deposits, as identified by Murray and his co-workers, may be stated as either (1) the presence of more than 30 to 40 per cent of predominantly pelagic organic remains, or (2) the absence of notable amounts of detrital or volcanic minerals (except in deposits far from land), usually together with a reddish or brownish color. Thus a red

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[1] Neaverson (1934) has suggested the use of the term glauconitic muds for green muds which contain glauconite; and has introduced the term diatomaceous mud for most nonglauconitic green muds.

Table A. Summary of characteristics and composition of

	Pelagic deposits				
Composition and constituents	Red clay		Radiolarian ooze	Diatom ooze	
	Challenger	Murray and Chumley	Challenger	Challenger	Valdivia
Physical composition					
Organic constituents in per cent					
$CaCO_3$, maximum	28.8	29.0	20	36.3	24.0
Minimum	0	0	tr	2.0	0
Average	6.7	10.4	4	23.0	2.7
Pelagic foraminifera, maximum	....	27.0	.....	.....	predominant part of $CaCO_3$
Minimum	....	0	.....	.....	
Average	4.77	8.8	3.1	18.2	
Benthonic foraminifera, maximum	....	3.0	.....	.....	....
Minimum	....	0	.....	.....	present
Average	0.6	0.6	0.1	1.6	....
Other calcareous remains, maximum	....	6.3	.....	.....	....
Minimum	....	0	.....	.....	present
Average	1.3	1.0	0.8	3.2	....
Siliceous remains, maximum	....	5.0	80.0	60.0	90.0
Minimum	....	0	30.0	20.0	40.0
Average	2.4	0.7	54.4	41.0	73.1
Inorganic constituents in per cent					
>0.05 mm diameter, maximum	20.0	60.0[a]	5.0	25.0	40.0
Minimum	1.0	tr	1.0	3.0	1.0
Average	5.6	2.4	1.7	15.6	8.4
<0.05 mm diameter "fine washings"					
Maximum	....	100.0	67.0[b]	27.9[b]	34.0
Minimum	....	31.0	17.0[b]	12.5[b]	9.0
Average	85.4	86.5	39.9[b]	20.4[b]	15.8
No. of samples averaged	70	126	9	5	16
	Number of samples in which substance is recorded				
Principal inorganic constituents other than clay minerals, hydroxides, and colloidal silica					
Allogenic minerals					
Amphibole[e]	44	19	10	100	60
Chlorite	...	...	...	.....	...
Epidote	3	...	...	.....	...
Feldspar, undifferentiated	76	19	90	60	90
orthoclase[f]	...	...	...	40	...
sanidine	10	...	...	....	...
plagioclase[g]	29	...	...	80	...
Garnet	1	...	...	20	...
Magnetite	89	23	...	100	...
Mica, undifferentiated	27	40	10	40	6
white mica	...	...	...	....	...
black mica[h]	...	...	10	20	...
Olivine	7	...	...	40	...
Pyroxene, undifferentiated	...	...	...	.....	...
enstatite	...	...	...	....	...
hypersthene[i]	...	...	...	....	...
augite	61	13	30	40	12
Quartz	30	58	...	80	80
Tourmaline	4	...	...	20	...
Zircon	4	...	...	20	...
Authigenic minerals					...
Analcite	...	...	10	....	...
Glauconite	9[j]	14[j]	...	20	6
Manganese grains, nodules	79	43	70	....	...
Palagonite	31	9	40	20	...
Phillipsite	14	...	40	....	...

deep-sea sediments according to Murray and co-workers

			Terrigenous deposits						
Globigerina ooze		Pteropod ooze	Blue mud		Green mud	Red mud	Volcanic mud		Coral mud
Challenger	Murray and Chumley	Murray and Chumley	Challenger	Murray and Chumley	Challenger	Challenger	Challenger	Murray and Chumley	Challenger
96.8	97.2	98.5	34.3	56.8	56.2	60.8	56.6	.....	89.7
30.2	30.0	44.8	tr	0	tr	5.8	tr	.....	77.4
64.5	64.7	73.8	12.5	17.0	25.5	32.3	20.5	32.6	85.5
80.0	95.0	75.0	25.0	34.0	35.0	30.0	35.0	.....	56.0
25.0	15.0	15.0	0	0	tr	3.0	tr	.....	10.0
53.1	58.9	34.7	7.5	9.1	14.6	13.4	10.5	15.2	31.3
.....	10.0	10.0	10.0	20.0	15.0	8.0	10.0	.....	40.0
.....	0	tr	tr	0	tr	1.0	tr	.....	2.0
2.1	2.1	3.6	1.8	3.5	2.9	3.3	2.8	3.7	14.6
31.8	26.0	57.0	16.0	41.8	31.2	40.8	21.6	.....	59.7
1.2	tr	15.8	tr	0	tr	1.8	tr	.....	26.3
9.2	3.7	35.5	3.2	4.4	8.0	15.5	7.2	13.7	39.6
10.0	15.0[c]	20.0	15.0	15.0	50.0[d]	.....	5.0	.....	2.0
4.0	tr	tr	1.0	tr	1.0[d]	.....	1.0	.....	tr
1.6	1.7	1.9	3.3	1.7	13.7[d]	1.0	1.8	2.0	1.4
50.0[a]	50.0[a]	20.0	75.0	70.0	80.0	25.0	75.0	.....	.....
1.0	tr	tr	1.0	tr	1.0	10.0	5.0	.....	.....
3.3	5.1	4.7	22.5	17.8	27.1	21.1	40.8	40.8	1.0
64.6	69.3	41.8	97.0	100.0	84.1	68.3	60.7	.....	20.6
1.2	1.2	tr	16.1	11.7	9.7	28.2	15.4	.....	8.3
30.6	28.5	19.6	61.8	63.6	33.7	45.6	36.9	24.7	12.1
118	772	40	58	342	22	10	38	91	16
in per cent of total number of samples analyzed									
50	36	60	79	57	50	60	25	26	30
...	...	...	5	...	...	...	...	...	...
...	...	...	5	...	10	10	...	...	...
73	38	50	66	23	80	70	40	85	80
x[k]	...	...	18	...	5	...	2	...	...
18	...	10	6	...	...	...	20	9	...
20	...	10	65	...	50	10	50	10	15
x[k]	...	...	6	...	x[k]	...	...	...	...
80	29	40	66	26	60	...	65	45	35
26	64	70	39	79	30	90	2	57	...
...	...	...	8	...	5	...	...	...	...
...	...	...	8	...	5	...	10	...	20
16	...	10	11	...	5	10	45	19	5
x[k]	...	...	3	...	...	...	5	...	...
x[k]	...	...	...	...	...	...	...	...	...
...	...	...	3	...	...	...	...	...	...
70	12	40	58	12	60	10	65	25	35
42	68	70	100	92	90	100	2	28	35
x[k]	...	...	11	3	20	25	...	...	...
x[k]	...	...	11	...	20	25	...	...	...
...	...	...	...	...	...	...	...	...	...
11	13	...	57	62	90	...	5	...	...
31	6	...	8	4	...	...	2	...	5
8	30	40	6	6	...	...	15	84	...
x[k]	...	...	...	...	...	...	2	...	...

Table A. Summary of characteristics and composition of deep-sea

Composition and constitutents	Pelagic deposits				
	Red clay		Radiolarian ooze	Diatom ooze	
	Challenger	Murray and Chumley	Challenger	Challenger	Valdivia
Principal inorganic constituents--(concluded)					
Authigenic minerals--(concluded)					
Phosphate	...	...	...	....	...
Pyrite	...	...	...	....	...
Rock fragments, etc.					
Crystalline, sedimentary	7	...	...	60	12
Volcanic, glass	64	23	70	80	70
lapilli, scoria	16	...	10	20	...
pumice	49	8	20	40	30
rock fragments	...	...	...	60	60
Magnetite, other (cosmic) spherules	11	...	30	....	...

---

[a] Only in one exceptional case. [b] Includes finely divided remains of siliceous organisms. [c] Only in two exceptional cases; the usual maximum is not more than 5 per cent. [d] Includes glauconitic and other casts of shells of foraminifera, etc. [e] Always listed as hornblende, except for one reference to

sediments according to Murray and co-workers--Concluded

			Terrigenous deposits						
Globigerina ooze		Pteropod ooze	Blue mud		Green mud	Red mud	Volcanic mud		Coral mud
Challenger	Murray and Chumley	Murray and Chumley	Challenger	Murray and Chumley	Challenger	Challenger	Challenger	Murray and Chumley	Challenger
x[k]	...	...	...	...	x[k]	...	...	...	...
...	...	...	2	...	...	...	...	...	...
...	9	...	23	24	x[k]	...	...	...	...
...	60	65	35	22	50	40	50	100	80
...	...	...	8	...	6	...	35	...	...
...	40	30	37	6	30	10	15	78	35
...	8	20	6	...	5	...	25	47	...
x[k]	...	...	...	...	...	...	...	...	...

glaucophane, in a blue mud, and to actinolite, in a globigerina ooze. [f] Includes all references to monoclinic feldspar. [g] Includes all references to triclinic feldspar. [h] Includes three references to green mica in blue and green muds. [i] Includes one reference to bronzite in globigerina ooze. [j] May be allogenic in part. [k] Mineral listed only in summary descriptions of deposit types is indicated by x.

clay may be defined as a fine-grained deposit, ordinarily of reddish or brownish color, in which the $CaCO_3$ content is less than 30 per cent and the content of detrital or volcanic minerals and of organic remains is usually small. Sediments in which there are large amounts of pelagic organisms are called pelagic oozes regardless of their color or content of unaltered minerals. Normally, however, as may be seen from the average values given in the table and from the descriptions on preceding pages, pelagic oozes are reddish brown to white in color, and contain only small amounts of relatively coarse-grained unaltered minerals. When the $CaCO_3$ content is greater than 30 per cent, the deposit is usually either a Globigerina or pteropod ooze. When the $CaCO_3$ content is less than about 30 per cent and siliceous organic remains are present in large amounts, the deposit is a diatom or radiolarian ooze. In the Antarctic diatom oozes the average content given in the table for mineral particles greater than 0.05 mm in diameter is comparatively large, but this is owing to the inclusion of a few samples of high mineral content. Of the seventeen diatom oozes described in the Valdivia report, twelve contain less than 5 per cent mineral particles of sand size. As will be shown later, the remaining five samples more appropriately may be designated as diatom muds.

Terrigenous deposits called sands and muds, as identified by Murray, may be distinguished by one or more of the following characteristics: (1) notable amounts of unaltered minerals or minerals characteristic of diagenesis under near-shore conditions; (2) notable amounts of neritic organic remains; (3) less than about 30 per cent of pelagic organic remains; (4) a bluish, blackish, gray, or greenish color. Blue muds, for example, are normally characterized by a bluish, blackish, gray, or greenish color, a relatively low content of $CaCO_3$ and of pelagic organic remains, and the presence of considerable amounts of detrital minerals. A reddish or brown color, the presence of large amounts of detrital minerals, and the absence of more than 30 per cent of pelagic organic remains distinguish a red mud. A high $CaCO_3$ content and the presence of large amounts of neritic organic remains characterize calcareous (coral) muds. Green muds and volcanic muds are characterized by the presence, in notable amounts, of glauconite or volcanic material, respectively, together with the absence of more than 30 to 40 per cent of pelagic organic remains. In two of the Challenger samples of green mud (numbers 149 and 236), however, no glauconite is recorded.

Difficulties of the Accepted Classification

The fundamental validity of much of the Murray classification of deep-sea sediments becomes more and more apparent on close consideration, and is shown well by the wide applicability of the classification and by the fact that it can usually be expressed in terms of the physical properties and composition of the sediments. There are, however, certain weaknesses in the present system.

The two basic criteria employed to distinguish pelagic and terrigenous deposits, namely (1) the amount of pelagic organic remains, and (2) the character and composition of the inorganic constituents, are often contradictory. For example, ten samples are listed by Murray and Chumley which they themselves state might have been called either Globigerina ooze because of the presence of pelagic organisms, or blue mud because of the bluish gray color and the presence of detrital minerals. Five samples are described by these authors which might have been called either Globigerina ooze or volcanic mud from the presence of large amounts of both pelagic foraminifera and volcanic material. Similarly, several of the Challenger red muds from off the South American coast contained, in addition to large amounts of detrital mineral grains, large amounts of pelagic organisms, and Murray and Rénard state that they might equally well have been called either Globigerina pteropod oozes, or red muds. Three cases are given by Murray and Chumley in which Globigerina ooze is said to overlie blue mud. This has been interpreted by some workers to mean that terrigenous deposits are here overlain by pelagic ones, whereas in fact, aside from the difference in the amount of $CaCO_3$, the deposits are quite similar. From their color and content of detrital minerals, the overlying Globigerina oozes might properly also be described as blue muds. Certain samples collected by the Albatross off the western coast of South America, which were called diatom oozes by Murray and Lee because of their high content of siliceous organisms, might also have been designated as blue or green muds, judging by their color. They are quite dissimilar to the typical Antarctic diatom oozes which were probably deposited at a much slower rate under oxidizing conditions. Many sediments collected in the region southeast of Japan contain large quantities of both pelagic foraminifera and fresh volcanic material. Some of these would be designated in the Murray system as volcanic mud, others as Globigerina ooze, even though they apparently form a continuous series, the relatively low $CaCO_3$ content of which is not owing to depth or other physical factors but merely to dilution by volcanic materials.

The color terms used in the description of some of the types of terrigenous deposits are occasionally anomalous or misleading. To illustrate, there are many green-colored sediments occurring off the west coasts of North and South America which appear to contain no glauconite and therefore would be called blue muds in the Murray system, even though they are similar in every other respect to the glauconite-bearing sediments of the same region which are called green muds. Likewise, Stetson (1933) was obliged to describe certain deposits from the Arctic as blue mud, because of the presence of minerals of continental type, even though the deposits are chocolate brown in color.

The simple deposit types of Murray and Rénard hold quite satisfactorily for deposits made up of pure materials. The fact is, however, that many deep-sea deposits are not pure but contain a number of constituents of various origins. Thus two sediments, whose major constituents are the shells of pelagic foraminifera and which consequently would be called simply Globigerina ooze in the Murray system, may differ widely with respect to the physical characters and composition of their other constituents, and these differences may indicate that the two sediments were formed under dissimilar conditions. It is desirable, therefore, to take such differences into account by subdividing many of the Murray deposit types.

Suggested Modifications

The primary separation of deep-sea sediments into terrigenous and pelagic types is a valuable one and should be retained but, as has been stated, the criteria which have been used for the distinction of the two types are often contradictory. A more precise delimitation may be attained by redefining pelagic deposits on the basis of the actual properties of the sediments, namely; color, texture, and composition. The term pelagic deposits would then be restricted to those deep-sea sediments which are red, brown, yellow, or white in color, and which contain only small amounts of neritic organic remains and of detrital or volcanic mineral grains of diameters greater than 5 microns. It is difficult to give a numerical value for texture, since relatively few mechanical analyses of deep-sea sediments have been published; but a maximum of 20 per cent of detrital or volcanic particles greater than 5 microns in diameter is valid at least for the samples described in this report and apparently agrees well with the average values given in the above tabular summary. The doubtful deposits discussed in preceding pages will be placed in the terrigenous group by this definition and should be called Globigerina, diatom, or other types of mud.

Besides texture and color, the most important character of deep-sea sediments is the presence or absence in large amounts of skeletal remains of organisms, and this long has been recognized in pelagic deposits by the separation into oozes and red clay. A corresponding division in terrigenous deposits should be made by the use of descriptive adjectives signifying the nature of the principal organic remains when these are present in amounts greater than 30 per cent. An important distinction between the various types of organic remains may be based on whether they are calcareous or siliceous.

Further subdivisions reflecting the varying conditions of formation of deep-sea sediments may be made on the basis of the nature of the inorganic materials, which should be indicated by the adjectival terms applied to the deposits. In pelagic deposits these are chiefly of four types, namely: (1) Free iron and aluminum hydroxides, and iron manganese oxides. These may be lumped together as ferruginous constituents. (2) Clay minerals or argillaceous constituents, that is, the minerals of the kaolinite, beidellite-nontronite, montmorillonite, and possibly other groups. These first two types of components (together with phillipsite and other products of diagenesis) may be regarded as alteration minerals. When unaltered minerals occur in pelagic deposits, they are usually either of (3) detrital (continental) or (4) volcanic origin. In terrigenous deposits the prominent altered and diagenetic mineral constituents are clays and glauconite. The unaltered materials are again either of detrital or volcanic origin. It is suggested, therefore, that the adjectives argillaceous, ferruginous, glauconitic, detrital, or volcanic be used when it is necessary to designate the characteristic type of inorganic material in a sediment. The inorganic constituents of most pelagic deposits are usually argillaceous, whereas terrigenous sediments usually contain argillaceous and detrital minerals, and these may be considered as the normal types for which no descriptive adjective is necessary. Furthermore, it is only when deposits contain important amounts of both mineral and organic debris that it is necessary to use adjectives for both constituents.

From the previous discussion of the significance of color, it is evident that the terms blue and green mud used for terrigenous sediments should be applied only to deposits which are actually bluish or green in color when collected (regardless of the presence of glauconite); and the descriptive adjectives brown, black, or gray should be used for other terrigenous deposits such as those mentioned above, described by Stetson and Bõggild.

The nouns used to describe terrigenous sediments, namely, sand and mud, indicate something of the texture of these deposits but, as has been stated previously, texture is of genetic significance, principally with regard to the size of the unaltered mineral or rock grains of the sediment. For muds in which the inorganic constituents have been mechanically analyzed, or in which there is a low content of remains of organisms, the adjectives silty and sandy for sediments of median particle diameters greater than 5 microns, and clayey for sediments of particle diameters less than 5 microns, may be used.

Summary

We may now summarize the above discussion and the suggested modifications of the usual classification and nomenclature of marine sediments.

1. The classification should be based on the physical properties and composition of the sediments themselves, namely: color, which is an index of the oxidation-reduction potential in a sediment and, therefore, of the rate of deposition; texture of allogenic mineral or rock particles, which indicates the effectiveness of the agents of transportation involved in the production of the sediment; and the kinds of organic and inorganic components, which indicate the origin of the materials in the deposit.
2. Since one of the fundamental distinctions between pelagic and terrigenous sediments is the relatively slow rate of deposition of the former, indicated by color and texture, the term "pelagic deposits" should be restricted to sediments of red, brown, yellow, or white color which have less than a certain amount (about 20 per cent in the Pacific) of allogenic mineral and rock particles larger than 5 microns in diameter and which contain only small amounts of neritic organic remains.
3. The accepted types of pelagic deposits should be retained, but subdivided when necessary on the basis of the inorganic constituents into argillaceous, ferruginous, volcanic, and detrital Globigerina and other oozes, and red clay.
4. Terrigenous sediments should be distinguished by any one or more of the following characteristics: a black, bluish, green, or gray color, or the presence of more than a certain amount of allogenic mineral and rock particles larger than 5 microns in diameter, or the presence in appreciable amounts of neritic organic remains.
5. The types of terrigenous deposits should be designated when necessary by adjectival terms (restricted to their actual descriptive meanings) for color, nature of organic and inorganic materials, and texture. In terrigenous sediments which contain more than thirty per cent of organic skeletal remains the adjectives Globigerina, pteropod, calcareous (for neritic organisms), diatom, or radiolarian should be used to indicate the predominant type of organic material. For terrigenous sediments which contain appreciable amounts of other than argillaceous inorganic material the terms glauconitic, volcanic, or detrital should be used when necessary.

Proposed Classification

On the basis of the above remarks a revised and more detailed classification of deep-sea sediments may be tentatively proposed. The capitalized words signify the terms which it is suggested should be used.

- I. Pelagic deposits
  - A. Oozes. Skeletal remains of organisms greater than 30 per cent in amount
    - 1. Calcium carbonate oozes. $CaCO_3$ greater than 30 per cent in amount. Divided on basis of calcareous skeletal remains into GLOBIGERINA, PTEROPOD, COCCOLITH OOZE. If calcareous material is very largely fine-grained and not in the form of recognizable skeletal fragments, the general term CALCIUM CARBONATE OOZE may be used. When noncalcareous material is present in appreciable amounts, a further designation should be applied, e.g. GLOBIGERINA OOZE may be divided into
      - a) Normal or argillaceous GLOBIGERINA OOZE. The noncalcareous material is very largely clay. Most GLOBIGERINA OOZES are of this type
      - b) FERRUGINOUS GLOBIGERINA OOZE. The noncalcareous material consists of free hydroxides to a considerable extent. Type: Carnegie sample 19
      - c) VOLCANIC GLOBIGERINA OOZE. Volcanic glass and mineral grains of sand and silt size make up to 20 per cent of the sediment
      - d) DETRITAL GLOBIGERINA OOZE. Quartz, feldspar, and other detrital mineral grains of sand and silt size make up to 20 per cent of the sediment
      - e) SILICEOUS GLOBIGERINA OOZE. In addition to calcareous skeletal remains, these sediments are rich in the skeletons of radiolaria and the frustules of diatoms. Examples: Carnegie samples 13 and 81
    - 2. Siliceous oozes. $CaCO_3$ less than 30 per cent in amount; remains of siliceous organisms greater than 30 per cent. May be called either DIATOM or RADIOLARIAN OOZE, depending on which type of organic remains is the more abundant. When volcanic or detrital remains are present in noticeable amounts the deposit may be called a VOLCANIC or DETRITAL DIATOM or RADIOLARIAN OOZE. Carnegie sample 57 is a VOLCANIC RADIOLARIAN OOZE. When calcareous remains are present in appreciable amounts the term CALCAREOUS DIATOM or RADIOLARIAN OOZE may be used. Type: Valdivia sample 121
  - B. Red clay. Skeletal remains of organisms less than 30 per cent in amount. When free hydroxides are known to be present in relatively large amounts the deposit may be designated as FERRUGINOUS RED CLAY. When detrital or volcanic mineral fragments or calcareous or siliceous organic remains are present in appreciable quantities the terms DETRITAL, VOLCANIC, SILICEOUS, or CALCAREOUS RED CLAY may be used. Carnegie sample 35 is a SILICEOUS RED CLAY; Carnegie sample 47 is a CALCAREOUS RED CLAY
- II. Terrigenous deposits, called muds
  - A. Organic muds. Skeletal remains of organisms greater than 30 per cent
    - 1. Calcium carbonate muds. $CaCO_3$ greater than 30 per cent in amount.
      - a) Calcareous organisms of neritic type, called CALCAREOUS MUD and SAND, depending on texture. These may be subdivided on the basis of the nature of the inorganic material into ARGILLACEOUS, DETRITAL, and VOLCANIC CALCAREOUS MUD. If, as in most cases, $CaCO_3$ makes up 80 per cent or more of the deposits, no qualifying adjective need be used
      - b) Calcareous organisms of pelagic type. These may be called GLOBIGERINA or PTEROPOD MUD, and may be further subdivided if the inorganic materials are other than argillaceous into GLAUCONITIC, DETRITAL, and VOLCANIC GLOBIGERINA MUD
    - 2. Siliceous muds. $CaCO_3$ less than 30 per cent in amount; remains of siliceous organisms greater than 30 per cent. The terms DIATOM and RADIOLARIAN MUD may be used, depending on which type of siliceous organisms is the more abundant. The deposits may be further subdivided if the inorganic materials are other than argillaceous into GLAUCONITIC, DETRITAL, or VOLCANIC DIATOM or RADIOLARIAN MUD. Albatross sample 4674 is a typical DIATOM MUD
  - B. Inorganic muds. Skeletal remains of organisms less than 30 per cent
    - 1. Clayey[1] muds. Median diameter less than 0.005 mm, called BLACK, BLUE, GREEN, or GRAY CLAYEY MUD. The adjectival terms GLAUCONITIC, DETRITAL, or VOLCANIC may be used, if recognizable materials of these types are present in abundance
    - 2. Silty or sandy[1] muds and sands. Median diameter of mineral particles greater than 0.005 mm, called BLACK, BLUE, GREEN, RED, BROWN, or GRAY SILTY or SANDY MUD, or SAND. The adjectival terms GLAUCONITIC or VOLCANIC may also be used, depending on the nature of the constituents, if the inorganic materials are other than detrital and argillaceous. If coprolitic pellets are abundant, the term COPROLITIC MUD may be employed

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[1] No designation for texture need be given for doubtful samples which have not been analyzed mechanically.

DESCRIPTION OF SAMPLES

General Discussion

A synoptic description of the deposit samples collected in the Pacific on the seventh cruise of the Carnegie is given in table 1 (pp. 18-41). The samples are numbered consecutively from 10 to 89 in column 1 of the table. Column 2 lists the stations at which the samples were collected. The latitude and longitude are given in column 3, and the corrected depths in column 4. The samples are then classified according to the system outlined in the section on classification, and the estimated calcium carbonate contents, together with the bases of the estimates, are given in the next column. The colors of the samples and brief descriptions of the physical characters are given in column 7. Column 8 lists the samplers and containers used in the collection and preservation of the samples. Extracts from the field notes made on shipboard at the time the samples were collected are given in column 9. Column 10 contains extracts from the descriptions given by Murray and Rénard (1891), Murray and Lee (1909), Murray (1906), and Flint (1905) of the nearest previous samples collected by the Challenger, Albatross, Nero, and other ships in the Pacific; and in the footnotes of the table brief descriptions of the organic and inorganic components, and of any characteristic or remarkable features of the samples are given. For mechanically analyzed samples, except when otherwise indicated, these descriptions are based only on microscopic examination of the sand grades (particles larger than 0.05 mm in diameter). For samples which were too small for mechanical analysis, a rough petrographic examination of a part of the undifferentiated material was made.

Of the total of eighty-nine samples obtained on this cruise, two were lost in the destruction of the Carnegie at Apia; and one other was not received in Washington. Samples 1 to 9 were collected in the Atlantic Ocean, and samples 88 and 89 represent shallow-water deposits which were collected from Callao harbor and from the beach at Easter Island, respectively. These eleven samples have not been taken into account in the following discussions although some of them were analyzed chemically and in other ways. The other seventy-five samples were collected from a very large area in the north and the southeast Pacific, ranging from latitudes 45°24′ north to 40°24′ south, and from longitudes 141°15′ east to 77°54′ west. The average depth of all samples is 4223 meters, the extremes being 6008 and 1089 meters.

Many of the primary types of deep-sea deposits are present in the collection. There are thirty-two Globigerina oozes, ranging in depth from 4953 to 1089 meters, with an average of 3368 meters, and having carbonate contents ranging between 30 and 94 per cent (averaging 78 per cent). Five of these are siliceous Globigerina oozes, eight are ferruginous, and one is volcanic, whereas the remaining eighteen samples are not subdivided. Of the eighteen, samples 18, 23, 26, 27, 29, 36, 44, and 85 are shown by chemical analysis to have silica sesquioxide ratios between 2.21 and 4.33 and, hence, to be argillaceous or normal Globigerina oozes. The remaining samples have not been chemically analyzed.

There are 26 red clays, with a range in depth between 5787 and 3657 meters (averaging 4762 meters) and having carbonate contents between less than 1 and 20 per cent, the average being 3.83 per cent. Two of these, samples 31 and 35, are siliceous red clays; the remaining twenty-four samples are normal or calcareous red clays.

Besides these major types of pelagic deposits, diatom ooze is represented by two samples from the northwest Pacific, collected at depths of 5296 and 5198 meters, both of which have carbonate contents of less than 1 per cent; radiolarian ooze is represented by three samples, two from the central Pacific and one volcanic radiolarian ooze from the northwest Pacific, collected at depths between 5396 and 4918 meters and having carbonate contents of 2 per cent or less. One siliceous ooze from the northwest Pacific is listed as either a volcanic diatom or radiolarian ooze, since both groups of organic remains are present in large amounts.

Twelve samples are listed as terrigenous. Five of these were collected off the coasts of North and South America and are designated, because of their color and the fact that the principal components are argillaceous and detrital, simply as green and gray silty and clayey (or coprolitic) muds. One sample from off the South American coast is a green diatom mud, and there is one volcanic Globigerina mud from southeast of Japan. The chief components of the remaining five samples are volcanic; one of these is a volcanic gravel, collected about a hundred miles west of Guayaquil; another, from off the coast of Japan, is a gray siliceous volcanic mud; and the remaining three are brown and gray volcanic muds, collected southeast of Japan.

It should be noted that three of the samples are assumed not to be representative of the region in which they occur. Sample 46 is listed as a Globigerina ooze, even though it consists only of a few manganese nodules, which are, however, partly covered with fresh, unbroken pelagic foraminifera. Likewise, samples 75 and 78 are designated as red clay, although they consist respectively of coarse volcanic ash and volcanic cinders, coated with manganese.

Relatively big volcanic fragments or manganese nodules were also present in samples 11, 15, 17, 24, 57, 58, 72, 79, 81, and 86. Considering the methods of collection of the samples, the large number of such materials obtained is a remarkable illustration of their widespread abundance on the floor of the deep sea. At station 49 (sample 17) the condition of the wire and sounding instruments when hauled in, indicated a rocky, very irregular bottom, probably a submarine lava flow, the presence of which is confirmed by the fact that the large broken pieces of basic volcanic glass collected at this station were coated with manganese only on one side.

Even a casual study of the descriptions given in table 1 shows that the assemblage of sand-sized minerals in the pelagic samples of the region investigated is chiefly volcanic, although small amounts of wind- and ice-borne detrital minerals occasionally occur. Furthermore, volcanic glass or pumice, or both, are recorded in about two-thirds of all samples described. In several pelagic samples also, relatively large euhedral crystals of hornblende, plagioclase feldspar, and hypersthene (the latter only in the siliceous volcanic muds and oozes collected northeast of Japan) were found, sometimes partly surrounded by pumice. Small manganese grains are nearly always present in the samples examined. Some of these,

Table 1. Synoptic table of bottom samples collected

For discussion see footnotes on

Sample	Station	Date	Position and depth in meters	Type of sample	Estimated $CaCO_3$ content in per cent; basis of estimate	Color and physical characters
		1928	° ′			
10	37	Nov. 1	5 59 N 82 56 W 3324 m	Green (coprolitic) mud	3; acid soluble CaO	(Wet) grayish-olive 21^4(O-YY) Sandy clay (U.S.B.S. class=clay); rounded grains; moderately coherent, slippery, granular
11	40	8	1 32 S 82 16 W 1344 m	Volcanic gravel	5; inspection	(Dry) from near deep mouse-gray 155i(Y-O) to pinkish-buff 172d(O-Y) Angular rock fragments; (Wentworth class=sandy gravel)
12	42	13	1 32 S 93 10 W 3539 m	Siliceous globigerina ooze ?	30; inspection	(Dry) tilleul-buff 17^3f(O-Y) Clay; few shells of foraminifera; slightly coherent, pulverulent
13	43	15	2 30 S 95 43 W 3352 m	Siliceous globigerina ooze	67; total CO_2	(Moist) buffy-brown 17^3i(O-Y) Sandy clay (U.S.B.S. class=clay); small shells of foraminifera; moderately coherent, slightly plastic, crumbly, granular
14	44	17	3 15 S 99 48 W 3423 m	Siliceous globigerina ooze	76; acid soluble CaO	(Moist) between sayal-brown and tawny-olive 16^2i(Y-O, O-Y) Sandy clay (U.S.B.S. class=clay); small shells of foraminifera; moderately coherent, slightly plastic, crumbly, granular
15	46	21	9 06 S 108 20 W 2905 m	Volcanic globigerina ooze	80; inspection	(Wet) avellaneous 17^3b(O-Y) Silty sand; small shells of foraminifera; incoherent, granular
16	47	23	14 07 S 111 50 W 3080 m	Ferruginous globigerina ooze	87; acid soluble CaO	(Dry) Saccardo's umber 17^2k(O-Y) Clayey sand (U.S.B.S. class=clay); small shells of foraminifera; slightly coherent, crumbly
17	49	27	23 16 S 114 45 W 3098 m	Ferruginous (volcanic) globigerina ooze	74; acid soluble CaO	No material available as entire sample was used in mechanical analysis. (U.S.B.S. class=clay)

Sample 10. Contains over 5 per cent organic matter, nearly 2 per cent MnO_2, and relatively high ZrO_2. Constituent particles of sand size include abundant dark grayish-green elongated ellipsoidal aggregates about 0.3 mm in diameter, probably coprolitic pellets (see Murray and Philippi, 1908, p. 103, pl. XX, and Moore, 1933, p. 24); together with a few broken pelagic and bottom foraminifera, echinoid spines, abundant radiolaria, sponge spicules, very common manganese grains, brown mica (-2E large), quartz, green-brown hornblende, augite, epidote, plagioclase feldspar, basic volcanic glass, and small rhombohedral calcite crystals.

Sample 11. Consists principally of angular fragments of altered volcanic material and iron concretions greater than 0.5 and less than 8 mm in diameter, partly encrusted with worm tubes; together with a few pelagic foraminifera, sponge spicules, wood fibers, but no mud.

Sample 12. Contains abundant fragments of radiolarian skeletons, diatom frustules, and sponge spicules in addition to foraminifera, but only small amounts of clay minerals.

on cruise VII of the Carnegie in the Pacific

each page under sample number

Sampler and container used	Field notes	Nearest previous samples
Ross snapper; 18-oz. bottle	Black mud in Ross snapper, top of Nansen bottle, and in lower end of 80-lb. weight. Sample smelled strongly of oil	Albatross 4631 (p. 41); 06° 26′ N, 81° 49′ W; 776 fathoms. Green mud, $CaCO_3$=25.2 per cent; containing rock fragments, casts of foraminifera, echinoid spines, sponge spicules, glauconitic grains, a little quartz
Ross snapper; vial	Small amount of black gravel in Ross snapper. Hard bottom	None
Ross snapper; vial	Ross snapper failed to shut, but small sample adhered to jaws	Albatross 4521 (p. 64); 02° 14.3′ S, 92° 29.9′ W; 1871 fathoms. Globigerina ooze, $CaCO_3$=45 per cent. Mostly broken pelagic and many benthonic foraminifera, gray clay residue containing many fragments of siliceous ogranisms and minute minerals, including augite, and a little manganese and hematite
Ross snapper; 18-oz. bottle	Good bottom sample	Albatross 4523 (p. 65); 03° 34′ S, 95° 35.4′ W; 2031 fathoms. Globigerina ooze, $CaCO_3$=55.9 per cent. Light gray, flocculent residue, almost entirely fragments of siliceous organisms, little clay, few minerals
Ross snapper; 18-oz. bottle	Good bottom sample. Red clay and globigerina ooze	Albatross 4717 (p. 65); 05° 10′ S, 98° 56′ W; 2153 fathoms. Globigerina ooze, $CaCO_3$=60.3 per cent. Rich brown, very flocculent clay residue, many fragments of siliceous organisms, few minerals, coccoliths
Ross snapper; 3 vials	Ross snapper closed, but brought up only small sample. Small particles of volcanic rock in lead weight	Albatross 4723 (p. 75); 10° 14.3′ S, 107° 45.5′ W. Depth? Globigerina ooze; washed sample, $CaCO_3$ not determined. Principally pelagic forams, etc., containing few manganese grains, angular augite grains, splinters of volcanic glass
Ross snapper; 18-oz. bottle		Albatross 4726 (p. 67); 12°30.1′ S, 111° 42.2′ W. 1700 fathoms. Globigerina ooze, $CaCO_3$=68 per cent. Pelagic and few benthonic foraminifera, brown clay residue very rich in manganese and limonite grains. Few remains of diatoms and sponge spicules. Minute mineral particles
Ross snapper; 2 vials and 18-oz. bottle	Ross snapper with 98-lb. lead weight on shaft let down on end of 4-mm wire, 50 m below Nansen water bottle. When hauled in, Nansen bottle was full of	None

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Sample 13. Abundant fragments of radiolarian skeletons and diatom frustules occur in sand grades, in addition to predominant amounts of broken pelagic and benthonic foraminifera; also present are arenaceous foraminifera, echinoid spines, sponge spicules, and brown mica.

Sample 14. Sand grades contain smaller amounts of remains of siliceous organisms than sample 13, and correspondingly larger amounts of pelagic and some benthonic foraminifera, also present are echinoid spines, gastropod shell, and a few disk-shaped and ellipsoidal pellets.

Sample 15. Appears to be partly washed. Contains angular cinder of altered basic volcanic rock, 1 cm in longest diameter, coated with manganese; also small fragments of volcanic glass and shells of bryozoa, in addition to predominant amounts of pelagic foraminifera and a few remains of siliceous organisms.

Sample 16. Sand and coarse silt grades consist almost entirely of unbroken pelagic and a very few benthonic foraminifera, together with numerous minute manganese grains less than 0.01 mm in diameter. Diatoms, radiolaria, etc., are scarce.

Table 1. Synoptic table of bottom samples collected

Sample	Station	Date	Position and depth in meters	Type of sample	Estimated CaCO$_3$ content in per cent; basis of estimate	Color and physical characters
		1928				
18	51	Dec. 1	29 06 S 114 48 W 2898 m	Globigerina ooze	94; acid soluble CaO	(Wet) near vinaceous-buff 18$^{2-1/2}$d(O-Y) Clayey sand (U.S.B.S. class= clay); moderately coherent, granular
19	52	3	31 28 S 112 51 W 2851 m	Ferruginous globigerina ooze	86; acid soluble CaO	(Wet) buffy-brown 17^{3}i(O-Y) Sandy clay (U.S.B.S. class= clay); shells of foraminifera; moderately coherent, sticky, granular
20	54	14	29 17 S 108 54 W 3061 m	Globigerina ooze	Top 76, bottom 80; total CO$_2$	Top: (moist) olive-brown 17^{3}k(O-Y); Bottom: (moist) olive-brown 17^{3}k(O-Y) Sandy clay; shells of foraminifera; (top, U.S.B.S. class=clay; bottom, U.S.B.S. class=silty clay loam)
21	57	20	33 59 S 106 43 W 3139 m	Ferruginous globigerina ooze	84; acid soluble CaO	(Dry) avellaneous 17^{3}b(O-Y) Sandy clay (U.S.B.S. class=clay); small shells of foraminifera; slightly coherent, crumbly
22	59	24	39 51 S 101 04 W 4116 m	Ferruginous globigerina ooze	42; acid soluble CaO	(Wet) between Brussels brown and raw umber 16m(Y-O,O-Y) Sandy clay (U.S.B.S. class=clay); small shells of foraminifera, and aggregates of fine material; coherent
23	60	26	40 24 S 97 33 W 4007 m	Globigerina ooze	75; acid soluble CaO	(Dry) avellaneous 17^{3}b(O-Y) Sandy clay (U.S.B.S. class=clay); shells of foraminifera; when

Sample 17. Sand grades consist largely of unbroken pelagic foraminifera, together with manganese grains and small volcanic glass shards, whereas silt grade contains very abundant small manganese and iron hydroxide grains. Sample also contains fragments several cm in diameter of a black, slightly vesicular, very brittle basic glass exhibition conchoidal fracture. These appear to have been thickly coated with manganese only on one side, indicating the top of a submarine lava flow. There are numerous cracks lined with orange and greenish palagonitic material containing phillipsite crystals. The glass itself (see plate XIII) is very fresh and unaltered, containing microscopic glomeroporphyritic clusters of basic plagioclase feldspar, small, euhedral partially altered olivine crystals, wedge and triangular shaped titanite, twinned alteration products, and augite. The relatively low content of alkalies shown by chemical analysis indicates that this rock is a member of the circum-Pacific suite, as contrasted with the rocks of Tahiti and other Pacific islands which are alkaline.

Sample 18. Sand grades consist almost entirely of unbroken pelagic foraminifera together with traces of echinoid spines, ostracod shells, benthonic foraminifera. Clay grade makes up nearly 60 per cent of sample, consists largely of finely divided calcium carbonate, with a few coccoliths.

Sample 19. Sand grades consist principally of light brownish-colored pelagic foraminifera, almost entirely unbroken, and a few benthonic foraminifera, together with pink and black irregularly shaped grains of organic (?) origin, echinoid spines, ostracod shells, and sponge spicules, one light gray fragment of acid pumice, and manganese grains.

on cruise VII of the *Carnegie* in the Pacific--Continued

Sampler and container used	Field notes	Nearest previous samples
	muddy water, and left-hand thermometer and brass tube were missing. End of wire for 4 m was torn and chafed, showing it had been caught in crevice on bottom. Snapper jaws badly bent at end, and fragments of black manganese-coated obsidian were mixed with globigerina ooze. Snapper fairly full	
Ross snapper; vial and 18-oz. bottle		None
Ross snapper; 2 vials and 18-oz. bottle	Brown chocolate clay and sand	None
Meteor tube; 2 vials	Used *Meteor* tube-sampler for first time. Got 24-in. sample with water in top of glass tube (only vial of top of section and vial of bottom of section saved)	*Albatross* 4517 (p. 56); 25° 50.9′ S, 109° 12.5′ W. 1723 fathoms. $CaCO_3$=63.55 per cent. Many species of pelagic forams, numerous small individuals. Augite, magnetite, microlites of basic plagioclase, dark brown clay with minute mineral particles
Ross snapper; vial and 18-oz. bottle	Good bottom sample. Hard reddish-brown clay-mud	None
Ross snapper; vial and 18-oz. bottle	Snapper no. 3 had not closed, but stiff red clay stuck to inside of both jaws. Good sample	None
Ross snapper; vial and 18-oz. bottle	Red clay	*Challenger* 294 (p. 128); 39° 22′ S, 93° 46′ W. 2270 fathoms. Red clay; $CaCO_3$=trace (more $CaCO_3$ in lower part of core). Pelagic foraminifera and coc-

Sample 20. (Top) In addition to pelagic foraminifera, very few of which are broken, there are a few flakes of plant material and echinoid spines in sand grades. Silt grades contain numerous manganese-iron grains. (Bottom) Same as top of core.

Sample 21. Contains more broken pelagic foraminifera than last sample. Benthonic foraminifera are common (*Cassidulina fava* noticeable). A few flakes of plant material, manganese grains, sponge spicules, echinoid spines, ostracod tests are present. Some of pelagic foraminifera, notably *Globigerina truncatulinoides*, exhibit recrystallization.

Sample 22. Very high in manganese, iron, and phosphate. Contains relatively more benthonic foraminifera than any other sample except no. 31. Most of pelagic foraminifera are broken. Numerous manganese grains are present in sand grades, in addition to radiolaria, twinned crystals of phillipsite, euhedral crystals of magnetite, plagioclase feldspar and basaltic hornblende, also many ellipsoidal and flat pellets, possibly formed in mechanical analysis. Fine material is very difficult to disperse. Manganese grains contain as nuclei aggregates of white, acid volcanic glass shards (index of refraction about 1.50).

Sample 23. Large proportion of pelagic foraminifera are broken, some exhibit recrystallization. Benthonic foraminifera and manganese grains are abundant in sand grades, also present are sponge spicules, echinoid spines, ostracods, white vesicular pumice, subrounded, polished quartz grains, and greenish fine-grained mica schist fragments. Manganese grains contain nuclei of acid volcanic glass.

Table 1. Synoptic table of bottom samples collected

Sample	Station	Date	Position and depth in meters	Type of sample	Estimated CaCO$_3$ content in per cent; basis of estimate	Color and physical characters
		1928	° ′			moist, coherent and plastic; when dry, moderately coherent and crumbly
24	61	Dec. 28	38 29 S 94 14 W 3299 m	Globigerina ooze	86; total CO$_2$	(Moist) avellaneous 17^{3}b(O-Y) Sandy silt; (U.S.B.S. class=clay loam); shells of foraminifera and manganese nodules up to 1 cm; slightly coherent, crumbly
25	62	30	34 35 S 91 52 W 3610 m	Ferruginous globigerina ooze	74; acid soluble CaO	(Dry) avellaneous 17^{3}b(O-Y); (wet) Saccardo's umber 17^{2}k(O-Y) Sandy clay (U.S.B.S. class=clay); shells of foraminifera; coherent, brittle
26	63	1929 Jan. 1	32 10 S 89 04 W 3393 m	Globigerina ooze	91; acid soluble CaO	(Moist) between wood-brown and buffy-brown 17^{3}h(O-Y) Clayey sand (U.S.B.S. class=clay loam); shells of foraminifera; moderately coherent, crumbly, granular
27	64	3	31 54 S 88 17 W 3879 m	Globigerina ooze	43; acid soluble CaO	(Dry) between cinnamon-brown and Saccardo's umber 16$^{1-1/2}$k(Y-O) Sandy clay (U.S.B.S. class=silt loam); small shells of foraminifera; coherent, brittle
28	65	5	31 07 S 86 39 W 3626 m	Globigerina ooze	66; total CO$_2$	(Dry) vinaceous-buff 17^{3}d(O-Y) Sand (U.S.B.S. class=fine sand); shells of foraminifera; slightly coherent, crumbly
29	67	8	24 57 S 82 15 W 1089 m	Globigerina ooze	94; acid soluble CaO	(Dry) light pinkish-cinnamon 15^{2}d(Y-O) (Moist) Sand (U.S.B.S. class=fine sandy loam); shells of foraminifera; slightly coherent, crumbly
30	68	10	21 28 S 80 26 W 4156 m	Red clay	3; total CO2	(Wet) raw umber 17m(O-Y) Sandy clay; shells of foraminifera and angular mineral grains, plastic, greasy feel

Sample 24. Contains abundant irregularly shaped manganese grains and nodules up to 6 mm in largest diameter. The silt grade consists largely of broken pelagic foraminifera, with only a small proportion of manganese grains, hence is very light in color when compared with the silt grades of samples 20 to 23.

Sample 25. Sand grades consist largely of pelagic foraminifera, many broken, some exhibiting recrystallization; benthonic foraminifera are common, manganese grains, echinoid spines, sponge spicules, and ostracods are rare. Phillipsite in small twinned crystals, cloudy plagioclase feldspar, chlorite palagonite, and altered volcanic glass are also present in sand grades.

Sample 26. Many pelagic foraminifera are broken, some exhibit recrystallization; benthonic foraminifera are fairly common (Cassidulina fava noticeable); sand grades also contain manganese grains, radiolaria, sponge spicules, echinoid spines, and ostracod tests.

Sample 27. Sample is very high in manganese, iron, and phosphate. Benthonic foraminifera are extremely abundant. Practically all pelagic foraminifera are broken, and many exhibit recrystallization Manganese grains are not so abundant as in sample 22 but contain as usual nuclei of acid volcanic glass. About half of sand grades consist of ellipsoidal or ovoid pellets, 0.1 mm to 1 mm in diameter, possibly formed

on cruise VII of the Carnegie in the Pacific--Continued

Sampler and container used	Field notes	Nearest previous samples
		coliths; numerous manganese particles, some phillipsite and fragments of palagonite, also feldspar, augite, quartz, magnetite, volcanic glass. Dark chocolate-colored clay, 97 per cent
Ross snapper; vial and 18-oz. bottle	Small amount of gray sand in snapper; apparently hard bottom. Jaws had not penetrated far. Slight trace of black substance on edge of jaws	Challenger 295 (p. 130); 38° 07′ S, 94° 04′ W. 1500 fathoms. $CaCO_3$ not determined, globigerina ooze. Contains pelagic and benthonic foraminifera, pteropods, ostracods, echinoid spines, cephalopod beaks, siliceous organisms, many particles of manganese, black volcanic glass and augite andesite
Ross snapper; 18-oz. bottle and vial	Red clay and sand	None
Ross snapper; 18-oz. bottle and vial	Sample gray sand; soft; snapper V3 full	None
Ross snapper; 18-oz. bottle and 2 vials	Good sample. Red clay, mud, and ooze	None
Ross snapper; vial	Snapper did not close, spring too tight, but small amount of chocolate-red clay was brought up	None
Ross snapper; 18-oz. bottle and vial	Good sample. Gray-white sand, globigerina ooze	None
Sigsbee tube; 18-oz. bottle and 2 vials	Chocolate mud	None

in mechanical analysis, since fine material is very difficult to disperse. Sample contains much phillipsite, also plagioclase feldspar and serpentine (?).

Sample 28. Coarse sand grades consist largely of broken fragments of pelagic foraminifera, with relatively small proportion of unbroken shells, together with numerous benthonic foraminifera, fairly common manganese grains and plant material, rare echinoid spines, sponge spicules and ostracods. Twinned crystals and aggregates of phillipsite are very common in fine sand and silt grades. Finer material is quite flocculent.

Sample 29. Sand grades consist almost entirely of unbroken shells of pelagic foraminifera, some stained yellowish brown; together with rare benthonic foraminifera (the shells of arenaceous species consist of broken pelagic shells), ostracods, calcareous algae, bryozoa, unidentified remains of calcareous organisms, and fragments of crustacea. Silt and clay grades are very small in amount.

Sample 30. Sand grades consist principally of rounded and angular aggregates of fine material; also common manganese and palagonite grains, some broken shells of pelagic foraminifera, and rare flakes of muscovite and biotite.

Table 1. Synoptic table of bottom samples collected

Sample	Station	Date	Position and depth in meters	Type of sample	Estimated $CaCO_3$ content in per cent; basis of estimate	Color and physical characters
31	69	1929 Jan. 12	° ′ 16 49 S 78 39 W 3657 m	Siliceous (calcareous) red clay	20; total CO_2	(Moist) buffy-brown 17^3i(O-Y) Clay (U.S.B.S. class=clay); few small shells of foraminifera; coherent, moderately plastic
32	70	13	13 53 S 77 54 W 4742 m	Green diatom mud	<1; total CO_2	(Dry) smoke-gray 21^4d(O-YY) Clayey silt (U.S.B.S. class=sand); moderately coherent, brittle
33	71	Feb. 6	11 57 S 78 37 W 3357 m	Green silty mud	<1; inspection	(Dry) pale smoke-gray 21^4f(O-YY) Silty clay; moderately coherent, crumbly, slightly gritty
34	72	8	9 58 S 82 10 W 4480 m	Green clayey mud	0.25; acid soluble CaO	(Moist) smoke-gray 21^4b(O-YY) Clay (U.S.B.S. class=clay); coherent, brittle
35	74	12	11 00 S 87 24 W 4141 m	Siliceous red clay	0.91; acid soluble CaO	(Moist) Saccardo's umber 17^2k(O-Y) Clay (U.S.B.S. class=clay); moderately coherent, sticky, greasy feel
36	75	14	14 15 S 92 05 W 3480 m	Globigerina ooze	91; acid soluble CaO	(Moist) between vinaceous-buff and avellaneous 17^3c(O-Y) Sandy silt (U.S.B.S. class=clay); shells of foraminifera; moderately coherent, granular
37	76	16	15 18 S 97 28 W 3197 m	Globigerina ooze	93; total CO_2	(Moist) (U.S.B.S. class=sand); incoherent, granular; shells of foraminifera

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Sample 31. Sand grades consist principally of remains of radiolaria, sponge spicules, and diatoms, together with numerous calcareous benthonic and some arenaceous and pelagic foraminifera, the latter exhibiting slight recrystallization; also present are echinoid spines, chitinous remains, light-colored rod and disk-shaped pellets, green-brown mica (sometimes considerably altered), euhedral green-brown hornblende in colorless pumice, plagioclase feldspar ($Ab_{50}An_{50}$), angular quartz, and olivine (?).

Sample 32. Consists largely of remains of siliceous organisms, especially diatoms, together with light grayish-green clayey material. The sand grades contain numerous light grayish-green rounded and irregularly shaped aggregates of clayey material and siliceous organisms, together with plant material, flakes of brown and greenish mica, sometimes considerably altered, quartz, and feldspar.

Sample 33. Too small for detailed examination. Appears to be similar to sample 32, except that remains of siliceous organisms are relatively less in amount. Contains abundant fresh and partially decomposed plagioclase (labradorite and oligoclase), quartz, green mica, green hornblende, augite, epidote or clinozoisite (2V about 90°), green garnet or ceylonite, rutile, apatite, magnetite (?), basic volcanic glass, calcite crystals, little clay.

on cruise VII of the Carnegie in the Pacific--Continued

Sampler and container used	Field notes	Nearest previous samples
Ross snapper; 18-oz. bottle and 2 vials	Snapper not closed but brought up good specimen of gray mud and ooze	None
Ross snapper; 18-oz. bottle and 2 vials	Jaws not closed but sample stuck on inside; blackish-green mud	Albatross 4672 (p. 47); 13° 11.6′ S, 78° 18.3′ W. 2845 fathoms. Red clay or blue mud; $CaCO_3$=zero per cent; nearly 50 per cent fine minerals, 0.01-mm diameter; angular quartz grains, green chlorite, decomposed feldspar, augite, hematite, hornblende (?), some sponge spicules and diatoms; gray flocculent clay
Ross snapper; vial	Snapper failed to close, but thimble full of blue-green mud was found back of tongue	Albatross 4671 (p. 47); 12° 06.9′ S, 12° 28.2′ W. 1490 fathoms. Blue mud; $CaCO_3$=zero per cent; fine greenish-colored clay, containing many very minute mineral particles, 0.01-mm diameter, and diatoms. Quartz, glauconite, little feldspar, magnetite, and hematite
Ross snapper; 18-oz. bottle and 2 vials	Snapper failed to close, but good amount of grayish clay came up in both jaws	None
Ross snapper; 18-oz. bottle and vial	Snapper failed to close again, but brought up good sample	Albatross 4658 (p. 46); 08° 29.5′ S, 85° 35.6′ W. 2370 fathoms. Red clay; $CaCO_3$=zero per cent; many genera of arenaceous foraminifera, manganese nodules, sharks' teeth, cetacean ear bones; small grains of manganese and iron oxide; scarce plagioclase, augite, magnetite, hematite; 95 per cent dark gray clay with few undeterminable mineral particles and diatoms
Ross snapper; 18-oz. bottle and 2 vials	Snapper no. 5, made in Callao, Peru, used. White ooze	None
Ross snapper; 2 vials	Snapper closed but most of loose white ooze had washed out	Albatross 4705 (p. 59); 15° 05.3′ S, 99° 19′ W. 2031 fathoms. Globigerina ooze; $CaCO_3$=78.62 per cent; 82 species of pelagic and benthonic foraminifera observed; traces of siliceous organisms and the following minerals: basic labradorite, pyrite, decomposed femic mineral, augite?; 21 per cent rich red-brown colored flocculent clay

Sample 34. Coarser material consists of skeletons of radiolaria, diatom frustules, sponge spicules, few pelagic and benthonic foraminifera, brown disk-shaped pellets, plant material and small mineral particles. The considerable amount of clayey material is very low in magnesium and calcium. One entire skeleton of a small crustacean was seen.

Sample 35. Sand grades consist of brown and light-colored (coprolitic?), disk-shaped and ellipsoidal pellets of fine material, together with abundant siliceous remains, common manganese grains, also fine-grained igneous rock, palagonite, angular quartz, and plagioclase.

Sample 36. Although this sample is high in calcium carbonate and in pelagic foraminifera (consequently very light in color), about 50 per cent of shells of foraminifera are broken sand grades. Also contains a few benthonic and arenaceous foraminifera, ostracods, echinoid spines, fish teeth, radiolaria, sponge spicules, manganese grains, and somewhat decomposed plagioclase feldspar. The tests of Globorotalia exhibit recrystallization.

Sample 37. Appears to have been partly washed, as it is very low in fine material. Consists almost entirely of pelagic foraminifera, about three-fourths of which are unbroken.

Table 1. Synoptic table of bottom samples collected

Sample	Station	Date	Position and depth in meters	Type of sample	Estimated $CaCO_3$ content in per cent; basis of estimate	Color and physical characters
		1929	° ′			
38	77	Feb. 18	14 20 S 103 12 W 4094 m	Red clay	<10; inspection	(Wet) between Brussels-brown and mummy-brown $16^{1/2}$m(O-Y) Sandy clay; shells of foraminifera and angular mineral grains; lumpy, greasy feel
39	78	20	13 02 S 108 03 W 3337 m	Globigerina ooze?	?	No material received
40	79	22	12 36 S 112 14 W 3090 m	Globigerina ooze	78; total CO_2	(Moist) Saccardo's umber 17^2k(O-Y) (U.S.B.S. class=clay)
41	80	24	12 39 S 117 22 W 3515 m	Ferruginous globigerina ooze	90; acid soluble CaO	(Moist) between Saccardo's umber and tawny-olive 17^2j(O-Y) Sandy clay (U.S.B.S. class=clay); shells of foraminifera; slightly coherent, granular, crumbly
42	81	26	13 03 S 121 12 W 2953 m	Globigerina ooze	93; total CO_2	(Dry) pale pinkish-cinnamon 15^2f(Y-O) Silty sand (U.S.B.S. class=sand); shells of foraminifera; slightly coherent, granular
43	82	28	14 52 S 126 07 W 3631 m	Globigerina ooze	89; total CO_2	Sample used up in mechanical analysis. (U.S.B.S. class=clay)
44	83	Mar. 3	17 00 S 129 45 W 3966 m	Globigerina ooze	75; acid soluble CaO and total CO_2	(Dry) avellaneous 17^3b(O-Y); (moist) mummy-brown 17^1m(O-Y) (wet) between Saccardo's umber and snuff-brown 16^2k(YO-OY) Sandy clay (U.S.B.S. class=clay loam); shells of foraminifera; when moist, moderately coherent, very slightly plastic, greasy feel; when dry, moderately coherent, pulverulent, granular

Sample 38. Too small for detailed examination, but appears to be quite similar to sample 30, except that there is a higher percentage of fragments of tests of pelagic foraminifera, and twinned crystals of phillipsite (?) are present.

Sample 39. No sample was received in Washington. According to Seiwell, this sample consisted entirely of broken and intact skeletons of foraminifera together with some "yellowish brown amorphous matter."

Sample 40. Sand grades consist almost entirely of pelagic foraminifera, about 20 per cent of which are broken, together with rare benthonic foraminifera and manganese grains. Silt fractions contain numerous small manganese grains, besides finely divided calcium carbonate and siliceous remains. Bright orange color of colloidal material indicates that it is high in iron.

Sample 41. Similar to no. 40, except that very few of pelagic foraminifera are broken, and small manganese grains are much less common. In both these samples the foraminifera are grayish-tan in color. In addition to pelagic foraminifera, traces of benthonic and arenaceous foraminifera, echinoid spines, ostracods, fish teeth, sponge spicules, and radiolaria are present in sand grades.

Sample 42. Consists almost entirely of pelagic foraminifera, very few of which are broken. Many of these are yellowish-brown in color and some exhibit slight recrystallization. Many very small tests are present. A few siliceous remains, and twins of phillipsite also occur.

on cruise VII of the Carnegie in the Pacific--Continued

Sampler and container used	Field notes	Nearest previous samples
Ross snapper; vial	Snapper not closed, spring too tight. Thimble full of black ooze back of clappers	None
Ross snapper	Snapper closed, but nearly all the white-sand ooze had washed out while hauling in	None
Sigsbee tube; 18-oz. bottle and vial	Snapper not closed, and sample washed out. Sent down Sigsbee tube; good sample black mud	Albatross 4726 (p. 67); 12° 30′ S, 111° 42.2′ W. 1700 fathoms. Globigerina ooze; $CaCO_3$=68 per cent. Pelagic and few benthonic foraminifera, brown clay residue very rich in manganese and limonite grains; few remains of diatoms and sponge spicules; minute mineral particles
Ross snapper; 18-oz. bottle and vial	Snapper, readjusted to hair trigger, closed and brought up good sample, light brown clay and sand	None
Ross snapper; 18-oz. bottle and vial	Snapper closed. One-third full of hard, gray sand and ooze	None
Sigsbee tube; 18-oz. bottle and vial	Good sample; gray globigerina ooze	Albatross 4534 (p. 71); 13° 51′ S, 126° 53.5′ W. 2185 fathoms. Globigerina ooze. $CaCO_3$=72.7 per cent. Pelagic and few bottom-living foraminifera; chocolate-brown flocculent clayey residue, numerous very small phillipsite crystals, few manganese grains, and angular splinters of colorless glass
Ross snapper; 18-oz. bottle and vial	Chocolate mud and ooze. Snapper full	Albatross 4532 (p. 70); 18° 29.4′ S, 130° 50.8′ W. 2319 fathoms. Red clay, $CaCO_3$=18 per cent. Pelagic and bottom-living foraminifera and fish teeth; very dark brown flocculent clay residue; great abundance of phillipsite crystals, few manganese grains, and angular splinters of colorless glass

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Sample 43. Sand grades consist almost entirely of pelagic foraminifera, about one-fourth of which are broken. The mechanical analysis shows two maxima in the sand and clay grades respectively, and the calcium carbonate content is similarly distributed, indicating two sources of calcareous material. Siliceous organic remains are common, and very small twinned crystals of phillipsite are rare consittuents of sand grades.

Sample 44. Coarse sand grades consist largely of remains of pelagic foraminifera, many of which are broken or considerably recrystallized, together with benthonic foraminifera, ostracods, echinoid spines, fish teeth, some siliceous remains, including radiolaria, sponge spicules, and arenaceous foraminifera, few manganese grains, large subhedral grains of fresh plagioclase feldspar, and one of basaltic hornblende, both over 1 mm long. The fine sand grades contain many twinned crystals and aggregates of phillipsite (identified by X-ray powder diagrams) in addition to the above. The clayey material of this sample is quite flocculent; it consists largely of small irregularly shaped grains of calcite, together with some small calcite spherules and rectangular plates, numerous horseshoe-shaped coccoliths, fragments of globigerina shells, large single and some twinned crystals of phillipsite, rounded reddish grains (iron oxide), mottled reddish aggregates (beidellite?), and crescent-shaped shards of brown altered volcanic glass.

Table 1. Synoptic table of bottom samples collected

Sample	Station	Date	Position and depth in meters	Type of sample	Estimated $CaCO_3$ content in per cent; basis of estimate	Color and physical characters
		1929	° ′			
45	85	Mar. 6	17 12 S 136 37 W 3791 m	Ferruginous globigerina ooze	94; acid soluble CaO	(Dry) pale pinkish-cinnamon 15^2f(Y-O); (moist) between avellaneous and wood-brown 17^3a(O-Y) Clayey sand (U.S.B.S. class= sandy loam); shells of foraminifera; when wet, slightly coherent, granular; when dry, moderately coherent, pulverulent-granular
46	86	9	17 36 S 141 55 W 2132 m	Globigerina ooze?	90; inspection	(Dry) fuscous 13^4k(OY-O) Manganese nodules up to 1 cm in diameter partly covered with small unbroken shells of pelagic foraminifera
47	87	11	18 05 S 145 33 W 4315 m	Calcareous red clay	15; total CO_2	(Moist) between bister and sepia 16^2m(Y-O, O-Y) (Dry) clay; coherent, brittle
48	94	Apr. 22	12 47 S 171 35 W 4760 m	Red clay	<10; inspection	(Dry) between light drab and avellaneous $17^{3-1/2}$b(O-Y) Clay; moderately coherent, pulverulent
49	96	26	6 47 S 172 23 W 5269 m	Red clay	<1; total CO_2	(Moist) between snuff-brown and bister 15^2l(Y-O); (dry) avellaneous 17^3b(O-Y) Clay (U.S.B.S. class=clay); coherent, brittle
50	97	28	3 47 S 172 39 E 5253 m	Red clay	<10; inspection	(Dry) between Saccardo's umber and buffy-brown $17^{2-1/2}$j(O-Y) Color of coarser fraction (dry) between avellaneous and light drab $17^{3-1/2}$b(O-Y) Silty clay; moderately coherent, pulverulent, somewhat gritty

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Sample 45. Sand grades are similar to sample 44, except that a greater proportion of pelagic shells are unbroken and phillipsite crystals and aggregates are less common. The silt and clay grades apparently contain much more calcium carbonate than sample 44.

Sample 46. The estimate of $CaCO_3$ content for this region is based on the fact that the small tests of pelagic foraminifera found on the manganese nodules are unbroken and fresh in appearance.

Sample 47. Well-formed, ovoid-shaped pellets of fine material, usually containing fragments of foraminiferal shells and sometimes cemented together by a coating of manganese, predominate in the coarser sand grades. Benthonic foraminifera make up a large part of the calcium carbonate content, together with broken shells of pelagic foraminifera, fish teeth, and unidentified calcareous materials; sponge spicules are also present. Manganese grains, volcanic rock fragments, palagonite and phillipsite are common, whereas biotite, feldspar, and hornblende are rare constituents of the sand grades.

Sample 48. The sample is very fine-grained but too small for mechanical analysis. Contains radiolaria, sponge spicules, coccoliths, and unidentified, irregular-shaped calcareous material, as well as basic

on cruise VII of the *Carnegie* in the Pacific--Continued

Sampler and container used	Field notes	Nearest previous samples
Ross snapper 18-oz. bottle and vial	Good sample; coffee-colored ooze	None
Ross snapper; vial	Snapper closed; hard bottom, few manganese nodules; no trace of ooze	*Albatross* 37 (p. 95); 18° 08′ S, 141° 49′ W. 2187 fathoms. Globigerina ooze; $CaCO_3$=74.2 per cent. Pelagic and benthonic foraminifera, echinoid spines, ostracods, alcyonarian spicules, coccoliths, rhabdoliths, tunicate spicules, siliceous organisms, obsidian, feldspar, augite, magnetite, manganese grains; single and aggregate crystals of phillipsite
Ross snapper; vial	Snapper not closed, but brought up small amount of reddish-brown clay-ooze	*Albatross* 34 (p. 94); 17° 10′ S, 145° 19′ W. 1679 fathoms. Globigerina ooze. $CaCO_3$=84.3 per cent. Pelagic and benthonic foraminifera, echinoid spines, ostracods, otoliths, tunicate spicules, coccoliths, rhabdoliths; few remains of radiolaria, sponge spicules; small angular grains of plagioclase, obsidian, chloritized hornblende, magnetite
Ross snapper; vial		*Penguin* 331. Murray (1906, p. 132); 14° 49.4′ S, 171° 51.9′ W. 2532 fathoms. Red clay or volcanic mud; $CaCO_3$=5 per cent. Small pelagic foraminifera; 50 per cent small pumice particles, 10 per cent radiolaria, sponge spicules, diatoms; 35 per cent brown "amorphous" matter and minute mineral particles
Sigsbee tube; 12-oz. bottle	Sigsbee tube; weight detached; chocolate mud and ooze	*Egeria* 47. Murray (1906, p. 131); 07° 52′ S, 171° 01.5′ W. 2766 fathoms. Red clay; $CaCO_3$ not determined. Few fragments of pelagic foraminifera and fish teeth, pumice fragments and manganese grains, sponge spicules, radiolaria, diatoms; dark brown or chocolate color. "Fine washings," 77 per cent
Sigsbee tube; 12-oz. bottle	Small sample chocolate ooze	*Tuscarora*, Dec. 25, 1875. Murray (1906, p. 127); 03° 21′ S, 171° 23′ W. 2835 fathoms. Globigerina ooze (with many radiolaria); $CaCO_3$=42.1 per cent. Mostly fragmentary pelagic foraminifera; numerous coccoliths, few tunicate spicules, much crystalline and "amorphous" calcareous matter, 25 per cent remains of siliceous organisms, a few manganese grains, palagonitic and glassy volcanic particles

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volcanic glass, pumice, palagonite, small manganese grains, plagioclase feldspar, augite, euhedral hypersthene (?), magnetite (?), birefringent clay minerals (?) and unidentified, small mineral particles.

Sample 49. One distinction of the sand grades of this sample is the presence of an extraordinary number of fish teeth and chitinous fragments. Sponge spicules, radiolaria, and both benthonic and pelagic foraminifera are other common organic constituents. Another feature is the presence of many compact, irregularly rounded particles probably of altered pumice, containing palagonite, augite, and unaltered plagioclase feldspar, together with much isotropic material. In addition, brownish, ovoid aggregates probably formed during mechanical analysis are present, as well as manganese grains.

Sample 50. Too small for mechanical analysis. Contains arenaceous foraminifera, fish teeth, pelagic foraminifera, radiolaria, sponge spicules, diatoms, unidentified calcareous fragments, biotite, manganese grains and flakes, basic volcanic glass (some grains of which are slightly birefringent), palagonite, a euhedral augite crystal, penninite (?), brown-colored clay mineral showing moderate birefringence, negative elongation, indices of refraction about 1.565, large 2E.

Table 1. Synoptic table of bottom samples collected

Sample	Station	Date	Position and depth in meters	Type of sample	Estimated $CaCO_3$ content in per cent; basis of estimate	Color and physical characters
		1929	° ′			
51	108	May 27	18 26 N 144 01 E 3573 m	Volcanic mud	16; total CO_2	(Moist) between light brownish-olive and brownish-olive 19^2l(Y-O-Y) (U.S.B.S. class=clay loam)
52	109	29	23 22 N 144 08 E 5252 m	Red clay	<5; inspection	(Dry) avellaneous 17^3b(O-Y) Clay; moderately coherent, crumbly
53	110	31	26 20 N 144 24 E 3036 m	Volcanic globigerina mud	48; total CO_2	(Dry) pale pinkish-cinnamon 15^2f(Y-O) Sandy clay (U.S.B.S. class=clay); foraminifera; volcanic glass; slightly coherent, pulverulent, gritty
54	111	June 3	31 00 N 144 16 E 6008 m	Brown volcanic mud	5; total CO_2	(Moist) light drab 17^3b(O-Y) Silty clay (U.S.B.S. class=silty clay loam); moderately coherent, pulverulent
55	112	5	33 51 N 141 15 E 3931 m	Gray volcanic mud	<10; inspection	(Dry) between hair-brown and deep grayish-olive 19^4i(Y-O-Y); (moist) silt; angular grains; slightly coherent, crumbly, gritty feel
56	113	25	34 44 N 141 04 E 2911 m	Gray siliceous volcanic mud	4; acid soluble CaO	(Moist) deep grayish-olive 21^4i(O-YY) Silty clay (U.S.B.S. class=clay); angular grains; moderately coherent, slightly sticky, gritty
57	115	29	37 40 N 145 26 E 5396 m	Volcanic radiolarian ooze	1; acid soluble CaO	(Dry) between buffy-brown and drab $17^{3\text{-}1/2}$h(O-Y) Silty clay (U.S.B.S class=clay); coherent, crumbly

Sample 51. Organic remains include abundant pelagic foraminifera, common arenaceous and benthonic foraminifera, and radiolaria. Predominant constituents of sand grades are angular fragments of fresh pumice (index of refraction about 1.50), fresh, dark-colored vesicular basic glass (index of refraction about 1.56), quartz, plagioclase feldspar, and hornblende.

Sample 52. Very small fine-grained sample. Organic skeletal material is scarce, chiefly radiolaria and sponge spicules. Basic volcanic glass (index of refraction somewhat less than 1.545), vesicular pumice, plagioclase feldspar (labradorite and some andesine), green augite, quartz, magnetite, manganese grains and flakes, limonite, clay mineral similar to that described for sample 50, and much fine unidentified material make up bulk of the sample.

Sample 53. Similar to sample 51, except that pelagic foraminifera are much more abundant and pumice fragments are replaced in the sand grades largely by vesicular basic volcanic glass. Quartz is abundant.

Sample 54. The organic remains consist of radiolaria shells (sometimes coated with manganese), fish teeth, occasional diatoms, sponge spicules, fragments of pelagic foraminifera, and arenaceous foraminifera, the latter consisting largely of angular grains of feldspar, sometimes coated with iron oxide, and volcanic glass. About 60 per cent of the sand grades is made up of pumice (index of refraction about 1.50), other inorganic materials are biotite, manganese grains, some basic volcanic glass, and plagio-

on cruise VII of the *Carnegie* in the Pacific--Continued

Sampler and container used	Field notes	Nearest previous samples
Sigsbee tube; vial	Bottom sample brown mud in Sigsbee tube no. 2 with detachable weight	*Nero* 1036. Flint (1905, p. 24); 18° 08.5′ N, 144° 04.7′ E. 2155 fathoms. Volcanic mud; CaCO3 not determined. Light brown, finely granular, nonadhesive mud, containing few foraminifera and relatively little "amorphous" matter. Remainder consists of fine angular mineral fragments
Sigsbee tube; vial	Hard bottom; small fragments of sample; two dents in Sigsbee tube no. 2; no water in tube	*Nero* 1084. Flint (1905, p. 24); 22° 45.5′ N, 143° 40.7′ W. 2313 fathoms. Volcanic mud; CaCO3 not determined. Light brownish-gray, granular. Occasional foraminifera, many radiolaria and much volcanic glass, some grains brown and porous, others filamentous, remainder sharp, angular, transparent fragments
Sigsbee tube; 12-oz. bottle	Used Sigsbee tube no. 2, detachable weight. Good sample of cream-colored clay-ooze and volcanic sand	*Nero* 1126. Flint (1905, p. 25); 26° 12.7′ N, 143° 08′ E. 972 fathoms. Volcanic mud; $CaCO_3$ not determined. Mostly volcanic sand with a few pelagic and benthonic foraminifera
Sigsbee tube; 12-oz. bottle	Good conditions	None
Sigsbee tube; vial	Tube had small fragment clay and black mud. Hard bottom	*Nero* 1207. Flint (1905, p. 25); 33° 22′ N, 140° 35.7′ E. 635 fathoms. Blue mud; CaCO3 not determined. Few small foraminifera and radiolaria; coarse mineral fragments, many of them black; many fragments coated with palagonite
Sigsbee-Ross snapper; 12-oz. bottle	Good sample	*Challenger* 237 (p. 112); 34° 37′ N; 140° 32′ E. 1875 fathoms. Blue mud; CaCO3=4.45 per cent; 1.5 per cent pelagic, 1 per cent benthonic foraminifera, 2 per cent otoliths and vertebrae of fish, cephalopod beaks, pteropod and heteropod fragments, echinoid spines. Siliceous organisms 5 per cent, remainder clay and a large amount of volcanic material including orthoclase and plagioclase, augite, hornblende, magnetite, black vesicular glass, pumice, biotite, manganese
Sigsbee-Ross snapper; 12-oz. bottle		None

clase feldspar (labradorite).

Sample 55. Very small, fine-grained sample. The small amount of siliceous organic material is made up of the remains of radiolaria, diatoms, and sponge spicules. Basic volcanic glass, pumice, and fine-grained material make up approximately one-half of sample. Other constituents are abundant plagioclase, some quartz, green hornblende, biotite, magnetite, augite, chlorite, colorless garnet, and palagonite.

Sample 56. Radiolaria make up about 60 per cent by volume of the sand grades of this sample; most of the remainder is of basic volcanic glass (index of refraction about 1.56), containing many microlites of feldspar and augite--some of the fragments of glass are slightly altered around the borders. Other constituents of sand grades are arenaceous foraminifera, few pelagic foraminifera, sponge spicules, some diatoms; colorless and light green pumice, quartz, biotite, euhedral hypersthene, plagioclase feldspar (labradorite), palagonite (?), hornblende, monoclinic feldspar, and augite. Magnetite is not common. The silt and clay fractions consist largely of plagioclase, monoclinic feldspar, volcanic glass, and the other minerals noted above, together with some diatoms and fragments of radiolaria. A clay mineral of high index of refraction (about 1.56) and appreciable birefringence is present in the clay grade.

Sample 57. Similar to sample 56, except for brown rather than gray color, greater abundance of siliceous organisms, and smaller amounts of basic volcanic glass and heavy minerals. Contains one large rounded

Table 1. Synoptic table of bottom samples collected

Sample	Station	Date	Position and depth in meters	Type of sample	Estimated $CaCO_3$ content in per cent; basis of estimate	Color and physical characters
		1929	° ′			
58	116	July 1	38 41 N 147 41 E 5545 m	Volcanic diatom or radiolarian ooze	1; acid soluble CaO	(Dry) olive-brown 17^3k(O-Y); (moist) silty clay (U.S.B.S. class=clay; frustules of diatoms; moderately coherent, crumbly
59	117	3	40 20 N 150 58 E 5296 m	Diatom ooze	0.46; acid soluble CaO	(Moist) mummy-brown 17^1m(O-Y) Silty clay (U.S.B.S. class=clay); frustules of diatoms; moderately coherent, crumbly
60	119	7	45 24 N 159 36 E 5198 m	Diatom ooze	0.93; acid soluble CaO	(Dry) between vinaceous-buff and avellaneous 17^3c(O-Y) Clayey silt (U.S.B.S. class=clay); frustules of diatoms; moderately coherent, crumbly
61	127	23	44 16 N 137 37 W 4026 m	Gray clayey mud	1; acid soluble CaO	(Dry) near light grayish-olive $21^{4-1/2}$c(OYY); (moist) brownish-olive 19^2m(YO-Y) Clay (U.S.B.S. class=clay); coherent; when moist, somewhat plastic; when dry, brittle
62	128	25	40 37 N 132 23 W 3806 m	Red clay	7; total CO_2	(Dry) between tilleul-buff and vinaceous-buff 17^3e(O-Y) Clay (U.S.B.S. class=clay); few shells of foraminifera; coherent; when moist, slightly plastic, moderately sticky; when dry, brittle
63	130	Sep. 4	37 05 N 123 43 W 3188 m	Green mud	<5; inspection	(Dry) between light grayish-olive and grayish-olive 21^4a(O-YY) Clay; coherent, brittle
64	131	6	33 49 N 126 20 W 4418 m	Red clay	0.57; acid soluble CaO	(Dry) between light drab and dark gray 17^4c(O-Y) Clay (U.S.B.S. class=clay); coherent, brittle

piece of fresh pumice over 1 cm in diameter and 2 manganese-palagonite nodules of about the same size. One of these, when sectioned (see plate XIII) shows the spherulitic alteration of colorless isotropic volcanic glass in the center, to reddish-orange palagonite, containing fresh phenocrysts of monoclinic feldspar and hornblende, near the surface. The palagonite spherulites are often surrounded by manganese; some of them are entirely replaced by manganese, which is distributed in more or less laminar fashion. Nearer the surface there are only isolated fragments of palagonite spherulites in the thick manganese coating.

Sample 58. Radiolaria are very abundant in this sample, but the principal component is perhaps diatoms at least in the finer grades. Other organic components are sponge spicules and arenaceous foraminifera. Inorganic components of sand grades include: rounded grains of fresh pumice, 3 mm in longest diameter, in which there are porphyritic clusters of magnetite, hypersthene, green hornblende and plagioclase feldspar (labradorite, $Ab_{45}An_{55}$); a few semiangular fine-grained volcanic rock particles about 1 mm in diameter which contain small crystals of plagioclase feldspar; together with plagioclase, quartz, basic volcanic glass, and monoclinic feldspar. Subhedral hornblende is the chief heavy mineral, followed by euhedral hypersthene, magnetite crystals, biotite, and colorless augite. Some of the plagioclase particles are zoned.

Sample 59. Both diatoms and radiolaria make up a very large proportion of this sample, but diatoms predominate, especially in the finer grades. Other organic remains are arenaceous foraminifera, sponge fragments, and pelagic foraminifera. Semiangular grains of quartzite, limestone, and a fine-grained volcanic rock are apparently ice-borne. Besides these, there are small amounts of basic volcanic glass (index of refraction greater than 1.56) and pumice (index of refraction 1.515). These are exactly similar in appearance to the glass and pumice from samples 56 on, the glass being packed as usual with microlites of feldspar. Some of the grains of the pumice are rounded. Very fresh plagioclase feldspar (labradorite), quartz, monoclinic feldspar, biotite, hypersthene in euhedral single and twinned crystals, hornblende, magnetite and pyroxene (?) are also present in the sand grades.

on cruise VII of the Carnegie in the Pacific--Continued

Sampler and container used	Field notes	Nearest previous samples
Sigsbee-Ross snapper; 12-oz. bottle	Snapper successful; weights detached. Good sample, reddish-brown and green mud	None
Sigsbee-Ross snapper; 12-oz. bottle	Good sample brown-gray mud	None
Sigsbee-Ross snapper; 12-oz. bottle	Good reddish-brown ooze in snapper	None
Sigsbee-Ross snapper; 2 12-oz. bottles		None
Sigsbee-Ross snapper; 2 12-oz. bottles		None
Sigsbee-Ross snapper; vial	Snapper did not close. Small amount of dark green mud in jaws	None
Sigsbee-Ross snapper; 12-oz. bottle	Snapper full of light brown clay	None

Sample 60. Diatoms greatly predominate in this sample. A few radiolaria and arenaceous foraminifera are present. Subrounded to subangular grains of volcanic rock, quartzite and unidentified fine-grained rocks, together with pumice, quartz, and volcanic minerals, as above, are present in the sand grades. Samples 56 to 60 are strikingly similar in chemical composition, but show a progressive increase in number of siliceous organisms, especially diatoms, and a decrease in volcanic components, particularly heavy minerals, toward the east. Ice-borne fragments also increase in number toward the east.

Sample 61. Radiolaria predominate in the sand grades. Arenaceous foraminifera are common, and sponge spicules and fish teeth are found. A few diatoms occur in the finer sand and silt, as well as some unidentified calcareous material. The inorganic constituents of the sand grades include pumice (index of refraction about 1.50), plagioclase feldspar (oligoclase $Ab_{75}An_{25}$), manganese flakes, and basic volcanic glass, the latter sometimes coated with iron oxide. The color of this sample indicates terrigenous influence even though the distance from shore is great and the nitrogen content is not larger than that of other north Pacific clays.

Sample 62. Radiolaria predominate in the sand grades. Other components of sand size are fragments of pelagic foraminifera, abundant benthonic foraminifera (ratio of pelagic to benthonic foraminifera about 7 to 1), fish teeth, echinoid spines, arenaceous foraminifera, manganese grains, biotite, feldspar, and hornblende.

Sample 63. Very small, fine-grained sample. Contains abundant radiolaria, also diatoms and sponge spicules, green hornblende, green garnet, titanite or octahedrite, quartz, brown mica (2E about 15 degrees), monoclinic feldspar, basic volcanic glass, brownish glauconite (?) magnetite, and unidentified fine-grained material.

Sample 64. Radiolarian skeletons are most abundant organic remains; arenaceous foraminifera are common; sponge spicules, black volcanic rock fragments, manganese grains, biotite, pumice and basic volcanic glass, the latter sometimes slightly birefringent, palagonite, plagioclase feldspar, and hornblende are observed in the sand grades.

Table 1. Synoptic table of bottom samples collected

Sample	Station	Date	Position and depth in meters	Type of sample	Estimated $CaCO_3$ content in per cent; basis of estimate	Color and physical characters
65	132	1929 Sep. 8	° ' 31 38 N 128 48 W 4251 m	Red clay	0.46; acid soluble CaO	(Dry) between vinaceous-buff and avellaneous 17^{3}c(O-Y); (moist) olive-brown 17^{3}k(O-Y) Clay (U.S.B.S. class=clay); when moist, moderately coherent, moderately plastic, slightly sticky; when dry, coherent, brittle
66	133	10	29 21 N 132 20 W 4426 m	Red clay	0.68; acid soluble CaO	(Dry) between light drab and drab 17^{4}a(O-Y); (moist) between raw umber and mummy-brown $17^{1/2}$m(O-Y) Clay (U.S.B.S. class=clay); coherent; when moist, plastic; when dry, brittle
67	134	12	27 45 N 135 22 W 4528 m	Red clay	<1; inspection	(Dry) sepia 17^{2}m(O-Y) (Slightly moist) clay; coherent, plastic (?)
68	135	14	26 39 N 139 07 W 4695 m	Red clay	<1; inspection	(Dry) avellaneous 17^{3}b(O-Y) Clay; coherent, brittle, smooth feel
69	136	16	26 13 N 142 02 W 4713 m	Red clay	0.80; acid soluble CaO	(Dry) between vinaceous-buff and avellaneous 17^{3}c(O-Y); (moist) between snuff-brown and Saccardo's umber 16^{2}k(YO-OY) Clay (U.S.B.S. class=clay); coherent; when moist; moderately plastic, slightly sticky; when dry, coherent, brittle
70	137	18	24 02 N 145 33 W 5208 m	Red clay	1; acid soluble CaO	(Dry) vinaceous-buff 17^{3}d(O-Y) (moist) between mummy-brown and Saccardo's umber $17^{1-1/2}$l(O-Y) Clay (U.S.B.S. class=clay); when moist, moderately coherent, moderately plastic, moderately sticky; when dry, coherent, brittle
71	138	20	22 53 N 151 15 W 5382 m	Red clay	<1; inspection	(Dry) between tilleul-buff and vinaceous-buff 17^{3}e(O-Y) Clay; coherent, brittle

Sample 65. Sand grades are very small in amount, as in most north Pacific red clays. They consist largely of radiolaria, arenaceous foraminifera, and sponge spicules, together with some flakes and grains of iron manganese oxide, somewhat altered fragments of plagioclase feldspar (oligoclase), and fresh microcline.

Sample 66. Radiolaria make up about 70 per cent of the sand grades. Fragments of arenaceous foraminifera, sponge spicules, diatom frustules, and fragments of fish teeth are other organic remains. Manganese grains and limonitic and manganese flakes, plagioclase feldspar (andesine), orthoclase, colorless pumice, and one magnetic spherule, are other identified components of sand size.

Sample 67. Small, fine-grained sample. Remains of organisms are rare--a few diatom fragments. Contains much birefringent material (clay minerals), also augite grains, hornblende needles and cleavage fragments, green garnet (?), oligoclase feldspar (or quartz?), basic glass, and manganese grains.

Sample 68. Very small, fine-grained sample. Remains of organisms are rare. Much birefringent

on cruise VII of the *Carnegie* in the Pacific--Continued

Sampler and container used	Field notes	Nearest previous samples
Carnegie-Ross pelican-snapper; 12-oz. bottle and glass jar	New triple-size pelican snapper sent down for first time. Struck something at 542 m, closed and weights detached. Hauled up, new weights put on and sent down again. Came up full, about 1 and 1/2 qts. dark brown clay, stiffer than usual	None
Carnegie-Ross pelican-snapper; 2 glass jars	Snapper not quite full of dark brown clay; fairly stiff	None
Carnegie-Ross pelican-snapper; vial	Snapper closed, but came up empty. Enough dark brown mud on outside of jaws for examination. Mud may have been too stiff to allow jaws to grip when the snapper was pulled off bottom	None
Carnegie-Ross pelican-snapper; vial	Snapper apparently closed going down, and struck closed. Small sample of dark brown mud on outside	None
Carnegie-Ross pelican-snapper; 3 glass jars	Snapper was full of dark brown mud, as for all previous samples since San Francisco. Sample weighed 4 lbs., 4 oz.	None
Carnegie-Ross pelican-snapper; 2 glass jars	Snapper full of dark brown mud as before	None
Carnegie-Ross pelican-snapper; vial	Snapper did not close owing to new spring being too stiff. Small sample dark brown mud inside jaws	None

material, probably mostly clay minerals, is present. Feldspar, hornblende, and a few manganese grains also were identified.

Sample 69. Remains of organisms are fairly common, and include radiolaria, sponge spincules, arenaceous foraminifera, and fish teeth. In addition, the sand grades contain cleavage fragments of brown hornblende ($-2V=80$), plagioclase feldspar (andesine, $Ab_{60}An_{40}$), and round manganese grains.

Sample 70. Sand grades are very small in amount. Remains of organisms are principally diatoms, together with radiolaria, sponge spicules, arenaceous foraminifera, and fish teeth. Round manganese-iron grains of sand size are also present.

Sample 71. Very small, fine-grained sample. Contains very few remains of organisms, chiefly radiolaria. Also contains augite, orthoclase, hornblende, plagioclase (andesine), basic volcanic glass, and manganese.

Table 1. Synoptic table of bottom samples collected

Sample	Station	Date	Position and depth in meters	Type of sample	Estimated $CaCO_3$ content in per cent; basis of estimate	Color and physical characters
		1929	° ′			
72	142	Oct. 7	32 42 N 160 44 W 5787 m	Red clay	0.57; acid soluble CaO	(Moist) raw umber 17m(O-Y). (Slightly moist) clay (U.S.B.S. class=clay); coherent, plastic
73	145	13	33 27 N 145 30 W 5584 m	Red clay	0.72; acid soluble CaO	(Dry) wood-brown 17^3(O-Y) Clay (U.S.B.S. class=clay); coherent, brittle
74	146	15	31 50 N 141 50 W 4756 m	Red clay	1; total CO_2	(Moist) mummy-brown 17^1m(O-Y) Clay (U.S.B.S. class=clay); moderately coherent, brittle, when dry
75	147	17	27 27 N 138 14 W 4840 m	Red clay (?)	<1; inspection	(Dry) between fuscous and fuscous-black 13^4l(OY-O) Sandy silt; angular grains of manganese; slightly coherent, gritty
76	148	19	24 57 N 137 44 W 4835 m	Red clay	<1; inspection	(Moist) olive-brown 17^3k(O-Y) Clay; coherent, plastic
77	149	21	21 18 N 138 36 W 5320 m	Red clay	0.72; acid soluble CaO	(Dry) drab 17^4(O-Y) Clay (U.S.B.S. class=clay); coherent, brittle
78	150	23	16 15 N 137 06 W 4553 m	Red clay (?)	<1; inspection	(Dry) between dark Quaker-drab and sooty-black 15^1l(red) Two cinders of volcanic rock coated with manganese. Average diameter approximately 1 cm
79	151	25	12 40 N 137 32 W 4918 m	Radiolarian ooze	1; acid soluble CaO	(Moist) near wood-brown; $17^{3\text{-}1/2}$(O-Y) Clay (U.S.B.S. class=clay); moderately coherent, slightly plastic, sticky
80	153	29	7 45 N 141 24 W 5003 m	Radiolarian ooze	Trace; acid soluble CaO	(Moist) Saccardo's umber 17^2k(O-Y) Clay (U.S.B.S. class=clay); few shells of foraminifera; moderately coherent, slightly plastic

Sample 72. Contains large amounts of siliceous organisms including radiolaria, sponge spicules, and arenaceous foraminifera; a few pelagic foraminifera and fish teeth are also present. Inorganic constituents of sand grades include pumice (in grains ranging up to 3 mm in diameter), manganese grains, feldspar, and hornblende.

Sample 73. Sand grades are small in amount. Organic remains include radiolaria, sponge spicules, arenaceous foraminifera and a few fish teeth. Manganese grains are common; other constituents of sand size are fresh and partially altered feldspar, hornblende, brown mica, and augite.

Sample 74. The small amounts of sand grades contain radiolaria, sponge spicules, fish teeth, arenaceous and pelagic foraminifera, also abundant manganese grains, pumice (often stained red brown), feldspar, and fractured euhedral grains of magnetite.

Sample 75. Consists of opaque angular grains of volcanic ash (less than 2 mm in longest diameter), coated with manganese, together with angular manganese grains, reddish-yellow, irregularly shaped, birefringent aggregates (beidellite), rare plagioclase feldspar, and considerable iron oxide.

Sample 76. Small, fine-grained sample, contains much birefringent material, also basic volcanic glass, small irregular grains of calcium carbonate of unknown origin, plagioclase feldspar, augite, needles of

on cruise VII of the Carnegie in the Pacific--Continued

Sampler and container used	Field notes	Nearest previous samples
Sigsbee-Ross snapper; glass jar	Full of light brown clay	None
Sigsbee-Ross snapper; 12-oz. bottle	Snapper did not close, but one jaw was full of light brown mud	None
Sigsbee-Ross snapper; 12-oz. bottle	Most of sample had washed out. Same color as before--light brown mud	None
Carnegie-Ross pelican-snapper; vial	Pelican snapper closed but brought up very small amount of fragments of manganese grains and black volcanic ash	None
Carnegie-Ross pelican-snapper; vial	Snapper not closed, but small sample of light brown clay on jaws	None
Carnegie-Ross pelican-snapper; 3 glass jars	Snapper closed; good sample; light brown mud	None
Carnegie-Ross pelican-snapper; vial	Snapper closed but only one small cinder of black lava inside	Albatross 11 (p. 83); 14° 38′ N, 136° 44′ W. 2646 fathoms. Red clay; $CaCO_3$=1 per cent; fish teeth; few siliceous organisms and small angular mineral grains; feldspar, glass, augite, magnetite, manganese grains; phillipsite. Dark mottled brown in color. Largely "amorphous" clayey matter
Carnegie-Ross pelican-snapper; 3 glass jars	Snapper came up full of light brown mud. Sample streaked with white clay and contained one manganese nodule, size of lemon	Albatross 12 (p. 83); 12° 07′ N, 137° 18′ W. 2883 fathoms. Radiolarian ooze; $CaCO_3$=1 per cent; greater than 30 per cent siliceous organisms, 2 per cent glass, feldspar, hornblende; the remainder "amorphous" clayey matter. Light brown in color
Carnegie-Ross pelican-snapper; 3 glass jars	Good sample. Snapper full of light brown, black-gray, white mixture mud-ooze	None

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hornblende, and manganese grains.

Sample 77. Sand grades contain radiolaria, sponge spicules, and fish teeth in addition to abundant manganese grains, pumice, plagioclase feldspar (andesine), and pyroxene.

Sample 78. Consists of two volcanic cinders about 1 cm in diameter coated with manganese and cemented together with the same material.

Sample 79. According to Piggott, the manganese nodule occurring in this sample contains alternating rings of clay and manganese dioxide, but no nucleus of other material. It was not received in La Jolla. Sand grades, large in amount when compared with samples 61 to 77, consist largely of radiolaria, together with diatoms, sponge spicules, arenaceous foraminifera, white (coprolitic?) pellets, manganese grains (containing nuclei of colorless volcanic glass), pumice, and green volcanic rock fragments.

Sample 80. Sand grades contain, besides radiolaria, numerous large manganese grains, white rod-shaped coprolitic pellets and tubes, gray ellipsoidal pellets, fish teeth, sponge spicules, arenaceous foraminifera, very few pelagic foraminifera, olivine, euhedral plagioclase (over 1 mm in diameter), quartz, hornblende, augite, and volcanic scoria.

Table 1. Synoptic table of bottom samples collected

Sample	Station	Date	Position and depth in meters	Type of sample	Estimated $CaCO_3$ content in per cent; basis of estimate	Color and physical characters
		1929	° '			
81	156	Nov. 4	3 01 N 149 46 W 4953 m	Siliceous globigerina ooze	40; acid soluble CaO	(Moist) partly pinkish-buff 17^2d(O-Y); partly Saccardo's umber 17^2k(O-Y). Sample has two colors but both parts have same physical characters Silty clay (U.S.B.S. class=clay); small shells of foraminifera and radiolarian tests; moderately coherent, sticky, greasy feel
82	157	6	1 48 S 152 22 W 4693 m	Siliceous globigerina ooze	85; acid soluble CaO	(Dry) pale pinkish-cinnamon 15^2f(Y-O); (moist) vinaceous-buff 17^3d(O-Y) Sandy clay (U.S.B.S. class=clay); shells of foraminifera and radiolarian tests; when moist, slightly coherent, crumbly; when dry, moderately coherent, pulverulent, gritty
83	158	8	6 33 S 154 58 W 4065 m	Globigerina ooze	90; inspection	(Wet) between tilleul-buff and white 17^3g(O-Y) Sand; all foraminifera shells and manganese grains; incoherent
84	159	11	9 24 S 159 01 W 5545 m	Red clay	<5; inspection	(Dry) mummy-brown 17^1m(O-Y) Clay; coherent, brittle
85	160	13	10 54 S 161 53 W 2614 m	Globigerina ooze	94; acid soluble CaO	(Dry) pale pinkish-cinnamon 15^2f(Y-O); (moist) between vinaceous-buff and avellaneous 17^3c(O-Y) Clayey sand (U.S.B.S. class=clay); shells of foraminifera; slightly coherent; when moist, crumbly, granular; when dry, crumbly
86	161	15	12 04 S 164 57 W 4484 m	?	?	
87	162	17	13 36 S 168 23 W 5124 m	?	?	

Sample 81. Sand grades consist almost entirely of remains of foraminifera, radiolaria, and other calcareous and siliceous organisms, including sponge spicules, arenaceous foraminifera, diatoms, echinoid spines, and fish teeth, but a few manganese grains are also present. Pronounced recrystallization is evident in tests of Globorotalia tumida. Eighty-five per cent of the tests of pelagic foraminifera are broken.

Sample 82. Many species of calcareous and arenaceous benthonic foraminifera; also radiolaria, diatoms, sponge spicules, fish teeth, echinoid spines, ostracods, are present in sand grades in addition to mostly broken tests of pelagic foraminifera, the latter exhibiting some recrystallization, and coccoliths. Inorganic constituents of sand size include manganese grains, fine-grained igneous rock fragments,

on cruise VII of the Carnegie in the Pacific--Continued

Sampler and container used	Field notes	Nearest previous samples
Carnegie-Ross pelican-snapper; 2 glass jars	Good bottom sample. Used Pelican no. 1. [Evidence of stratification of red clay and globigerina ooze. Contains one cinder (?)]	Challenger 270 (p. 120); 02° 34′ N, 149° 09′ W. 2925 fathoms. Globigerina ooze; $CaCO_3$=71.47 per cent; 65 per cent pelagic foraminifera; 1 per cent benthonic foraminifera; 5 per cent fish teeth, echinoid spines, abundant coccoliths; 5 per cent radiolaria, diatoms; 1 per cent angular volcanic glass, feldspar, manganese grains; 23 per cent fine "amorphous" matter and siliceous organisms. Lower part of core nearly pure globigerina ooze, upper part half and half siliceous and calcareous organisms
Carnegie-Ross pelican-snapper; 2 glass jars	Pelican no. 1 full of white globigerina ooze	Challenger 271 (p. 120); 00° 33′ S, 157° 34′ W. 2425 fathoms. Globigerina ooze; $CaCO_3$=81.27 per cent. Pelagic foraminifera 70 per cent; 3 per cent benthonic foraminifera; 8 per cent fish teeth, lamellibranchs, ostracods, echinoderm fragments, bryozoa, coccoliths; 10 per cent radiolaria, sponge spicules, arenaceous foraminifera; 9 per cent clay and siliceous remains; 1 egg-sized pumice fragment collected
Nansen water bottle; vial	Small amount of globigerina ooze in Nansen bottle Y	Challenger 274 (p. 122); 07° 25′ S, 152° 15′ W. 2750 fathoms. Radiolarian ooze; $CaCO_3$=3.89 per cent; red-brown colored, unctuous, slightly coherent, earthy; largely siliceous organisms, some angular small mineral grains, feldspar, augite, magnetite, magnetic spherules, manganese, phillipsite, pumice. Numerous manganese nodules, earbones of cetaceans, shark teeth, pumice, palagonitic and zeolitic materials obtained in trawl
Carnegie-Ross pelican-snapper; vial	Snapper not closed. Small amount red clay inside jaws	None
Carnegie-Ross pelican-snapper; 2 glass jars	Snapper half full of white globigerina ooze	None
Carnegie-Ross pelican-snapper; ?	Snapper came up with jaws held partly open by small black nodule; small amount ooze and clay inside jaws	
Carnegie-Ross pelican-snapper	Pelican no. 1 came up closed, but only smear of bottom mud. Must have closed going down	

plagioclase feldspar, angular quartz grains (possibly owing to contamination), basic volcanic glass, and magnetite.

Sample 83. Probably partially washed on being brought up. Consists of pelagic foraminifera and small amount of manganese grains.

Sample 84. Too small for detailed microscopic examination.

Sample 85. Consists almost entirely of unbroken tests of pelagic foraminifera, together with traces of calcareous and arenaceous benthonic foraminifera, echinoid spines, radiolaria, and sponge spicules.

Sample 86. Lost in destruction of Carnegie at Apia.

Sample 87. Lost in destruction of Carnegie at Apia.

Table 1. Synoptic table of bottom samples collected

Sample	Station	Date	Position and depth in meters	Type of sample	Estimated $CaCO_3$ content in per cent; basis of estimate	Color and physical characters
88	Callao harbor Peru	1929 Between Jan. 13 and Feb. 6	° ' 12 00 S 77 00 W ?	Gray mud	4; acid soluble CaO	None
89	Hanga Rua, Easter Island		27 00 S 109 00 W ?	Volcanic calcareous sand	70; acid soluble CaO	None

Sample 89. Contains over 5 per cent $MgCO_3$; 70 per cent of sample consists of calcareous organisms: madreporarian corals 15 per cent; coralline algae 12 per cent, Halimeda 3 per cent, foraminifera 10 per cent, gastropods 10 per cent, pelecypods 10 per cent, echinoid spines 8 per cent, tunicate spicules 1 per

Table 2. Summary of deposit types, depths, and $CaCO_3$ content of Carnegie deep-sea samples

Type of sample	No. of samples	Depth in meters			Carbonate content in per cent		
		Maximum	Minimum	Average	Maximum	Minimum	Average
Pelagic	63	5787	1089	4183	94	0	40.2
Globigerina ooze	31	4953	1089	3369	94	30	78.4
Normal or undifferentiated	17	4065	1089	3199	94	43	83.5
Ferruginous	8	4116	2851	3400	94	42	78.9
Siliceous	5	4953	3352	3992	85	30	59.6
Volcanic	1	2905	......	......	80	.....	.....
Siliceous ooze	6	5545	4918	5226	2	0	0.7
Diatom	2	5296	5198	......	0.9	0.5	.....
Radiolarian	3	5396	4918	5106	1	0	0.7
Diatom or radiolarian	1	5545	......	......	1	.....	.....
Red clay	26	5787	3657	4752	20	0.5	3.8
Normal or undifferentiated	23	5787	3806	4845	10	0.5	2.8
Siliceous	2	4141	3657	......	20	0.9	.....
Calcareous	1	4315	......	......	15	.....	.....
Terrigenous	12	6008	1344	3660	48	0.3	8.3
Detrital mud (green and gray silty, clayey, and coprolitic)	5	4480	3188	3675	5	0.3	2
Volcanic sediments							
Volcanic mud	4	6008	2911	4106	16	4	9
Volcanic globigerina mud	1	3036	......	......	48	.....	.....
Volcanic gravel	1	1344	......	......	5	.....	.....
Green diatom mud	1	4742	......	......	1	.....	.....

on cruise VII of the Carnegie in the Pacific--Concluded

Sampler and container used	Field notes	Nearest previous samples
Mann diatom dredge; 7 18-0z. bottles	Field notes destroyed	None
Mann diatom dredge; 18-oz. bottle (alcoholic)	Field notes destroyed, except label	None

cent, trace alcyonarian spicules and worm tubes; inorganic remains make up 30 per cent: fragments of volcanic rock and volcanic minerals.

Table 3. Colors of certain globigerina oozes from the south Pacific compared with their contents of manganese, iron, phosphate, and $CaCO_3$

Samples arranged in order of decreasing content of MnO_2

Sample no.	MnO_2	Total iron as Fe_2O_3	P_2O_5	$CaCO_3$	N	Color		
	Values in per cent					Dry	Moist	Wet
22	5.61	14.96	0.64	42.19	0.02	....	....	16 m
27	2.15	8.44	0.43	42.66	0.03	$16^{1\ 1/2}$k	....	....
23	1.98	4.68	0.27	75.30	0.05	17^3 b	17^1m	....
25	1.87	5.72	0.33	74.48	0.03	17^3 b	....	17^2k
21	1.77	5.28	0.25	84.28	0.03	....	....	....
44	1.69	4.42	0.86	74.82	0.02	17^3 b	17^1m	16^2k
19	1.44	4.40	0.26	86.47	0.02	....	....	17^3i
16	1.42	3.24	0.22	87.48	0.03	17^2 k	....	....
81	0.78	2.92	0.37	39.89	0.07	....	17^2k*	....
41	0.72	2.63	0.18	89.70	0.02	....	17^2j	....
13	0.71	1.22	0.11	65.66	0.06	....	17^3i	....
14	0.53	1.50	0.17	76.67	0.06	....	16^2i	....
26	0.38	1.16	0.09	90.74	0.03	....	17^3h	....
45	0.34	0.78	0.21	93.61	0.02	15^2f	17^3a	....
36	0.18	0.51	0.11	90.97	0.04	....	....	....
18	0.17	0.49	0.10	94.42	0.02	....	....	$18^{2\ 1/2}$d
82	0.13	0.42	0.09	85.44	0.07	15^2 f	17^3d	....
85	0.08	0.18	0.10	94.51	0.04	15^2 f	17^3c	....
29	0.07	0.19	0.09	94.42	0.03	15^2 d	....	....

*Color of larger part of sample

from samples 22, 23, 27, and 79, were dissolved in acid and found to contain as nuclei small colorless shards of siliceous volcanic glass (index of refraction less than 1.50). Dr. J. D. H. Wiseman[1] has shown that most manganese nodules contain such finely divided volcanic glass, instead of the clay minerals which were formerly believed to be present in them.

The observations summarized in the preceding paragraph merely confirm the long recognized fact that the coarser-grained inorganic constituents of pelagic deep-sea sediments are chiefly of volcanic origin. It is not a necessary deduction, however, that the fine-grained, partly colloidal materials which are the predominant inorganic constituents of these sediments either are volcanic or have originated mainly from the decomposition on the sea floor of volcanic debris. A priori, at least, it is equally possible that in certain regions the major part of this fine-grained material is of continental origin and has been carried in suspension from land and deposited on the sea bottom simultaneously with coarser-grained volcanic debris from other sources. Any conclusions as to the origin of the fine-grained and colloidal inorganic constituents in the sediments of a given region should be based on a comparison of the properties of these constituents themselves with those of similar substances of known origin.

Twin crystals and aggregates of the interesting zeolitic mineral phillipsite were observed in the sand grades of nine Globigerina oozes and two red clays from the southeastern Pacific. This mineral is shown by X-ray analysis to be present also in the finer fractions of another Globigerina ooze and probably in several additional noncalcareous samples.

Evidences of stratification of siliceous and calcareous organic remains and clay were observed in two of the siliceous oozes collected between Boca Perde and Christmas Island in the central Pacific, namely, sample 79, radiolarian ooze and sample 81, siliceous Globigerina ooze. It is noteworthy that Challenger sample 270 from this same region showed a similar stratification.

Distribution of Deposit Types

Chart 1 shows many of the routes or areas in the region of the Pacific covered by the Carnegie from which bottom samples have been collected by other ships and expeditions. Only those expeditions have been included, however, in which the bottom samples collected either are described in publications or have been available for examination by the writer. In addition, the location, deposit type, and percentage of calcium carbonate of the samples collected by the Carnegie are shown on chart 1.

Chart 2 shows the probable general distribution of the chief types of pelagic deposits and the boundaries between pelagic and terrigenous deposits in the region investigated: that is, east of 140° east, north of the equator; east of 180°, between the equator and 20° south; and east of 150° west, between 20° and 50° south. Where no new information is available as to the nature of the bottom material or the depth, the maps given by Murray and Lee (1909) for the entire Pacific, and by Hanzawa for the northwest Pacific, have usually been followed. (See also pages 99 to 126 and chart 10 which describe the distribution of $CaCO_3$ in the bottom deposits of the region.) Since chart 2 was constructed, a corresponding map of the areal distribution of deep-sea deposits in the Pacific and Indian oceans, prepared by Wolfgang Schott from all available material (including that of the Carnegie) has been published (W. Schott, 1935). Although the writer's chart and that of Schott are rather similar in so far as the Carnegie area is concerned, there are several important differences. These are chiefly matters of opinion, either about doubtful areas from which few samples have been described, or as to the criteria for separation of pelagic and terrigenous sediments.

There are three large areas of Globigerina ooze in the area investigated. By far the greatest of these, occupying about ten million square miles, is that which covers most of the bottom of the southeastern Pacific. This area was enlarged by the work of the Albatross, as may be seen by comparing the map of Murray and Rénard published in 1891 with that given by Murray and Lee nearly twenty years later. On both Schott's and the writer's charts this area is extended even farther, as a result of the bottom samples collected by the Carnegie and of the echo soundings made by the Dana. Of the other two large Globigerina ooze areas, that surrounding the Marshall, Gilbert, and Caroline islands, between 140° and 179° east and between the equator and 15° north, has been developed through the work of the Japanese and is shown in detail on Hanzawa's chart. According to Schott, this area is probably continuous with the great Globigerina ooze region of the southwest Pacific, as is also the area between Samoa, Tonga, and Fiji, which is shown on chart 2. In the north Pacific, at depths less than 2000 fathoms, there are numerous small areas surrounding oceanic islands or on sharply sloping submerged peaks and ridges which the Challenger workers, Flint (1905) and others, have found to be covered with Globigerina ooze. Many of these are small and uncertain in extent, being based on single samples, some of which were only casually examined, and not all of them are shown on chart 2.

By far the larger part of the bottom of the north Pacific north of 10° north, is covered by red clay; indeed, this is the premier red clay area of the ocean basins. There are, besides, five large red clay areas in the region south of 10° north included on the chart. Two of these lie in the deep water to the west of the zone of terrigenous deposits off the South American coast, one between the equator and 38° south, the other south of 45° south. The former extends westward as a wide curved tongue bounded on the southeast by the Merriam Ridge, and turns to the north up to 5° south as a narrow strip which includes the Bauer Deep. The third area lies, in general, west of 140° west, except for an indentation between latitudes 30° and 43° south. It is part of the large red clay area of the central south Pacific shown on Schott's chart. The fourth red clay area between the equator and 6° north and 152° to 140° east is based on Hanzawa's chart. North of 10° south, between 170° west and about 180°, there is also a belt of red clay, continuous with the great north Pacific red clay region.

The long strip of radiolarian ooze shown on chart 2, and on the map of Murray and Lee, to extend west of the zone of terrigenous deposits off the Central American coast between about 7° and 15° north to 165° west, and thence southwest to about 10° south, is based principally on samples collected at its western and eastern extremities. It is not believed by Schott to be continuous. The central part is almost entirely unexplored. The fact that

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[1] Personal communication.

this strip underlies the average path of the Counter Equatorial Current, which is known to have a high plankton content, and the fact that the Carnegie found siliceous Globigerina oozes to the south of the eastern part of the area, make it seem reasonable to believe that this zone of radiolarian ooze does exist as a continuous belt. Small areas of radiolarian ooze lie to the south of the Marianas, and near Malden Island, and Schott also shows several patches of radiolarian ooze in the northeast Pacific, based on samples collected by the Egeria.

The presence of siliceous oozes on the bottom underlying the area north of the north Pacific polar front, first shown by Murray and Rénard from a study of samples collected by the Tuscarora, was confirmed in part by Carnegie samples 57 to 60. It should be noted that sample 57 is a radiolarian ooze, whereas sample 58 contains about equal proportions of radiolaria and diatoms. In its eastern half this area is based on the map by Murray and Lee. The writer has pointed out already that the diatomaceous deposits off the South American coast, indicated by Schott as diatom ooze, should more properly be regarded as terrigenous diatom mud, a suggestion which has also been made by Neaverson.

The criteria for distinction between terrigenous and pelagic deposits given in the section on classification have resulted in a considerable extension of the zone of terrigenous deposits off the coasts of North and South America. It is probable that this zone would be even further enlarged by a critical survey of the boundary area. Similarly, in the northwest Pacific the zone of terrigenous (volcanic) sediment shown on chart 2 is somewhat larger than that indicated by Hanzawa.

Calcium Carbonate Content

The calcium carbonate contents of the samples were determined in one of the three ways which are listed in column 6 of table 1 as acid soluble CaO, total CO_2, and inspection.

Partial chemical analyses were carried out on forty-six of the samples and these included determinations of the amounts of calcium and magnesium soluble in 10 per cent hydrochloric acid. Brazier (1891) assumed that the results obtained by such a procedure would give rough determinations of the percentages of calcium and magnesium carbonate in the samples, and on the basis of this assumption he recorded the presence of considerable amounts of magnesium carbonate in deep-sea deposits, especially red clays. From this Hōgbom (1894) was led to conclude that enrichment of magnesium carbonate is taking place in the deep sea. That Brazier's assumption is untenable was pointed out by Harrison and Jukes Brown (1895) and by Andrée (1920). It will be shown later that the Globigerina oozes contain practically no magnesium carbonate. Determinations, however, carried out by an absorption method, similar to that described by Hillebrand and Lundell (1929), of the carbon dioxide content of eight of the samples in which acid-soluble calcium had also been determined (see table 12), show that the latter determination is a rather accurate measure of the amount of total carbonate in a bottom sample. The results were accurate to about 1 per cent, an error which is commensurate with those arising in the course of the collection and preliminary handling of the samples.

Besides the eight analyses of total CO_2 content just mentioned, the total carbon dioxide content of fifteen other samples was kindly determined by Harald Hammar of the American Petroleum Institute. For most of these twenty-three samples the basis of estimate of $CaCO_3$ is listed in table 1 as total CO_2. For the chemically analyzed samples in which determinations of the total CO_2 were not carried out, the basis of estimate of carbonate content is listed in table 1 as acid-soluble CaO. The results are reported to the nearest 1 per cent.

The amounts of calcium carbonate in the remaining samples, which were either too small in amount or for other reasons were not quantitatively analyzed for calcium, were roughly estimated by inspection. This procedure sometimes leads to large errors when the samples are unusual in color or appearance, but often the agreement between an estimate of $CaCO_3$ by inspection and a subsequent quantitative determination is rather close. Such estimates were carried out on the fifteen samples later quantitatively determined by Hammar. The average deviation between the estimates by inspection and the actual determinations was 10.6 per cent, but this was chiefly caused by a large discrepancy of about 35 per cent in two samples. In eight of the fifteen samples the deviation was 3 per cent or less, and in twelve of them the deviation was 12.5 per cent or less. Owing to the magnitude of the errors involved, the estimates by inspection are reported in table 1 to the nearest 5 per cent.

A comparison of the samples collected by the Challenger, Albatross, and other ships near the Carnegie stations, as listed in column 10 of table 1, shows that in general the carbonate contents given by Murray and his co-workers are lower than those recorded in this paper for the Carnegie samples. Murray's determinations of CO_2 were carried out by the alkalimeter method, which consists essentially of weighing a sample before and after the displacement of carbon dioxide by dilute acid. The samples were first dried in an air or water oven at temperatures of 100° to 110°, but apparently they were not washed free of salt. The Carnegie samples were dried to constant weight at 110° or, in the case of the samples analyzed by Hammar, were heated above 110°. Examination of the section on chemical analyses given below will show that the amounts of water in presumably dry samples are quite variable in amount, depending on the nature of the drying process. Most of the analyzed Carnegie samples were washed partly free of salt. Since, as Gebbing (1909) has shown, the salt content of fine-grained sediments is sometimes as much as 7 per cent, removal of the salt would cause a considerable increase in calcium carbonate content.

Color

As stated already, the colors of the samples are indicated in column 7 of table 1. Colors were determined according to the scheme of color standards and nomenclature given by Ridgway (1912). In this system the spectrum is divided into seventy-two hues which are each designated by a number; 1 designates red, 16 halfway between orange and yellow, 21 orange to yellowish-yellow, and so on. The tint or shade, that is the amount of white or black for any particular hue, is designated by a letter. The seven letters a to g indicate progressive increments of white, and h to n increments of black.

The lack of intensity, that is the amount of neutral gray in any color, may be shown by a small exponential number, which increases from 1 to 5 with increasing amounts of gray: thus 17^3b indicates a color nearly intermediate between orange and yellow in hue, having admixtures of 9.5 per cent white as measured by a color wheel and 77 per cent neutral gray measured by the same means. In addition to the numerical descriptions of the colors, every alternate hue and admixture of white or black and each increment of neutral gray is indicated by a distinct name. Ridgway's system of color classification is the basis of Goldman and Merwin's (1928) color chart, and these authors recommend the use of Ridgway's book when it is available.

The color of a sample was determined, except in the case of very incoherent muds and oozes, by placing a small part on a knife blade and holding it directly above the colored paper in Ridgway's book with which it was being matched, always as nearly as possible at the same angle to the eye of the observer. Most of the *Carnegie* samples are homogeneous in appearance, and therefore could be compared fairly accurately with a homogeneous surface of colored paper, but for coarse-textured samples it was necessary to make a crude approximation to homogeneity by trying to blend visually the various color components which were evident.

Sumner (1927) has outlined the limitations of sets of standard colors such as Ridgway's and the necessary conditions for their use. He points out that it is impossible to make determinations which are quantitative in the sense of being expressible in significant figures through any system of matching standards. Furthermore, colorimetric tests made by him on many of the plates of Ridgway's book show some wide discrepancies between colors which are said to be of the same hue or to have the same amount of dilution with white. He states, however, that plates XV, XXIX, and XL, which happen to be the principal ones used in the determination of the colors of deep-sea sediments, seem to conform fairly well with each other, at least in respect to hue.

Besides the inaccuracies inherent in the method of color comparison used, there are certain sources of error peculiar to the material observed, namely, those due to (1) possible changes in color after collection and during storage, and (2) differences in color due to the amount of water present.

It is not believed that the colors of the red clays or Globigerina oozes in the collection suffered any marked changes except those incident to the unavoidable drying of some samples during storage. Only very rough color determinations were made on board and these are given in table 1, column 9, in the extracts from the field notes made at the time of collection, but Dr. E. G. Moberg, who was on board the *Carnegie* between San Francisco and Hawaii, has kindly compared some of the samples of red clay from this region with his memory of their condition when collected, and he does not believe that any marked color differences exist. On the other hand, a few of the terrigenous samples, which probably contained considerable amounts of decomposable organic matter, have, perhaps, suffered more or less decided color changes.

The samples when examined had widely differing water contents, which differed also from the amounts of water originally present in them: some were quite dry; in others partial drying had taken place and the samples were only slightly moist; still others, especially many red clays, appeared to have approximately their original amount of water; whereas in others considerable water had been added during handling. Since color is so largely dependent on water content, only those samples of approximately the same state are comparable. The samples are recorded as being either (1) dry, (2) moist, when the original interstitial water content is largely or partly present, or (3) wet, when water has been added and the sediment has obviously been shaken up several times and dispersed in it.

When the samples were stored in two or more bottles, the material in one bottle would often be moist, whereas in another it would be dry, and in these cases the color in both the moist and dry states is recorded. A comparison of such determinations shows that in Globigerina oozes the dry part of a sample may be from two to seven shades lighter than the corresponding wet part. The hue is often unchanged, but sometimes the dried material is slightly more reddish, probably owing to partial dehydration of the hydrated oxides of iron present in the sediments. Red clays become six to nine shades lighter when dried and about 1° more gray, but there is usually no change in hue, although sometimes they become less reddish.

The importance in classification of the colors of marine sediments has been discussed on pages 5 and 6. In two other recent papers on marine sedimentation attention has been paid to the factors affecting color. Pratje (1931), who has employed Ostwald's[1] system and standards of color nomenclature (which are fundamentally the same as Ridgway's) in describing the sediments of the German Bight of the North Sea, points out that these deposits exhibit only a small range of color, in spite of the wide variation in sedimentary types. He claims that the contents of organic matter and calcium carbonate, together with the states of oxidation of the iron compounds, are the factors most closely related to color in such terrigenous deposits. Gorshkova (1931) has studied the significance of color in the bottom deposits of the White and Barents seas. The variation from brown through gray to greenish gray in the colors of these sediments was found to be accompanied by a decrease in their contents of iron, manganese, and phosphate, and a corresponding increase in organic matter and sulphur, together with a change from predominantly ferric to predominantly ferrous iron. The greenish gray deposits contain from five to fifteen times as much living matter as the brown soils.

The *Carnegie* samples, like those of Pratje and those of Thorp (1931), exhibit a small range of color. The total variation in moist samples is between $15^2$1 (yellowish orange in hue, containing 80 per cent of black and 58 per cent of neutral gray) for sample 49, a south Pacific red clay; and 21^4b (orange-yellowish yellow in hue, with 9 per cent white and 90 per cent neutral gray, called light grayish olive by Ridgway) for sample 34, a green clayey mud from off the South American coast.

Certain red clays from the south Pacific, namely samples 30, 38, 47, 48, 49, and 50, are the reddest and darkest of the sediments collected (excluding nonrepresentative samples and rock fragments, such as samples 11, 75, and 78). When moist they exhibit colors between 15^2l and 17 m (orange yellow, with 87.5 per cent black, called raw umber by Ridgway). Two other red clays from the south Pacific, samples 31 and 35, collected near

[1] Ostwald, Wilh., Farbtonleiter 2. Afl. Verlag Unesma g.m.b.H, Leipzig, quoted by Pratje.

the South American coast, are lighter and more grayish in color. It is noteworthy that sample 31 is relatively high in nitrogen for a pelagic deposit, therefore presumably in organic matter. On the other hand, the amount, kind, and state of oxidation of iron and manganese compounds are probably the controlling factors of color in Pacific pelagic deposits. These are not functions of the total organic matter content of a sediment, but rather may, in part at least, be dependent on the amount of decomposable organic materials which it contains. The latter, in turn, is dependent on the origin and relative rate of deposition of organic matter.

The darkness and intensity of the brown colors of south Pacific Globigerina oozes are directly proportional to their contents of manganese and iron. Samples high in these substances also tend to be high in phosphate, in agreement with the findings of Gorshkova, but there seems to be little correlation with the organic matter contents. These relations are indicated in table 3 (page 41), which gives a comparison of the color values shown in table 1 with the amounts of MnO_2, Fe_2O_3, P_2O_5, organic nitrogen, and $CaCO_3$ found by chemical analysis, as given in table 9. The $CaCO_3$ contents and other constituents of these samples probably serve only to dilute the colors produced by the hydrated oxides of manganese and iron.

In the northeast Pacific the colors of the red clays, as well as their other physical and chemical characters, show very little variation. Samples 69 and 72 are the reddest and darkest of the moist samples, their color designations being 16^2k and 17m, respectively; whereas sample 76 (17^3k, olive brown) is the lightest and grayest. Five of the seven moist samples examined have colors between $17^{1/2}$m and 17^3k, a range of only two shades and $1^{1/2}$ increments of neutral gray.

Samples 57 to 60, which are siliceous oozes collected in the region northeast of Japan, are similar in color to the red clays of the northeast Pacific, as are samples 79 and 80, radiolarian oozes from the central Pacific. Most of the representatives of terrigenous deposits in the collection, namely samples 10, 32, 33, 34, 51, 55, 56, 61, and 63, are a slightly greenish gray in color, ranging between 19^2l and 21^4b for moist samples. The remaining three terrigenous samples, 11, 53, and 54, are brown in color, but are nevertheless designated as terrigenous because of their high content of volcanic materials.

Physical Characteristics

Besides a designation for color, column 7 of table 1 also contains a description of the physical characteristics of the samples, that is, of their texture, structure, and consistency. The structure and consistency were determined by examining a representative part of each sample on a knife blade or in the hand. They are expressed in terms of certain standard expressions suggested by the descriptions of the *Challenger* samples, and follow, in part, the definitions given by Shaw (1927) for the physical characteristics of soils. The textural designations are of two types: (1) those based on the feel of a sample when rubbed between the fingers, together with its macroscopic appearance, and (2) the textural classes of the system used by the United States Bureau of Soils, given only when mechanical analyses are available. It was found impossible to express the textures of many of the samples in terms of Wentworth's (1922) size classification. On the other hand, since the great majority of deep-sea sediments contain more than 30 per cent of particles less than 5 microns in diameter, and therefore must be classified as clays in the Bureau of Soils' system, this classification often does not serve to distinguish between different types of samples. It does have the advantage of being quantitative, whereas the terms based on the appearance and feel of the samples are only qualitative and subjective. The samples have been divided on this latter basis into gravels, sands, silts, and clays. When, as often happens, particles of two different sizes are present in appreciable amounts, the adjectival terms sandy, silty, and clayey have been used. Most Globigerina oozes, for example, are sandy clays or clayey sands.

When macroscopic grains are present in noticeable amounts, the shape and nature of the grains have been given. If rocks or mineral fragments are present, the grains are described as angular, subangular, subrounded, or rounded; similarly, the varying amounts and sizes of macroscopic shells of foraminifera and other organisms, and of clayey aggregates and manganese grains and nodules have been noted.

The structure, that is, the arrangement of the individual grains and aggregates making up the sample, and the consistency, that is, the degree of cohesion of the material and the resistance opposed to forces tending to deform or rupture aggregates, will obviously depend on the amount of moisture in the samples. Correspondingly, the descriptive terms used to express these characteristics vary somewhat according to whether the sample was dry, moist, or wet when examined. For both wet and dry samples, however, the terms *coherent*, *moderately coherent*, *slightly coherent*, and *incoherent* were employed; the first meaning that the individual grains and aggregates have a high degree of cohesion, and the last that the individual grains and aggregates do not adhere to each other at all. For moist and wet samples the terms *plastic*, *sticky*, *slippery* (*greasy*), *granular*, and *gritty*, together with modifying adverbs, were employed, and for dry samples the terms *brittle*, *pulverulent*, *crumbly*, and *gritty* were used. These terms may be defined as follows: (1) *plastic* was used in the sense given by Mellor (1922), "plasticity is the property which enables a clay to change its shape without cracking when it is subjected to a deforming stress;" (2) *sticky* is defined by Mellor as follows: "a sticky clay is one in which the particles do not have a marked tendency to adhere together. Such clay adheres to anything it touches which water can wet;" (3) *slippery* and *greasy* were used to mean simply that a sample felt unctuous or greasy to the touch; (4) a *brittle* soil is defined by Shaw (1927) as one which "when dry will break with a sharp clean fracture. If struck a sharp blow it will shatter into cleanly broken hard fragments;" (5) *crumbly* is used to describe dry samples that break up easily into soft, irregular "earthy aggregates;" (6) *pulverulent* is used in the sense of Murray and Rénard (1891), that is, to describe a dry substance which easily crumbles to an impalpable powder. The above terms are all properties of the amount and kind of the clayey materials in the sediments. For samples containing larger particles or aggregates the terms *gritty*, implying the presence of a noticeable amount of angular hard grains, and *granular*, implying the presence of smooth aggregates or rounded grains (as determined by the feel), were used.

When moist, red clays are usually moderately plastic to plastic, moderately coherent to coherent, and sometimes slightly sticky; when dry they are usually coherent and brittle. Macroscopic elements are only rarely present. Fine-grained terrigenous deposits or muds when moist or wet are slightly to moderately coherent, sticky, and sometimes crumbly. These terms also apply to siliceous oozes. Globigerina oozes are usually only slightly coherent, crumbly, and granular when moist, and moderately coherent to incoherent, crumbly, and granular when dry.

Organic Constituents of the Samples

Plant Remains. The plant remains in the samples are of three kinds, namely (1) coccoliths and rhabdoliths, the skeletal plates of Coccolithophores and Rhabdospheres, (2) the frustules of diatoms, and (3) calcareous algae. Coccoliths and rhabdoliths are usually present in small amounts in the silt fractions of Globigerina oozes. A horseshoe-shaped form was the principal type observed. Diatoms are the predominant organic constituents of samples 59 and 60 in the northwest Pacific and make up large amounts of the other siliceous oozes from that region, as well as of the noncalcareous samples off the coast of South America. Traces of diatom frustules are always present in siliceous oozes even when these are highly calcareous. Remains of Corallinaceae and Halimeda were observed in only one sample, number 29, collected from the top of the Merriam Ridge.

Foraminifera. Some of the specimens of foraminifera from sixteen samples were picked out, mounted on cardboard slides, and sent for identification to Dr. J. A. Cushman, who kindly undertook to determine the species of those forms which could be readily identified. With the aid of his determinations the writer then identified many of the species in several other samples. The results, together with the order of abundance of various species, are given in table 5 (pp. 48-55). At the time the specimens were sent to Dr. Cushman he had not yet completed the study of the family Anomaliidae from the tropical Pacific collections of the Albatross (see U.S.N.M. Bull. 161), and was consequently unable to give a report on most of the species of this group in the collection.

Although for this and other reasons the results are far from complete, one hundred and forty-two species, not including most of the Anomaliidae but including those specimens listed merely as manuscript species or sp(?), are listed. This is a minimum estimate, as in many cases more than one species is represented in the latter categories. Fifty-six genera are present. Of these, eight are pelagic, seventeen are arenaceous benthonic, and thirty-one are calcareous benthonic genera, the total number of benthonic genera being forty-eight. There are twenty-three pelagic species, and one hundred and nineteen benthonic species, of which nineteen are arenaceous and one hundred are calcareous forms.

A comparison of the pelagic species listed in the table with the list of pelagic species given by Cushman (1928) shows that eleven species noted as pelagic are not present in the collection. Conversely, Globigerina conglomerata and rotundata, Globorotalia hirsuta, and several unnamed species are not listed in Cushman's book. Globigerina conglomerata, G. inflata, and G. rotundata, Globigerinoides conglobata and sacculifera, Globigerinella aequilateralis, Orbulina universa, Pulleniatina obliquiloculata, Globorotalia menardii, G. truncatulinoides, and G. tumida are all widely distributed pelagic species in the Pacific, although the relative proportions of each present in different samples vary considerably. Globigerina Sp. cf. G. bulloides, Globigerinoides rubra, and n. sp(?), Globigerinella digitata, Candeina nitida, Sphaeroidinella dehiscens, Globorotalia hirsuta, and various unnamed species are not common in occurrence.

The most common benthonic genera, in approximate order of abundance, are Eponides, Pulvinulinella, Uvigerina, Cibicides, Pullenia, and Nonion. As with the pelagic forms, the relative abundance of these genera is quite variable in different samples. The genus Lagena, of which over thirty species are identified, is widely distributed. Other characteristic foraminifera of Pacific deep-sea deposits are Dorothia bradyi, Pyrgo depressa, Gyroidina soldanii, Cassidulina fava and C. subglobosa, Ehrenbergina bradyi, and Laticarinina pauperata. Arenaceous foraminifera are also characteristic, particularly of deposits low in calcium carbonate, but these are variable in appearance, usually fragmentary, and difficult to identify.

It may be seen from an examination of tables 1 and 9 that in general the samples which have the highest percentage amounts of benthonic foraminifera are usually, other things being equal, those of relatively lower content of pelagic foraminifera (hence relatively lower $CaCO_3$ content), higher proportions of broken shells, and higher percentages of organic matter than other samples of the same depth and general location. Correspondingly, there is an inverse relation between the numbers of benthonic species in the samples and the percentages of $CaCO_3$. This relation is shown in table 4 which gives, in addition to the depth and percentage of $CaCO_3$, the numbers of benthonic species found in ten samples in which all the observed benthonic foraminifera were carefully studied.

Table 4. Relation between numbers of benthonic species of foraminifera and the percentage of $CaCO_3$

Samples arranged in order of decreasing $CaCO_3$ content

Sample no.	$CaCO_3$	Depth in meters	No. benthonic species		
			Arenaceous	Calcareous	Total
29	94	1089	2	16	18
85	94	2614	1	9	10
26	91	3393	0	11	11
36	91	3489	2	20	22
41	90	3515	2	12	14
82	85	4693	8	49	57
25	74	3610	3	33	36
27	43	3879	4	34	38
31	20	3657	9	40	49
62	7	3806	1	17	18

Samples 25 to 41 are from the southeast Pacific. It may be seen from table 4 that the average number of benthonic foraminifera in the samples from this region which have more than 90 per cent calcium carbonate is less than half the numbers present in samples of intermediate carbonate content. Sample 31, a red clay having only 20 per cent $CaCO_3$, contains the largest number of benthonic foraminifera of any sample from this area. Similarly, there is a great variation in samples 82 and 85 from the south central Pacific in the numbers of benthonic foraminifera present, and a corresponding difference, though of smaller magnitude, in the percentage of $CaCO_3$. The difference between Globigerina oozes of high and of intermediate $CaCO_3$ content is particularly marked in the fine sand grades of the mechanically analyzed samples, as may be seen from the plates. In samples having more than 90 per cent calcium carbonate these grades usually consist almost wholly of entire shells of immature pelagic foraminifera, whereas in samples of lower carbonate content they consist largely of broken fragments of larger shells, together with benthonic foraminifera. The inverse relation between $CaCO_3$ content and amounts of benthonic foraminifera in pelagic sediments does not hold when the relatively low $CaCO_3$ content of a sample is owing to dilution by volcanic or detrital material, nor is it valid in relatively shallow-water sediments such as pteropod oozes.

Murray and Philippi (1908) noticed in the samples collected by the Valdivia expedition that "es scheint im Globigerina-schlamm öfters ein umkristallisierungsprozess vor sich zu gehen" (p. 154), which affects the shells of pelagic foraminifera. In the Carnegie samples, recrystallization often seems to have occurred in the shells of certain pelagic species, notably Globorotalia tumida, and G. truncatulinoides, Globigerina conglomerata, G. rotundata, and G. inflata, and Globigerinoides sacculifera and G. conglobata. The shells of these animals ordinarily consist of very small, closely packed crystals, but when recrystallization has apparently taken place, they are formed of separate prismatic calcite crystals varying in length up to 0.05 mm. As is shown in the section on X-ray analysis, the shells of pelagic foraminifera in deep-sea samples, even when only partially recrystallized, consist of calcite, and not aragonite, which forms the skeletons of certain other groups of organisms. Obvious recrystallization is largely confined to those samples of intermediate $CaCO_3$ content and of high percentage of benthonic foraminifera in which most of the pelagic shells are broken. In the samples in which the $CaCO_3$ content is greater than 90 per cent, the shells of pelagic foraminifera, especially immature forms, are usually smooth and polished in appearance.

Radiolaria. Besides foraminifera, radiolaria are common constituents of siliceous Globigerina oozes and are, of course, the chief constituents of radiolarian oozes. The remains of radiolaria also make up large amounts of the siliceous oozes collected northeast of Japan.

Sponges. Traces of sponge spicules were found in every sample examined, but the abundance of sponge fragments was more or less inversely proportional to the amount of calcium carbonate in the samples and directly proportional to the amounts of other siliceous organic remains. Sample 72 contained an unusually high percentage of sponge fragments. Dr. M. W. de Laubenfels kindly examined specimens of sponge fragments from 13 samples but was unable, owing to the fragmentary nature of the material, to make any definite identifications. His report, in tabular form, is given in table 6 (p. 54).

Echinoids. The presence of minor amounts of echinoid spines is recorded from twenty-three samples, all but three of which are Globigerina oozes from the south Pacific, and undoubtedly, on careful examination, these remains would be found also in the other Globigerina oozes of the collection. In general, the amounts of echinoid spines seem to vary directly with the percentages of benthonic foraminifera in the samples. Specimens of echinoid spines from samples 14, 17, 18, 25, 27, 29, 31, 36, 41, 62, 81, 82, and 85 were sent to Mr. Austin H. Clark for examination. His report is as follows.

"The echinoid spines are all from deep water spatangoids, some from immature individuals.

"About twenty species of spatangoids are known from deep water in the Pacific, many, probably most, of which have a very wide distribution. They are all exceedingly delicate. In each individual the spines and pedicellariae are very highly diversified. But there is so little that is distinctive about the spines in the several genera concerned that spine fragments cannot be identified with any degree of certainty.

"As all of these fragments are from secondary or miliary spines, from young spines, or from pedicellariae, it is likely that most, if not all, of them came from a more or less considerable distance, and some of them, at least, may be from one or other of the numerous shallow-water species. Had these fragments all been from species living on the bottom where they were found, one would expect to find among them parts of the larger spines and the still more solid spine bosses."

Bryozoa. Remains of bryozoa have been positively identified in only one sample, no. 15, a Globigerina ooze from the southeast Pacific. Dr. R. S. Bassler identified a small fragment from sample 29 collected from the top of the Merriam Ridge off the South American coast at a depth of 1089 meters, as possibly representing the bryozoan genus Retepora.

Mollusca. Possibly owing to the fact that all the samples were collected from depths greater than 1000 meters, the remains of mollusca are very scarce. One or two shells of gastropods were noticed in a few samples. Pteropod remains were only doubtfully recognized. Murray and his co-workers pointed out the virtual absence of pteropod ooze in the Pacific, except for certain small areas near oceanic islands.

Ostracods. Ostracods are a widely distributed constituent of the sediments of the south Pacific, but are always present in very minor amounts, no more than ten individual shells having been seen in any of the fourteen samples in which the presence of ostracods is recorded. These samples range in depth from 1089 to 4693 meters and, with the exception of no. 31, all are Globigerina oozes having carbonate contents ranging between 66 and 94 per cent. In general, ostracod shells are most abundant in relatively highly calcareous sediments.

Dr. C. I. Alexander examined specimens of ostracods from eleven samples, and was able to identify most of them as belonging to the benthonic genera Cythereis and Krithe. His report, in tabular form, is given in table 7 (p. 55).

Vertebrate Remains. Although vertebrate remains are said to be rather common in dredgings from the deep-sea areas of the Pacific, they are not common in the Carnegie samples, owing to the method of collection. What appear to be small teeth of fish, however, are of frequent occurrence in all types of samples, being especially noticeable in samples 17, 18, 22, 25, 27, 31, 35, 36, 44, 49, 79, and 82 from the south and central Pacific and sample 62 from the north Pacific. Dr. Paul Bartsch of the United States National Museum doubts that these are fish teeth.[1]

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[1] Communication to Dr. T. W. Vaughan.

Table 5. Species of foraminifera identified

Identifications made by Dr. J. A. Cushman, except those

Sample no.	Family and species	Station								
		13[a]	14[a]	17[a]	18[a]	19[a]	21[a]	22[a]	23[a]	25
	Astrorhizidae									
1	Rhabdammina	....	......	.....	....	...	...	....	.....	......
	Rhizamminidae									
2	Bathysiphon arenacea Cushman	....	C	.....	....	...	...	....	.....	......
3	Rhizammina indivisa H. B. Brady	....	......	.....	....	...	...	....	.....	......
	Saccamminidae									
4	Saccammina sphaerica M. Sars	....	......	.....	....	...	...	....	.....	R?
5	Proteonina difflugiformis (H. B. Brady)	....	......	.....	....	...	...	....	.....	......
	Hyperamminidae									
6	Saccorhiza ramosa (H. B. Brady)	....	C	.....	....	...	...	....	.....	......
	Reophacidae									
7	Reophax distans H. B. Brady	....	......	.....	....	...	...	....	.....	......
8	Reophax sp.	R?	......	.....	....	...	...	....	.....	......
	Ammodiscidae									
9	Glomosphira gordialis (Jones and Parker)	....	......	.....	....	...	...	....	.....	......
10	Tolypammina vagans (H. B. Brady)	....	......	.....	....	...	...	....	.....	......
	Lituolidae									
11	Haplophragmoides subglosum (G. O. Sars)	....	......	.....	....	...	...	....	.....	......
12	Haplophragmoides sp.	....	......	.....	....	...	...	....	.....	......
13	Cyclammina (?) bradyi Cushman	....	......	.....	....	...	...	....	.....	......
13^{A}	Cribrostomoides bradyi Cushman*	....	......	.....	....	...	...	....	.....	......
	Textulariidae									
14	Spiroplectammina milletti Cushman	....	......	.....	....	...	...	....	.....	......
15	Textularia catenata Cushman	....	......	.....	....	...	...	....	.....	R[b]
	Valvulinidae									
16	Eggerella bradyi (Cushman)	....	......	.....	....	...	...	R*	R	R
17	Dorothia bradyi (Cushman)	....	R	.....	R	...	...	....	.....	.....
	Miliolidae									
18	Quinqueloculina cf. venusta Karrer	....	......	.....	....	...	...	....	.....	A
19	Sigmoilina edwardsi (Schlumberger)	....	......	.....	....	...	...	....	.....	VC[c]
20	Sigmoilina tenuis (Czjzek)	R	......	.....	....	...	...	....	.....	C
21	Triloculina sp.	....	......	.....	....	...	...	....	.....	......
22	Pyrgo depressa (d'Orb.)	R	C	.....	....	...	...	C*	.....	A
23	Pyrgo cf. depressa (d'Orb.)	....	......	.....	R	...	...	....	.....	......
24	Pyrgo cf. elongata (d'Orb.)	....	......	.....	....	...	...	....	.....	......
25	cf. globula (Bornemann)	....	......	.....	....	...	...	....	.....	......
26	murrhina (Schwager) (?)	....	......	.....	....	...	...	....	.....	......
27	sp.	....	......	.....	....	...	...	....	.....	......
	Trochamminidae									
28	Trochammina sp.	....	......	.....	....	...	...	....	.....	......
	Lagenidae									
29	Robulus sp.	....	......	.....	....	...	...	....	.....	......
30	Lenticulina sp.	....	......	.....	....	...	...	....	.....	......
31	Marginulina cf. subcrassa Schwager	....	......	.....	....	...	...	....	.....	......
		....	......	.....	....	...	...	....	.....	......
32	Dentalina costai (Schwager)	....	......	.....	....	...	...	....	.....	......
33	neugeboreni (Schwager)	....	......	.....	....	...	...	....	.....	......
34	pyrula d'Orbigny	R*	......	.....	....	...	...	....	.....	......
35	sp. or Marginulina sp.	....	R?	.....	....	...	...	....	.....	......
36	sp.	R?	......	.....	....	...	...	....	.....	......
37	Lagena acuticosta Reuss	....	......	.....	....	...	...	....	.....	R

in certain *Carnegie* bottom samples

marked with an asterisk (*), which were made by the author

Station														
26	27	29	31	34^a	35^a	36	41	44^a	45^a	59	62	81^a	82	85
.....	.....	......	R*	....	....	.....	.....	.....	.....	VC?	.....	....	....	....
.....	.....	......	R*	....	....	.....	.....	.....	.....	C?	.....	....	R	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	C?	....
.....	.....	......	R*	....	....	.....	.....	.....	.....	C	.....	....	....	....
.....	.....	......	R*	....	....	.....	.....	.....	.....	C	.....	....	R	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	....	....
.....	.....	......	R*	....	....	.....	.....	.....	.....	R	.....	....	....	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	R?	.....	....	....	....
.....	R*	......	C*	....	....	.....	.....	.....	.....	......	.....	R	C	....
.....	.....	......	.....	....	....	R	.....	.....	.....	......	.....	....	....	....
.....	C*	......	C*	....	....	.....	R?	.....	.....	C	.....	....	....	....
.....	.....	......	.....	....	....	.....	R?	.....	.....	......	.....	....	....	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	R*	....	R	....
.....	.....	......	R*	....	....	.....	.....	.....	.....	......	.....	....	....	....
.....	.....	R?	.....	....	....	.....	.....	.....	.....	......	.....	....	....	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	VC	....
.....	R*	......	.....	....	....	.....	.....	.....	R	......	.....	....	R	R
.....	C*	C	R*	....	....	R	.....	.....	.....	......	.....	....	R	....
.....	.....	......	.....	....	....	.....	R*	.....	.....	......	.....	....	....	R
.....	.....	......	.....	.....	....	.....	.....	.....	.....	......	.....	....	....	....
.....	.....	......	R*	....	....	.....	.....	.....	.....	......	.....	....	....	....
.....	C*	......	.....	....	....	.....	.....	R?	.....	......	.....	....	....	....
C	VC*	......	C*	....	....	C	.....	R	C	......	.....	R	R	....
.....	.....	......	R*	....	....	.....	.....	.....	.....	......	.....	....	....	R
.....	.....	R	.....	....	....	.....	.....	.....	.....	......	.....	....	....	....
.....	.....	R	.....	....	....	.....	.....	.....	.....	......	.....	....	....	....
.....	R?*	......	.....	....	....	.....	.....	.....	.....	......	.....	....	R?	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	R?	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	R?	.....	....	....	....
.....	R*	......	R*	....	....	.....	.....	.....	.....	......	R?	....	R?	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	R?	....
.....	.....	......	.....	....	....	R^d	.....	.....	.....	......	.....	....	....	....
.....	.....	......	R*	....	....	.....	.....	.....	.....	......	.....	....	....	....
.....	.....	......	R?*	....	....	.....	.....	.....	.....	......	R?	....	....	....
.....	.....	......	C*	....	....	.....	.....	.....	.....	......	.....	....	C	....
.....	.....	R	.....	....	....	.....	.....	.....	.....	......	.....	....	....	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	....	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	C?	....
.....	R*	......	.....	....	....	.....	.....	.....	.....	......	.....	....	....	....

Table 5. Species of foraminifera identified in

Sample no.	Family and species	Station								
		13^a	14^a	17^a	18^a	19^a	21^a	22^a	23^a	25
	Lagenidae--Concluded									
38	Lagena alveolata H. B. Brady	....	R	.....	....	...	...	....	.....	......
39	alveolata H. B. Brady var. plebeia Cushman	....	......	.....	....	...	...	....	.....	......
40	cf. apiculata Reuss	....	R	.....	....	...	...	....	.....	......
41	auriculata H. B. Brady	....	......	.....	....	...	...	....	.....	......
42	cota Cushman	....	......	.....	....	...	...	....	.....	......
42^A	elongated (Ehrenberg)	....	......	.....	....	...	...	....	.....	......
43	favoso-punctata H. B. Brady	....	......	.....	....	...	...	....	.....	R
44	cf. flintiana Cushman	R	......	.....	....	...	...	....	.....	......
45	formosa Schwager	....	......	.....	....	...	...	....	.....	......
46	globosa (Montagu)	....	......	.....	....	...	...	....	.....	......
47	gracilis Williamson	....	......	.....	....	...	...	....	.....	R
48	hispida Reuss var.	....	......	.....	....	...	...	....	.....	......
49	iota Cushman	....	......	.....	....	...	...	....	.....	......
50	laevis (Montagu)	R	......	.....	....	...	...	....	.....	......
51	lagenoides Williamson	....	......	.....	....	...	...	....	.....	......
52	marginata (Montagu)	....	R	.....	....	...	...	....	.....	......
53	marginata (Montagu) var.	....	......	.....	....	...	...	....	.....	......
54	marginato-perforata (Seguenza)	....	......	.....	....	...	...	....	.....	......
55	orbignyana (Seguenza)	....	R	.....	....	...	...	....	.....	......
56	paradoxa Sidebottom	....	......	.....	....	...	...	....	.....	......
57	plumigera H. B. Brady	....	......	.....	....	...	...	....	.....	......
58	cf. sacculus Fornasini	....	......	.....	....	...	...	....	.....	......
58^A	semiformis Schwager	....	......	.....	....	...	R*	R*	.....	......
59	semistriata Williamson	....	......	.....	....	...	...	....	.....	......
60	staphyllearia (Schwager)	....	......	.....	....	...	...	....	.....	......
61	striata d'Orbigny	....	......	.....	....	...	...	....	.....	R
62	striata (d'Orb.) var. strumosa Reuss	....	......	.....	....	...	...	....	.....	......
63	striata (d'Orb.) var.	....	......	.....	....	...	...	....	.....	R
64	sublaginoides Cushman var. striatula Cushman	....	......	.....	....	...	...	....	.....	R
65	truncata H. B. Brady	....	......	.....	....	...	...	....	.....	......
65^A	sp. (?)	....	......	.....	....	...	...	....	.....	C*
	Polymorphinidae									
66	Glandulina laevigata d'Orbigny	....	......	.....	....	...	...	....	.....	......
67	Pseudopolymorphina sp.	....	......	.....	....	...	...	....	.....	......
68	Pyrulina extensa (Cushman)	....	......	.....	....	...	...	....	.....	......
69	labiata (Schwager)	....	......	.....	....	...	...	....	.....	......
70	sp.	....	......	.....	....	...	...	....	.....	R?
	Nonionidae									
71	Nonion pacificum Cushman	....	R	.....	....	...	...	....	.....	C
72	pompiloides (Fichtel and Moll)	R.	......	.....	C	...	...	....	.....	VC
73	Nonionella auris (d'Orbigny)	....	......	.....	....	...	...	....	.....	R*
	Buliminidae									
74	? cf. Bulimina torta Cushman	....	......	.....	....	...	...	....	.....	R^f
74^A	Bulimina sp.?	....	......	.....	....	...	...	....	.....	......
75	Virgulina complanata Egger	....	......	.....	....	...	...	....	.....	C
76	ms.	....	......	.....	....	...	...	....	.....	R
77	Bolivina seminuda Cushman	....	......	.....	....	...	...	....	.....	......
78	ms.	....	......	.....	....	...	...	....	.....	......
79	Uvigerina proboscidea Schwager	C	VC	.....	....	...	...	....	.....	......
80	proboscidea Schwager var. ms.	....	R	.....	....	...	...	R*	.....	......
81	sp.	....	......	.....	....	...	...	A*	R?	A?
	Ellipsoidinidae									
82	Ellipsolagena sp.	....	......	.....	....	...	...	....	.....	......
	Rotaliidae									
83	Valvulineria ms.	....	......	.....	....	...	...	....	.....	......
84	sp.	....	......	.....	....	...	...	....	.....	......
85	Gyroidina soldanii d'Orbigny	R	C	R*	....	...	...	C*	.....	R

certain Carnegie bottom samples--Continued

Station														
26	27	29	31	34^a	35^a	36	41	44^a	45^a	59	62	81^a	82	85
.....	.....	......	R*	....	....	.....	.....	.....	.....	......	.....	....	....	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	R	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	....	....
.....	.....	......	R*	....	....	.....	.....	.....	.....	......	.....	....	R*	....
.....	.....	......	.....	....	....	R	.....	.....	.....	......	.....	....	....	....
.....	.....	......	R*	....	....	.....	.....	.....	.....	......	.....	....	....	....
.....	R*	......	.....	....	....	.....	.....	.....	.....	......	.....	....	....	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	R*	....
.....	.....	......	.....	....	....	.....	.....	R?*	.....	......	.....	....	C	....
.....	.....	......	R*	....	....	.....	.....	.....	.....	......	.....	....	R	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	....	....
.....	.....	......	.....	....	....	.....	R	.....	.....	......	.....	....	....	....
R	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	....	....
.....	.....	......	R*	....	....	.....	.....	.....	.....	......	.....	....	R	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	R	....
.....	R*	......	R*	....	....	R	.....	.....	.....	......	.....	....	R	....
.....	.....	R	.....	....	....	.....	R	.....	.....	......	.....	....	C	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	C	....
.....	R*	......	R*	....	....	.....	.....	.....	.....	......	.....	....	R*	....
.....	.....	......	R*	....	....	.....	R	.....	.....	......	.....	....	R	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	R	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	C*	....
.....	R*	......	R*	....	....	.....	.....	.....	.....	......	.....	....	....	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	R	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	R	....
.....	R*	......	.....	....	....	.....	.....	.....	.....	......	R	....	C	....
.....	R*	......	.....	....	....	R	.....	.....	.....	......	.....	....	R	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	....	....
.....	.....	......	.....	....	....	R	.....	.....	.....	......	.....	....	....	....
.....	R*	......	.....	....	....	.....	.....	.....	.....	......	R	....	R*	....
.....	C*	......	R*	....	....	.....	.....	.....	.....	......	.....	....	R*	....
.....	.....	C?	.....	....	....	.....	.....	.....	.....	......	.....	....	....	....
.....	.....	......	.....	....	....	.....	R?	.....	.....	......	.....	....	....	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	R^e	....
.....	.....	......	.....	....	....	.....	R	.....	.....	......	.....	....	....	....
.....	R*	......	C*	....	....	R	.....	.....	.....	......	R?	....	C?	....
.....	R*	......	A*	....	....	R	R	.....	.....	......	.....	....	C	R
R	C*	......	R*	....	....	R	C	.....	.....	......	.....	....	VC	R
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	....	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	....	....
.....	C*	......	R*	....	....	.....	.....	.....	.....	......	.....	....	....	....
.....	.....	......	C*	....	....	.....	.....	.....	.....	......	.....	....	C	....
R	.....	......	.....	....	....	.....	.....	.....	.....	......	R	....	R	....
.....	.....	......	C*	....	....	.....	.....	.....	.....	......	.....	....	R?	....
.....	R*	......	R*	....	....	.....	.....	.....	.....	......	.....	....	R	....
.....	.....	......	.....	....	....	C	.....	.....	.....	......	.....	....	....	....
.....	R*	A	A*	....	....	C	.....	.....	.....	......	A	....	....	....
.....	A*	A?	.....	....	....	C?	.....	.....	.....	......	R?	....	....	....
.....	.....	R?	.....	....	....	.....	.....	.....	.....	......	.....	....	....	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	A	....
.....	.....	......	R*	....	....	.....	.....	.....	.....	......	.....	....	....	....
C	C*	C	C*	....	....	.....	.....	.....	R	......	.....	....	....	R

Table 5. Species of foraminifera identified in

Sample no.	Family and species	Station								
		13^a	14^a	17^a	18^a	19^a	21^a	22^a	23^a	25
	Rotaliidae--Concluded									
86	Gyroidina soldanii var.	....	......	.....	....	...	...	....	.....	......
87	Eponides bradyi Cushman	....	......	.....	....	...	...	....	.....	C
88	tenera (H. B. Brady)	R	R	.....	....	...	...	A*	.....	C
89	ms.	....	......	.....	....	...	...	....	.....	R
90	sp.	....	R?	.....	....	...	...	....	.....	......
	Cassidulinidae									
91	Pulvinulinella exigua (H. B. Brady)	....	......	.....	....	...	...	....	.....	......
92	pacifica Cushman	....	......	.....	....	...	...	....	.....	A
93	ms.	....	......	R*	....	...	...	....	.....	A
94	Cassidulina decorata Sidebottom	....	......	.....	....	...	...	....	.....	......
95	fava (H. B. Brady)	....	C	.....	....	...	...	....	.....	C
96	pulchella d'Orbigny	....	......	.....	....	...	...	....	.....	R
97	cf. quadrata Cushman and Hughes	....	......	.....	....	...	...	....	.....	......
98	subglobosa H. B. Brady	R	......	.....	....	...	...	....	R?	......
99	ms.	....	......	.....	....	...	...	....	.....	......
100	sp.	....	......	.....	....	...	...	....	.....	A
101	Ehrenbergina bradyi Cushman	....	......	.....	....	...	...	R*	.....	R
102	n. sp.	....	......	.....	....	...	...	....	.....	......
	Chilostomellidae									
103	Allomorphina trigona Reuss	....	......	.....	....	...	...	....	.....	......
104	Chilostomella colina Schwager	R	......	.....	....	...	...	....	.....	......
105	Pullenia bulloides (d'Orb.)	....	R	.....	....	...	...	R*	.....	VC
106	quadriloba Reuss	....	......	.....	....	...	...	....	.....	......
107	quinqueloba (Reuss)	....	......	.....	....	...	...	....	.....	......
108	salisburyi R. E. and K. C. Stewart	....	......	.....	....	...	...	....	.....	R
109	sphaeroides (d'Orb.)	....	......	.....	....	...	...	....	.....	......
110	Sphaeroidina bulloides d'Orbigny	....	......	.....	....	...	...	....	.....	......
	Globigerinidae									
111	Globigerina bulloides d'Orbigny	....	......	.....	....	...	...	VC?*	C*?	VC?
112	conglomerata Schwager	A*	A*	A*	C*	C*	A*	A*	A*	A
113	cf. inflata d'Orbigny							VC*	C	VC
114	rotundata d'Orbigny							C*	C	A
115	sp. ms.	....	......	.....	....	...	...	....	.....	......
116	sp.	....	......	.....	....	...	...	....	.....	......
117	Globigerinoides conglobata (H. B. Brady)	A*	C*	A*	A*	A*	A*	A*	C*	VC
118	cf. rubra (d'Orb.)	....	......	.....	R	...	...	....	.....	R
119	sacculifera (H. B. Brady)	C*	R*	C*	C*	C*	...	....	C*	VC
120	n. sp. (?)	....	......	.....	....	...	...	....	.....	......
121	Globigerinella aequilateralis (H. B. Brady)	....	R*	.....	C*	...	...	R*	.....	......
122	digitata (?) (H. B. Brady)	....	......	.....	R?	...	...	....	.....	R
123	sp.	....	......	.....	....	...	...	....	.....	......
124	Orbulina universa d'Orbigny	R*	R*	VC*	C*	C*	C*	VC*	C*	R*
125	Pulleniatina obliquiloculata (Parker and Jones)	C*	R*	.....	....	...	...	R*	C*	R
126	Candeina nitida d'Orbigny	....	......	.....	....	...	...	....	.....	......
127	Sphaeroidinella dehiscens (Parker and Jones)	....	R*	.....	R*	R*	...	....	.....	R*
	Globorotaliidae									
128	Globorotalia hirsuta (d'Orbigny)	R	......	.....	....	...	...	....	.....	......
129	menardii (d'Orbigny)	C*	C*	.....	R*	...	C*	....	.....	C
130	truncatulinoides (d'Orb.)		......	.....	A*	A*	A*	A*	A*	A
131	tumida (H. B. Brady)		VC*	.....	R*	...	C*	A*	.....	C
132	sp.	....	......	R*	R?	...	...	....	.....	A?
133	ms.	....	......	.....	....	...	...	....	.....	......
	Anomalinidae									
134	Laticarinina pauperata (Parker and Jones)	R	C	.....	C	R*	R*	....	.....	R

certain Carnegie bottom samples--Continued

Station														
26	27	29	31	34[a]	35[a]	36	41	44[a]	45[a]	59	62	81[a]	82	85
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	R	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	....	....
R	A*	C	A*	....	....	R?	.....	.....	R	......	C	R	VC	R
.....	R*	......	R*	....	....	.....	.....	.....	.....	......	C	....	R	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	C?	....	R?	R?
.....	.....	R	.....	....	....	.....	.....	.....	.....	......	.....	....	....	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	....	....
.....	A*	......	A*	....	....	.....	C	VC	.....	......	A	R	A	....
.....	R	R	.....	....	....	.....	.....	.....	.....	......	.....	....	....	....
C	R*	......	.....	....	....	C	.....	.....	.....	......	.....	R	A	....
.....	VC*	......	.....	....	....	.....	.....	.....	.....	......	.....	....	....	....
.....	.....	......	.....	....	....	.....	.....	.....	R	......	R	R	....	....
R	R*	R	R*	....	....	R	.....	.....	.....	......	R	....	R	....
.....	.....	......	R*	....	....	R	.....	.....	.....	......	.....	....	VC	....
.....	C*	......	.....	....	....	.....	.....	.....	.....	......	.....	....	....	....
R	.....	VC	R*	....	....	R	.....	.....	.....	......	.....	....	....	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	C	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	R	.....	....	....	....
.....	R*	......	C*	....	....	.....	.....	.....	.....	......	R	R	....	....
.....	C*	......	A*	....	....	R	C	.....	.....	......	VC	....	....	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	....	R
.....	.....	......	C*	....	....	R	R	.....	.....	......	VC	....	R	R
.....	R*	R	.....	....	....	R	.....	.....	.....	......	.....	....	C	....
.....	.....	......	R*	....	....	.....	.....	.....	.....	......	.....	....	VC	....
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	R?	....
.....	R*?	C?	.....	....	....	.....	.....	.....	.....	......	.....	....	....	....
A*	A*	VC	VC*	....	....	C	C*	A*	A*	......	A*	R?	VC	C*
C*	R*	A	C*	C*	R*	A*	A*			......	.....	....	R*	....
VC*	A*	A	.....	R*	R*	.....	.....			......	.....	....	C*	A
.....	.....	......	.....	....	....	R?	.....	.....	.....	......	.....	....	....	....
.....	.....	......	.....	....	....	R?	R?	.....	.....	......	.....	....	....	....
A*	A*	A	C*	R*	R*	VC*	A	VC*	VC*	R*	.....	....	C	A
.....	.....	R	.....	....	....	.....	.....	.....	.....	......	.....	....	....	....
VC*	.....	C	.....	C*	....	R*	VC*	C*	C*	R*	.....	....	C	VC
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	....	A[g]
.....	.....	C	.....	....	....	.....	C*	.....	C*	......	.....	....	C	C
.....	.....	......	.....	....	....	.....	R	.....	.....	......	.....	....	....	C
.....	.....	......	.....	....	....	.....	C?	.....	.....	......	.....	....	....	....
R*	R*	C*	R*	R*	....	C*	C*	C*	R*	......	.....	R*	R*	C*
R*	R*	R*	R*	....	....	A*	VC*	VC*	VC*	......	VC*	C*	A*	C*
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	....	....
R*	R*	R*	R*	....	....	C*	C*	C*	C*	......	.....	R*	R*	C*
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	....	....
VC*	C*	VC*	R*	R*	R*	A*	.....	C*	C*	......	.....	....	C	C
A*	A*	A	.....	....	....	.....	C*	.....	.....	......	.....	....	....	....
VC*	C*	C*	VC*	....	....	VC*	VC*	A*	A*	......	.....	A*	A	C
.....	A*	R?	.....	R*	....	.....	.....	.....	.....	......	.....	....	....	....
.....	.....	......	.....	....	....	.....	C	.....	.....	......	.....	....	....	....
.....	A*	C	C*	R*	....	.....	.....	.....	.....	......	.....	....	....	....

Table 5. Species of foraminifera identified in

Sample no.	Family and species	Station								
		13[a]	14[a]	17[a]	18[a]	19[a]	21[a]	22[a]	23[a]	25
	Anomalinidae--Concluded									
135	Laticarinina ?	....	......	.....	....	...	...	......	.....	......
136	Cibicides sp.	R*	VC ?	R*	C ?	R*	C	A*	R ?	A ?

The symbols for abundance (A, VC, C, and R) have different meanings for pelagic and benthonic species: For pelagic species, A = more than 10 to 15 per cent of coarser sand grades; VC = 5 to 15 per cent; C = 1 to 5 per cent; R = <1 per cent. For benthonic species, these letters refer to number of individuals seen, e.g.: A = more than 10 individuals; VC = 5 to 10; C = 2 to 5; R = 1 or 2.

Table 6. Sponge fragments in the samples

Sample	Station												
	14	25	27	29	31	34	35	49	59	72	79	81	82
Class Hexactinellida													
Order Hexasterophora[a]													
Fragments, normal dictyonine mesh	..	x	..	x	..	..	..	..	..	..	..	..	..
Fragments, dictyonine mesh with clavate protusions	..	..	..	..	..	..	..	..	..	..	x	..	..
Normal spicules	..	..	..	..	x	..	x	..	..	..	..	..	..
Typical oxeasters	..	..	..	..	..	..	..	..	..	..	x	..	..
Rhabds, more or less acanthose	x	x	x	x	x	..	x	..	x	x	..	x	..
Class Demospongia													
Order Choristida													
Spicule types:[b]													
Oxea	..	..	..	x	..	x	..	..	..	..	..	..	..
Rhabds, possibly oxeate	..	..	x	..	x	x	..	..	..	..	..	..	x
Protriaene	..	..	..	..	x	..	..	..	..	..	..	..	..
Anatriaene	..	..	..	..	x	..	x	..	..	..	..	..	..
Dichotriaene	x	x	x	..	x	x	x	..	..	x	..	..	..
Asters (not quite typical because somewhat flattened)	..	..	..	..	x	..	..	..	..	..	..	..	..

[a] Besides these fragments, which are definitely from sponges, there are also fragments which may be parts of radiolarian skeletons. [b] All these spicules could be from the same species and any one of them could have been from any species of the entire order. It is impossible even to assign families. Besides these known spicules there are certain structures in sample 79 which may be chemical in origin or from some other phylum, but which, if sponge, must be the so-called spherasters, characteristic of the family Geodiidae.

certain Carnegie bottom samples--Concluded

Station														
26	27	29	31	34[a]	35[a]	36	41	44[a]	45[a]	59	62	81[a]	82	85
.....	.....	......	.....	....	....	.....	.....	.....	.....	......	.....	....	....	....
R?	A*	......	A*	....	....	R	.....	.....	.....	......	.....	R*	C*	R*

[a] Complete lists of only the pelagic species are given. [b] Cushman, J. A., U. S. Nat. Mus., Bull. 71, p. 23, 1910. [c] Ibid., Bull. 161, pt. 1, pl. 11, fig. 9, 1932. [d] Ibid., pt. 2, pl. 2, fig. 11, 1932. [e] Cushman, J. A., and Y. Ozawa, U. S. Nat. Mus., Proc., vol. 77, pl. 12, fig. 5, 1930. The specimen in this sample is fragmentary. [f] Cushman, loc. cit., Bull. 71, pt. 2, p. 81, 1911. [g] Possibly a new species.

Table 7. Ostracods in the samples

Specimen	Sample number										
	17	18	23	25	26	27	29	31	36	41	82
Genus Cythereis Sens. strict.	..	C	..	FC	..	..	C	..	..	..	..
Subgenus, indet.	x	..	x	C	x	..	..	..	..	..	x
Shells of young individuals, probably moulted	..	..	..	..	..	x	..	..	x	x	..
Genus Krithe	..	C	..	..	..	..	..	..	..	..	..
Genus not determined	..	..	..	x	..	..	..	x	..	..	..

CHEMICAL ANALYSES

General

Partial chemical analyses were carried out on forty-six samples, of which forty-three are from the Pacific, including twenty south Pacific Globigerina oozes, nine northeast Pacific red clays, four siliceous oozes collected northeast of Japan, two south Pacific red clays, four terrigenous deposits, two radiolarian oozes from the central Pacific, and two shallow-water deposits, one from the harbor of Callao and the other a calcareous beach sand from Easter Island. Determinations of SiO_2, TiO_2, Al_2O_3, total iron (as Fe_2O_3), MnO_2, MgO, CaO, Na_2O, K_2O, P_2O_5, ZrO_2, and acid-soluble CaO and MgO were made by the Sharp-Schurtz Company of Lancaster, Ohio, who also determined the amounts of chloride (Cl) in twelve of the samples. Dr. Parker D. Trask determined the amounts of organic nitrogen (N) in the samples, and Miss Esther C. Allen and the writer determined the percentage of carbon dioxide in certain of them (see table 8). Spectrographic analyses (for boron, barium, and other elements) of all the samples mentioned above, together with about thirty others, were made by Mr. George Steiger. Dr. C. S. Piggot made determinations of the content of radioactive substances in twenty-eight samples. The results obtained by Dr. Piggott and Dr. Trask have been published already (see Trask [1932] and Piggott [1933]).

The results of the chemical analyses are shown in table 9 which gives, in addition to the analytical values for the substances above mentioned, calculated values for organic carbon, water, chloride, sulfate, and carbon dioxide.

When the samples were received in Washington from the Carnegie, they were divided and the separate parts were sent to Drs. Trask and Piggott for analysis. Most of the remaining samples were sent to the Scripps Institution in 1930. After arrangements had been made between Dr. Fleming and Dr. Vaughan for the carrying out of chemical analyses, the samples of sufficient size for analysis were again roughly quartered by Mr. Alfred Barker and parts sent to the Sharp-Schurtz Company. During these processes of division of the samples, some washing apparently took place, as the amounts of chloride found in them are usually much less than might be expected from Gebbing's (1909) analyses of deep-sea clays.

The parts received by the Sharp-Schurtz Company in 1931 were quite moist or were suspended in water. Their report on the procedure of analysis is as follows:

"These samples individually were completely transferred to platinum dishes, evaporated to dryness on a steam bath and finally dried completely in an air bath at 110° C. They then were transferred individually to an agate mortar, powdered, thoroughly mixed, and returned to the original containers. Before analysis all samples were dried at 110° C to constant weight. For the separation and determination of silicon dioxide, aluminium oxide, titanium dioxide, zirconium dioxide, calcium oxide, and magnesium oxide, the methods described by Hillebrand and Lundell (1929, pp. 862-868) were followed closely, with the exception that the filtrate from the R_2O_3 group was given a preliminary treatment with ammonium persulphate to remove the manganese that otherwise would be carried down by both the calcium and magnesia.

"The alkalies, (Na_2O) and (K_2O), were determined by the J. Lawrence Smith method on a separate portion. Manganese was determined on a separate portion by the bismuthate method. Phosphorus pentoxide was precipitated on a separate portion as ammonium phosphomolyb-

Table 8. Comparison of $CaCO_3$ determinations made by direct measurement of CO_2 and by determination of acid-soluble CaO

1	2	3	4	5	6	7	8	9	10
Sample no.	Per cent CO_2 found	Per cent deviation between duplicate determinations	Per cent acid-soluble CaO	Per cent total CaO	Per cent $CaCO_3$ calculated from per cent CO_2	Per cent $CaCO_3$ calculated from per cent acid-soluble CaO	$\Delta CaCO_3$ = col. 7 - col. 6	Per cent $CaCO_3$ calculated from per cent total CaO	$\Delta CaCO_3$ = col. 9 - col. 6
13	29.27	0.06	36.79	37.79	66.56	65.66	-0.90	67.44	+0.88
31	8.66	0.59	10.01	11.04	19.69	17.86	-1.83	19.70	+0.01
44	33.15	1.22	41.92	42.44	75.38	74.82	-0.56	75.74	+0.36
62	3.24	0.09	3.42	4.12	7.37	6.10	-1.27	7.35	-0.02
72	0.48	0.03	0.32	0.77	1.09	0.57	-0.52	1.37	+0.28
80	0.16	0.12	1.16	2.32	0.36	2.07	+1.71	4.14	+3.78
81	16.87	no dupl.	22.35	23.12	38.36	39.89	+1.53	41.26	+2.90
85	41.39	0.92	52.96	53.86	94.12	94.51	+0.39	96.12	+2.00
Average							-0.18		+1.28
Average deviation		0.43					1.09		1.28

A large part of the deviations in columns 8 and 10 may be owing to errors of sampling, since different parts of the original unground, undried samples were taken for the CO_2 determinations (made in La Jolla) and the CaO determinations (made by Sharp-Schurtz Co.)

date and determined by the alkalimetric method. Total iron oxide was determined on a separate portion by the potentiometric method. In determining the acid soluble calcium and magnesia, a separate portion was treated with 10 per cent hydrochloric acid until effervescence ceased. It was then filtered and the usual procedure followed."

Molecular Ratios

Owing to the varying amounts of calcium carbonate, sea salts, and water present in the samples, the most satisfactory way of making comparisons between different analyses and with the results of other workers on fine-grained sediments and soils, is by calculation of the molecular ratios between various constituents, namely, the ratios of silica to the combined sesquioxides of iron and alumina and to each one of these individually, the ratios between the two sesquioxides themselves, the ratios between silica and the total bases, the ratios of sesquioxides to total bases, and the ratios between the bases. These ratios are given in table 10, and represent values obtained after attempted elimination of calcium carbonate, and of the bases present as soluble sea salts. It may be seen that most of the samples analyzed can be classified in the following groups corresponding to deposit types and location: (1) a group of ten clays from the northeast Pacific, samples 61 to 77; (2) five siliceous sediments collected northeast of Japan, samples 56 to 60; (3) five south Pacific clays, samples 31 to 35; (4) a group of fourteen normal and ferruginous Globigerina oozes from the southeast Pacific, samples 16 to 29, and 41 to 45; (5) four siliceous Globigerina oozes from the southeast and central Pacific, samples 13, 14, 81, and 82; (6) two radiolarian oozes from the central Pacific, samples 79 and 80. Average and extreme values of the ratios for each one of these groups are given in table 11.

The group of northeast Pacific clays is very uniform in chemical composition, the extreme silica sesquioxide ratios deviating by only 3 per cent from the average value of about 4.0. In these clays alumina is the principal sesquioxide, there being nearly four times as much alumina as ferric oxide. The ratio between silica and total bases of approximately 7, though rather narrow, is close to that of certain soils. The sum of the divalent bases is greater than that of monovalent bases. Magnesium is the principal divalent base, and the amount of potassium is nearly twice that of sodium.

Owing to the presence of acid volcanic glass, and of colloidal hydrated silica in the skeletons of siliceous organisms, the average silica sesquioxide ratio of the siliceous volcanic mud and more or less volcanic siliceous oozes collected northeast of Japan is about 6, which is considerably higher than in the northeast Pacific clays. This ratio, however, is remarkably constant in view of the marked differences, corresponding to distance from shore, in the relative amounts of siliceous organisms and volcanic debris in these samples. Sample 56, for example, probably contains more than 50 per cent of volcanic material, whereas sample 60 consists very largely of the remains of siliceous organisms and clays. It would seem logical to infer that silica leached out during the process of subaerial or submarine weathering of volcanic material, similar to that present in sample 56, has been utilized by marine organisms whose dead skeletons, fallen to the bottom, have restored the silica to the deposits. Although sample 60 represents a profound physical alteration of the original volcanic debris present in sample 56, there has been only a small net change in chemical composition.

In these siliceous muds and oozes, as in the northeast Pacific clays, the molecular amount of alumina is about four times that of ferric oxide. There are twice as many molecules of divalent as of monovalent bases; sodium and potassium are present in about equal proportions; there is more than twice as much magnesium as calcium.

The siliceous oozes from the central Pacific differ in several respects from those from the northwest Pacific. The silica sesquioxide ratio is again nearly 6, and the molecular amount of alumina is about three times that of ferric oxide; but the ratio of silica to total bases is relatively very low. Calcium and magnesium make up about two-thirds of the bases. There is more than twice as much potassium as sodium and more than four times as much magnesium as calcium.

The three south Pacific clays selected for analysis contain considerable amounts of siliceous organic remains and this is reflected in the average silica sesquioxide ratio of more than 5. There are again about four times as many molecules of alumina as of ferric oxide; the ratio of silica to total bases is somewhat wider than in any other sediments analyzed, owing to the very low magnesium content of sample 34. Calcium and magnesium are present in only slightly greater amounts than sodium and potassium, and there is a slight excess of potassium over sodium. There is about three times as much magnesium as calcium in samples 31 and 35.

In the group of normal and ferruginous Globigerina oozes from the south Pacific the silica sesquioxide ratio never exceeds 3.23 and in several cases is less than 1.5. In other words, the noncalcareous parts of some of these samples, far from being similar to red clays even of the same region, are almost lateritic in composition. Three possible explanations suggest themselves for the observed composition of the noncalcareous material. (1) It may be in part lateritic soil material, so characteristic of the tropics, which has been carried in suspension from land and deposited with the shells of pelagic foraminifera. That not all the material has originated in this manner is shown from the fact that the red clays of this same region do not have as low silica sesquioxide ratios as the Globigerina oozes. (2) It may represent the residue of submarine weathering of volcanic and other deposits under the alkaline conditions presumably present in the $CaCO_3$-saturated interstitial water of the Globigerina ooze. (3) The alkaline condition referred to may have been favorable especially for the precipitation from solution or colloidal suspension of ferric and manganese oxides, and to some extent of free alumina. It is noteworthy that the molecular amount of iron oxide is about three times that of alumina. The calculation of the silica-base ratios and the ratios of divalent to monovalent bases could not be carried out successfully, owing to the difficulty of eliminating all the carbonate calcium. It may be seen, however, that the average ratio of sodium to potassium is about unity. Magnesium probably makes up at least two-fifths of the total divalent bases.

The average silica sesquioxide ratio of the four siliceous Globigerina oozes which were analyzed, is very high. Alumina is the principal sesquioxide present; sodium and potassium are present in about equal amounts; at least two-fifths of the total divalent bases after

Table 9. Partial chemical analyses

Constituent	1^{b}	2^{b}	9^{b}	10	13	14	16	17
SiO_2^{a}	16.78	65.00	25.84	47.22	21.80	14.08	1.62	5.68
TiO_2^{a}	0.23	1.23	0.29	0.86	0.06	0.02	0.03	0.16
$Al_2O_3^{a}$	5.74	9.03	9.51	15.08	1.49	0.60	0.28	2.19
Total iron as $Fe_2O_3^{a}$	2.04	8.48	3.44	8.04	1.22	1.50	3.24	8.44
MnO_2^{a}	0.12	0.13	0.18	1.79	0.71	0.53	1.42	3.15
MgO^{a}	1.13	3.34	0.60	2.67	0.44	0.56	0.23	1.40
CaO^{a}	38.39	5.75	28.74	2.26	37.79	43.28	50.06	41.57
Na_2O^{a}	0.17	1.46	0.76	1.22	0.32	0.58	0.14	0.12
K_2O^{a}	0.99	1.40	0.98	1.09	0.27	0.26	0.17	0.34
$P_2O_5^{a}$	0.09	0.22	n.d.	n.d.	0.11	0.17	0.22	0.43
ZrO_2^{a}	0.04	0.18	0.10	0.32	0.14	0.08	0.06	0.04
CO_2^{c}	29.76	1.02	21.35	1.41	29.27^{m}	33.71	38.46	32.44
N^{d}	0.07	n.d.	0.13	0.37	0.06	0.06	0.03	0.02
Organic carbon[e] (calculated)	0.70	....	1.30	3.70	0.60	0.60	0.30	0.20
Organic matter[f] (calculated)	1.33	....	2.47	7.03	1.14	1.14	0.57	0.38
Cl^{g}	0.10^{n}	....	0.43^{n}	0.33^{p}	0.18^{n}	0.27^{a}	0.08^{n}	0.07^{n}
SO_4^{h} (calculated)	0.02	....	0.06	0.05	0.03	0.04	0.01	0.01
Total (not including N and organic carbon)	96.93	(97.24)	94.75	89.37	94.97	96.82	96.59	96.42
H_2O (by difference)[i]	3.07	....	5.25	10.63	5.03	3.18	3.41	3.58
B^{j}	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Ba^{j}	<0.05	n.f.	n.f.	>0.05	>0.05	>0.05	>0.05	>0.05
Ra^{k}(gms per gm, x 10^{12})	1.80	n.d.	n.d.	n.d.	7.84	5.96	3.64	n.d.
CaO acid sol.[a]	37.92	1.30	27.20	1.80	36.79	42.96	49.02	41.34
MgO acid sol.[a]	0.67	0.87	0.52	2.50	0.38	0.42	0.15	0.15

Constituent	35	36	41	44	45	56	57	58
SiO_2^{a}	56.88	2.72	1.86	7.66	1.20	60.18	60.66	61.36
TiO_2^{a}	0.51	0.04	0.01	0.16	0.04	0.48	0.57	0.54
$Al_2O_3^{a}$	14.47	0.74	0.22	3.04	1.03	13.62	13.48	15.61
Total iron as $Fe_2O_3^{a}$	6.04	0.51	2.63	4.42	0.78	5.88	5.92	4.64
MnO_2^{a}	0.70	0.18	0.72	1.69	0.34	0.10	0.31	0.47
MgO^{a}	1.75	0.27	0.30	0.97	0.05	2.32	2.41	2.35
CaO^{a}	1.42	51.25	50.52	42.44	52.70	4.20	2.06	1.93
Na_2O^{a}	1.92	0.06	0.19	0.81	0.23	1.12	1.90	1.38
K_2O^{a}	2.71	0.15	0.08	0.74	0.12	1.92	2.32	1.97
$P_2O_5^{a}$	0.30	0.11	0.18	0.86	0.21	0.11	0.13	0.15
ZrO_2^{a}	tr	n.f.	0.06	0.04	0.08	0.10	0.02	tr
CO_2^{c}	0.40	40.00	39.44	33.15^{m}	41.16	1.72	0.46	0.50
N^{d}	0.09	0.04	0.02	0.02	0.02	0.13	0.12	0.11
Organic carbon[e] (calculated)	0.90	0.40	0.20	0.20	0.20	1.30	1.20	1.10
Organic matter[f] (calculated)	1.71	0.76	0.38	0.38	0.38	2.47	2.28	2.09
Cl^{g}	0.52^{p}	0.03^{n}	0.11^{n}	0.56^{a}	0.13^{n}	0.31^{p}	0.52^{p}	0.38^{p}
SO_4^{h} (calculated)	0.07	tr	0.02	0.08	0.02	0.04	0.07	0.05
Total (not including N and organic carbon)	89.40	96.82	96.72	97.00	98.47	94.58	93.11	93.42
H_2O (by difference)[i]	10.60	3.18	3.28	3.00	1.53	5.42	6.89	6.58
B^{j}	<0.05	n.f.	n.f.	n.f.	n.f.	>0.05	>0.05	>0.05
Ba^{j}	>0.05	>0.05	>0.05	>0.05	>0.05	n.f.	n.f.	n.f.
Ra^{k}(gms per gm, x 10^{12})	n.d.	n.d.	n.d.	n.d.	n.d.	1.88	4.12	4.76
CaO acid sol.[a]	0.51	50.97	50.26	41.92	52.45	2.20	0.58	0.64
MgO acid sol.[a]	1.44	0.25	0.27	0.58	0.04	1.09	1.41	1.28

of Carnegie bottom samples

Sample number										
18	19	21	22	23	25	26	27	29	31	34
Values in per cent										
0.78	1.50	1.72	16.58	7.38	6.92	2.42	22.78	0.40	47.02	57.66
0.02	0.05	0.06	0.29	0.13	0.04	0.06	0.45	0.03	0.47	0.59
0.13	0.53	0.41	5.41	2.50	2.29	0.53	8.82	0.09	12.57	16.32
0.49	4.40	5.28	14.96	4.68	5.72	1.16	8.44	0.19	5.12	6.32
0.17	1.44	1.77	5.01	1.98	1.87	0.38	2.15	0.07	0.22	0.59
0.18	1.30	1.82	1.63	0.99	0.93	0.22	1.97	0.09	2.17	0.38
53.46	48.90	47.77	24.22	44.02	42.70	51.35	25.12	53.24	11.04	1.42
0.28	0.03	0.18	0.86	0.14	0.46	0.17	1.38	0.11	1.43	1.91
0.05	0.10	0.16	0.98	0.47	0.34	0.19	0.76	0.24	2.14	2.62
0.10	0.26	0.25	0.64	0.27	0.33	0.09	0.43	0.09	0.22	0.21
0.04	0.02	0.10	0.24	0.02	0.08	n.f.	0.08	0.08	0.14	n.f.
41.52	38.02	37.06	18.55	33.11	32.75	39.90	18.76	41.52	8.66[m]	0.11
0.02	0.02	0.03	0.02	0.05	0.03	0.03	0.03	0.03	0.14	n.d.
0.20	0.20	0.30	0.20	0.50	0.30	0.30	0.30	0.30	1.40	....
0.38	0.38	0.57	0.38	0.95	0.57	0.57	0.57	0.57	2.66	....
0.40[a]	0.01[n]	0.09[n]	0.27[a]	0.08[n]	0.39[a]	0.10[n]	0.53[a]	0.06[n]	0.39[p]	0.28[a]
0.06	tr	0.01	0.04	0.01	0.05	0.02	0.07	0.01	0.06	0.04
98.06	96.94	97.25	90.06	96.73	95.44	97.16	92.31	96.79	94.31	(88.45)
1.94	3.06	2.75	9.94	3.27	4.56	2.84	7.69	3.21	5.69	....
n.d.	n.d.	n.f.	>0.05	n.f.	n.f.	n.f.	>0.05	>0.05	>0.05	<0.05
>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05
5.00	n.d.	n.d.	n.d.	3.20	4.40	3.40	3.96	1.92	n.d.	n.d.
52.90	48.45	47.22	23.64	42.19	41.73	50.84	23.90	52.90	10.01	0.14
0.12	1.24	1.64	0.86	0.84	0.60	0.02	1.33	0.03	1.42	0.36

Sample number										
59	60	61	62	64	65	66	69	70	72	73
Values in per cent										
60.14	60.40	55.02	49.36	52.94	52.76	53.44	54.50	54.12	55.52	54.68
0.53	0.51	0.80	0.79	0.79	0.82	0.81	0.82	0.85	0.77	0.71
13.01	12.71	18.20	15.82	16.67	16.93	17.26	18.19	18.66	18.67	18.98
5.96	6.08	7.52	7.84	8.56	8.48	8.04	7.92	8.16	6.80	7.04
0.91	0.82	1.60	1.40	0.64	0.88	0.89	0.63	0.61	0.29	0.44
2.34	2.37	2.58	2.60	3.78	3.62	3.65	2.51	2.53	2.47	2.55
1.87	2.06	1.26	4.12	0.84	1.03	0.64	0.90	0.97	0.77	0.97
1.97	1.85	1.68	1.98	1.62	1.71	1.55	1.50	1.38	1.54	1.56
2.04	2.30	3.24	2.60	2.89	2.88	3.42	3.48	3.48	3.44	3.44
0.12	0.14	0.23	0.17	0.18	0.13	0.17	0.17	0.19	0.12	0.11
n.f.	0.02	0.08	0.10	0.08	0.06	0.08	0.12	0.20	0.24	0.18
0.20	0.41	0.46	3.24[m]	0.25	0.20	0.30	0.35	0.46	0.48[m]	0.32
0.12	0.09	0.08	0.10	0.10	0.08	0.10	0.07	0.10	0.10	n.d.
1.20	0.90	0.80	1.00	1.00	0.80	1.00	0.70	1.00	1.00	....
2.28	1.71	1.52	1.90	1.90	1.52	1.90	1.33	1.90	1.90	....
0.54[p]	0.50[p]	0.46[p]	0.52[a]	0.44[p]	0.47[p]	0.42[p]	0.41[p]	0.38[p]	0.46[a]	0.43[p]
0.08	0.07	0.07	0.07	0.06	0.07	0.06	0.06	0.05	0.06	0.06
91.99	91.95	94.72	92.51	91.64	91.56	92.73	92.89	93.94	93.53	(91.47)
8.01	8.05	5.28	7.49	8.36	8.44	7.27	7.11	6.06	6.47	....
n.f.	>0.05	>0.05	>0.05	n.f.	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05
>0.05	<0.05	n.f.	<0.05	>0.05	>0.05	n.f.	<0.05	n.f.	n.f.	>0.05
7.12	3.00	3.08	9.60	5.80	10.40	8.96	9.48	10.40	n.d.	n.d.
0.26	0.52	0.58	3.42	0.32	0.26	0.38	0.45	0.58	0.32	0.40
1.28	1.50	2.15	1.19	2.70	2.63	2.32	1.74	1.94	1.93	2.15

Table 9. Partial chemical analyses of Carnegie bottom samples--Concluded

Constituent	Sample number							
	77	79	80	81	82	85	88	89
	Values in per cent							
SiO_2[a]	54.08	57.84	52.48	34.66	5.28	0.84	52.90	11.74
TiO_2[a]	0.84	0.66	0.52	0.19	tr	0.03	0.63	0.69
Al_2O_3[a]	17.84	13.82	11.02	5.14	1.10	0.53	15.96	3.74
Total iron as Fe_2O_3[a]	7.88	6.16	6.72	2.92	0.42	0.18	6.60	3.60
MnO_2[a]	0.61	0.32	1.03	0.78	0.13	0.08	0.12	0.07
MgO [a]	2.55	3.25	3.23	1.55	0.31	0.14	2.79	3.43
CaO[a]	0.97	1.67	2.32	23.12	49.42	53.86	2.33	40.05
Na_2O[a]	1.58	1.10	2.20	1.17	0.34	0.11	2.40	0.94
K_2O[a]	3.41	3.38	3.06	1.53	0.46	0.05	2.72	0.46
P_2O_5[a]	0.19	0.41	0.84	0.37	0.09	0.10	0.33	0.17
ZrO_2[a]	0.16	0.12	0.12	0.06	n.f.	0.12	0.20	0.12
CO_2 [c]	0.32	0.63	0.16[m]	16.87[m]	37.57	41.39[m]	1.42	28.65
N[d]	0.10	0.08	0.06	0.07	0.07	0.04	n.d.	n.d.
Organic carbon[e] (calculated)	1.00	0.80	0.60	0.70	0.70	0.40	....	....
Organic matter[f] (calculated)	1.90	1.52	1.14	1.33	1.33	0.76	....	....
Cl[g]	0.54[a]	0.30[p]	1.54[a]	1.01[a]	0.19[n]	0.06[n]	....	....
SO_4[h] (calculated)	0.08	0.04	0.21	0.14	0.03	0.01	....	....
Total (not including N and organic carbon)	92.95	91.22	86.59	90.84	96.67	98.26	(88.40)	(93.66)
H_2O (by difference)[i]	7.05	8.78	13.41	9.16	3.33	1.74	....	....
B [j]	>0.05	>0.05	>0.05	>0.05	<0.05	>0.05	n.d.	n.f.
Ba[j]	n.f.	>0.05	>0.05	>0.05	>0.05	>0.05	n.d.	n.f.
Ra[k](gms per gm, x 10^{12})	6.04	21.40	16.72	10.92	3.96	3.88	n.d.	n.d.
CaO acid sol.[a]	0.40	0.81	1.16	22.35	47.89	52.96	n.d.	n.d.
MgO acid sol.[a]	1.84	2.50	2.46	1.00	0.03	0.08	1.34	2.67

n.d. = not determined; n.f. = none found; tr. = trace. [a] Chemical analyses by Sharp-Schurtz Company, Lancaster, Ohio. [b] Atlantic samples. For depth and location see table 18. [c] Except when actual determinations are indicated, this value is calculated from per cent acid sol. CaO on basis of assumption that all of acid sol. CaO represents $CaCO_3$. [d] Determinations by Dr. Parker D. Trask of the United States Geological Survey. [e] Calculated from per cent N; = per cent N x 10. [f] Calculated from per cent N; = per cent N x 19. [g] Except where indicated, calculated from per cent Na_2O. When $CO_2 > 10$ per cent, Cl = per cent Na_2O x .564. When $CO_2 < 10$ per cent, Cl = per cent Na_2O x .273. [h] Calculated from per cent Cl; = per cent Cl x .13. [i] The errors in analysis are included in per cent H_2O = 100.00 - total. [j] Spectrographic determinations by George Steiger of the United States Geological Survey. [k] Determinations of radium content by Dr. Charles S. Piggot of the Geophysical Laboratory. [m] Determinations by Miss Esther C. Allen and Roger Revelle, Scripps Institution. [n] Per cent Cl = per cent Na_2O x .564. [p] Per cent Cl = per cent Na_2O x .273.

Table 10. Molecular ratios calculated from chemical analyses of certain Carnegie bottom samples

Sample no.	$\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	$\frac{SiO_2^*}{\text{Total bases}}$	$\frac{Al_2O_3 + Fe_2O_3^*}{\text{Total bases}}$	$\frac{CaO^*}{MgO}$	$\frac{Na_2O^*}{K_2O}$	$\frac{CaO + MgO}{Na_2O + K_2O}$
1	4.04	4.96	21.9	0.23	(5.8)	(1.4)	(0.3)	(0.15)	(3.0)
9	3.72	4.58	20.0	0.23	(7.3)	(2.0)	(2.0)	(0.69)	(2.4)
10	3.97	5.32	15.6	0.34	7.83	1.98	0.12	1.36	2.68
13	16.3	24.8	47.5	0.52	(>10.6)	.....	.....	(1.1)	.....
14	15.3	39.8	25.0	1.60	(> 8.5)	.....	(0.4)	2.3	(2.1)
16	1.17	9.82	1.33	7.39	....	.....	.....	(0.7)	.....
17	1.27	4.40	1.79	2.46	....	.....	.....	(0.3)	.....
18	2.99	10.2	4.23	2.41	....	.....	.....	.....	.....
19	0.76	4.81	0.91	5.30	....	.....	.....	(0.3)	.....
21	0.77	7.12	0.87	8.22	....	.....	.....	(1.0)	.....
22	1.88	5.20	2.95	1.77	3.9	2.1	0.26	1.0	2.4
23	2.28	5.01	4.19	1.20	....	.....	.....	(0.3)	.....
25	1.98	5.13	3.22	1.60	(2.5)	(1.3)	(0.8)	0.8	(6.3)
26	3.23	7.75	5.55	1.40	....	.....	.....	(0.8)	.....
27	2.72	4.38	7.18	0.61	4.1	1.5	0.45	2.0	2.9
29	3.21	7.54	5.60	1.35	....	.....	.....	(0.4)	.....
31	5.04	6.35	24.4	0.26	7.02	1.39	0.34	0.81	1.74
34	4.81	6.00	24.3	0.25	(11.1)	(2.31)	(2.62)	0.99	(0.57)
35	5.27	6.67	25.0	0.27	8.49	1.61	0.38	0.86	1.09
36	4.33	6.24	14.2	0.44	....	.....	.....	(0.4)	.....
41	1.66	14.4	1.88	7.63	(2.1)	(1.2)	(0.6)	(2.0	(4.4)
44	2.27	4.28	4.61	0.93	(2.8)	(1.2)	(0.4)	0.82	(2.3)
45	1.33	1.98	4.09	0.48	....	.....	.....	(1.6)	.....
56	5.88	7.50	27.2	0.28	7.89	1.34	0.62	0.71	2.66
57	5.97	7.64	27.3	0.28	7.56	1.27	0.45	1.00	1.73
58	5.61	6.67	35.2	0.19	8.62	1.54	0.40	0.85	2.09
59	6.07	7.85	26.8	0.29	7.60	1.25	0.51	1.17	1.82
60	6.18	8.07	26.4	0.31	7.57	1.23	0.48	0.98	1.77
61	4.06	5.13	19.5	0.26	7.02	1.73	0.19	0.63	1.33
62	4.02	5.30	16.7	0.32	6.39	1.59	0.20	0.93	1.42
64	4.06	5.39	16.4	0.33	5.76	1.42	0.10	0.68	1.98
65	4.01	5.29	16.5	0.32	5.69	1.42	0.15	0.72	1.95
66	4.05	5.26	17.7	0.30	5.93	1.46	0.05	0.55	1.67
69	3.98	5.09	18.3	0.28	7.25	1.82	0.13	0.52	1.24
70	3.85	4.92	17.6	0.28	7.33	1.90	0.11	0.48	1.26
72	4.10	5.05	21.7	0.23	7.49	1.83	0.13	0.53	1.22
73	3.95	4.89	20.7	0.24	7.01	1.77	0.16	0.55	1.28
77	4.01	5.15	18.3	0.28	7.04	1.76	0.16	0.53	1.31
79	5.53	7.10	25.0	0.29	6.65	1.20	0.19	0.39	1.91
80	5.82	8.08	20.8	0.39	6.0	1.04	0.26	0.52	1.97
81	8.40	11.4	31.6	0.36	8.0	1.0	0.4	0.43	2.1
82	6.55	8.15	33.4	0.24	....	.....	.....	0.7	.....
85	2.21	2.69	12.4	0.22	....	.....	.....	(2.2)	.....

*Calcium carbonate and sea salts are eliminated, in accordance with the following equations: per cent noncarbonate CaO = per cent total CaO - per cent acid-soluble CaO; per cent non-sea-salt MgO = per cent MgO found - per cent Cl x 0.11; per cent non-sea-salt Na_2O = per cent Na_2O found - per cent Cl x 0.745; per cent non-sea-salt K_2O = per cent K_2O found - per cent Cl x 0.024. Values for the various base ratios were omitted when it was found impossible to eliminate calcium carbonate satisfactorily, or when appreciable amounts of magnesium carbonate were probably present. With the information available, carbonate MgO cannot be satisfactorily eliminated. Values in parentheses are of doubtful validity.

attempted elimination of carbonate calcium is magnesium.

The north Pacific clays always contain about eight-tenths per cent of titanium dioxide. Noncalcareous siliceous oozes and south Pacific clays contain about one-half of 1 per cent of this substance, and it is present in widely varying amounts in Globigerina oozes, depending on the amount of noncalcareous material.

Analyses of Colloidal Fractions

The above discussions of the molecular ratios for deep-sea clays do not give a true picture of the composition of the clay minerals present in the samples owing to the presence, shown by X-ray analysis, of quartz and other unaltered minerals in the coarser fractions. Partial chemical analyses were therefore made of the parts of samples 31, 34, 72, 73, and 77 which were less than 1 micron in particle diameter, separated during the mechanical analyses, and combined with other separates from the same samples separated by centrifuging or repeated decantations after settling for twenty-four-hour periods. Although X-ray powder diagrams of these finer fractions also give a very faint quartz pattern, it was hoped that the results, shown in tables 12 and 13, would indicate at least approximately the composition of the clay minerals themselves. The samples were not dried thoroughly and therefore have wide varying water contents. Comparison of table 12 with table 9 shows, however, that the percentages of silica and TiO_2 in the colloidal fractions are less than in the whole samples, whereas alumina, iron, and manganese have increased in every case. There is no constant variation in the amounts of bases. During the process of mechanical analysis and separation of the fine fractions, a certain amount of cations may have been dissolved, and these would be concentrated in the colloidal separates or, as in the case of sample 34, some cations may have been removed by washing.

The silica sesquioxide ratios vary between 2.3 in sample 72 and 3.1 in sample 34, averaging about 2.7; the silica alumina ratios range between 3.2 in sample 72 and 4.2 in sample 34, averaging about 3.5; whereas the molecular amount of alumina is, on the average, more than three times that of ferric oxide. In samples 31, 73, and 77 the average silica-base ratio is slightly over 6. Magnesium is always the principal divalent base, whereas sodium and potassium are present either in about equal

Table 11. Average and extreme molecular ratios for various types of deposits

Molecular ratios	N. E. Pac. clays (nos. 61, 62, 64-66, 69, 70, 72, 73, 77)	N. W. Pac. siliceous mud and oozes (nos. 56-60)	S. Pac. clays (nos. 31, 34, 35)	Globigerina oozes (nos. 16-19, 21-23, 25-27, 29, 41, 44, 45)	Siliceous globigerina oozes (nos. 13, 14, 81, 82)	Siliceous oozes (nos. 79, 80)
$\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$	4.01	5.94	5.04	1.97	11.6	5.68
Extremes	4.10 (72) 3.85 (70)	6.18 (60) 5.61 (58)	5.27 (35) 4.81 (34)	3.23 (26) 0.76 (19)	16.3 (13) 6.55 (82)	5.82 (80) 5.53 (79)
$\frac{SiO_2}{Al_2O_3}$	5.15	7.55	6.34	6.57	21.0	7.59
Extremes	5.39 (64) 4.89 (73)	8.07 (60) 6.67 (58)	6.67 (35) 6.00 (34)	14.4 (41) 1.98 (45)	39.8 (14) 8.15 (82)	8.08 (80) 7.10 (79)
$\frac{SiO_2}{Fe_2O_3}$	18.3	28.6	24.6	3.46	34.4	22.9
Extremes	21.7 (72) 16.4 (64)	35.2 (58) 26.4 (60)	25.0 (35) 24.3 (34)	7.18 (27) 0.87 (21)	47.5 (13) 25.0 (14)	25.0 (79) 20.8 (80)
$\frac{Fe_2O_3}{Al_2O_3}$	0.28	0.27	0.26	3.05	0.68	0.34
Extremes	0.33 (64) 0.23 (72)	0.31 (60) 0.19 (58)	0.27 (35) 0.25 (34)	8.22 (21) 0.48 (45)	1.60 (14) 0.24 (82)	0.39 (80) 0.29 (79)
$\frac{SiO_2}{\text{total bases}}$	6.69	7.85	8.87 7.76 (without no. 34)	3.1 ?	9.0 ?	6.33
$\frac{CaO + MgO}{Na_2O + K_2O}$	1.47	2.01 1.85 (without no. 56)	1.13 1.42 (without no. 34)	3.7 ?	2.1 ?	1.94
$\frac{Na_2O}{K_2O}$	0.61 0.58 (without no. 62)	0.94	0.89	[0.9]	[1.1]	0.45
$\frac{CaO}{MgO}$	0.14	0.49 0.46 (without no. 56)	1.11 0.36 (without no. 34)	0.5 ?	0.4 ?	0.23

molecular proportions or, as in samples 72 and 77, the amount of potassium is greater than that of sodium.

The average composition of the clay mineral or minerals in the samples, thus roughly corresponds to the empirical formula:

$$(Mg, K_2, Na_2, Ca)O \cdot 2(Al_2O_3, Fe_2O_3) \cdot 6\ SiO_2$$

This is approximately the formula of beidellite, except for the water, which has not been taken into account. The fact that the average silica sesquioxide ratio is somewhat less than 3 indicates that more or less kaolinite, halloysite, or muscovite may be present.

Besides the colloidal fractions of the five terrigenous and pelagic clays, the clay and silt fractions of sample 17 and the colloidal separates of samples 19, 21, 23, and 81 were analyzed. In these five Globigerina oozes the calcium carbonate content is smaller in the colloidal parts than in the whole samples, hence most of the other components are larger in relative amount. It is interesting

Table 12. Partial chemical analyses of fine fractions in per cent

Constituent	From globigerina oozes						From South Pacific clays		From North Pacific red clays		
	Sample number										
	17 silt	17 clay	19	21	23	81	31	34	72	73	77
	Station number										
	49	49	52	57	60	156	69	72	142	145	149
SiO_2	6.46	4.76[d]	2.68[a]	7.12	25.80	41.52	47.00	45.96	38.24	45.44	45.64
TiO_2	....	0.09	0.06	0.10	0.41	0.31	0.39	0.36	0.55	0.51	0.61
Al_2O_3	3.93	0.88[d]	9.24[b]	9.02	15.27	13.16	22.92	18.64	20.33	23.33	22.05
Total iron as Fe_2O_3	14.67	12.96[d]	2.18	9.27	10.48	4.05	8.04	9.76	11.72	9.12	10.14
MnO_2	....	1.70[d]	2.12	1.62	2.84	0.92	0.62	1.36	0.48	0.88	0.96
MgO	....	0.90[d]	0.44	1.10	1.25	1.05	3.58	tr	4.60	1.68	1.28
CaO	....	42.00[d]	35.15	38.74	14.15	10.55	5.91	n.f.	1.04	n.f.	0.35
Na_2O	....	0.28	0.08	n.d.[c]	0.15	1.01	1.55	1.22	1.59	2.47	1.16
K_2O	....	0.52	0.15	n.d.[c]	0.53	1.96	2.44	1.86	3.14	3.76	3.58
Loss on ignition	....	n.d.	47.91	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Total	....	64.09	100.01	66.97	70.88	74.53	92.45	79.16	81.69	87.19	85.77
CO_2	ca. 25.0[e]	32.17[f]	....	....	....	....	....	....	....	....	....

Abbreviations used as follows: n.d. = no determination, n.f. = none found, tr = trace.

Analyses by Sharp-Schurtz Co., Lancaster, Ohio, except where indicated. Maximum size of particles in fractions analyzed about 1 micron, except for sample 17. [a] Duplicate determination on small sample gave 2.71 per cent. [b] Duplicate determination on small sample gave 9.07 per cent. [c] Sample insufficient for determinations of Na_2O or K_2O. [d] Analysis by J. D. Loudermilk. [e] Analysis by titration method; see table 26. [f] Analysis by Esther C. Allen and the writer.

Table 13. Molecular ratios of fine fractions

Sample no.	$\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{FeO_2}{Al_2O_3}$	$\frac{SiO_2}{\text{Total bases}}$
		Globigerina oozes			
17 clay	0.88	9.18	0.98	9.41	.....
17 silt	0.83	2.80	1.18	2.38	.....
19	0.43	0.49	3.26	0.15	.....
21	0.81	5.11	7.78	0.66	.....
23	1.99	2.87	6.56	0.44	.....
81	4.47	5.36	27.25	0.20	.....
		South Pacific clays			
31	2.84	3.48	15.54	0.22	5.6
34	3.13	4.18	12.52	0.33	19.3
		North Pacific red clays			
72	2.34	3.20	8.68	0.37	3.3
73	2.65	3.31	13.26	0.25	6.2
77	2.54	3.52	11.97	0.29	8.0

to note, however, that in all cases except sample 21 the silica sesquioxide ratio is narrower than in the whole samples, owing usually to a large increase in alumina. Except for sample 17, the silica ferric oxide ratios are much wider than in the whole samples.

Base Exchange Capacity

The base exchange capacities of three whole samples of clay and of four fine fractions (two from Globigerina oozes and two from north Pacific red clays) were determined by Professor W. P. Kelley. By base exchange capacity is meant the amount of cations, usually expressed as milliequivalents per 100 grams, contained by a given material and exchangeable for the cations of a neutral salt solution. This quantity was determined by leaching with neutral normal ammonium acetate, and the total base exchange capacity represents the quantity of NH_4 ions absorbed by the sample. The amounts of cations removed from the sample in all cases exceed the amounts of NH_4 ions absorbed from the solution. This shows that the samples analyzed contained substances which merely dissolved in the salt solutions. The results are as follows:

Table 14. Replaceable and soluble bases and base exchange capacities

Milliequivalents per 100 grams base exchange

Sample no.	Ca	Mg	K	Na	Capacity
34 (Whole sample)	14.5	21.7	05.7	09.7	39.3
72 (Whole sample)	13.9	20.4	03.6	04.0	26.7
77 (Whole sample)	15.6	22.6	06.4	10.3	34.3
73 (<1.5 microns)	18.5	41.2	12.0	20.4	53.0
77 (<1.5 microns)	21.5	37.2	13.4	28.6	58.0
17 (<5.0 microns)	683.0	15.6	02.0	04.1	18.0
19 (<1.5 microns)	1254.0	22.0	03.1	08.2	14.0

The base exchange capacities of the colloids separated from samples 73 and 77, which are noncalcareous red clays, are close to those of three soil colloids, nos. 431, 3232, and 7083, investigated by Kelley, Dore, and Brown (1931). (The smaller base exchange capacities of the Globigerina oozes, nos. 17 and 19, and of entire samples 34, 72, and 77 are owing to the lesser amounts of clay and colloids present in them.) Soil no. 431 is designated as Ramona clay loam taken near La Habra, California, and represents a soil of granitic origin recently formed under semiarid conditions. Soil no. 7083, called Dublin clay adobe, taken near Gilroy, California, was also formed under semiarid conditions, whereas no. 3232 is a glacial drift soil from Indiana. Optical and other studies indicate that nos. 431 and 7083 contain in addition to quartz a beidellite-like mineral.

The mineral beidellite was found by these authors to have a base exchange capacity of about 51 milliequivalents per 100 grams, whereas in three bentonites investigated by them, the exchangeable bases varied in amount between 110 and 35 milliequivalents. The base exchange capacities of kaolinite and halloysite are much lower than any of these values, and those of zeolites are a great deal higher, the amounts of exchangeable bases in natrolite and stilbite, for example, being respectively 221 and 312 milliequivalents per 100 grams. A soil colloid containing halloysite, investigated by Kelley, Dore, and Brown, had a base exchange capacity of only 18 milliequivalents.

Kelley and Liebig (1934), among others, have shown that the chief replaceable base of soils which have been in contact with sea water is magnesium. Correspondingly, it may be seen from table 14 that, except for the Globigerina oozes in which large amounts of calcium carbonate were dissolved by the ammonium acetate, magnesium is the principal cation removed from the analyzed samples by the leaching solution.

Nitrogen and Organic Matter

In addition to the values for nitrogen in table 9 (determined by Dr. Trask), calculated values for organic carbon and organic matter are also given. These calculations are based on the fact that both in soils and in marine sediments there has been found to be a more or less constant ratio between organic carbon and nitrogen, and, at least in soils, between organic carbon and total organic matter. The values of these ratios are dependent on the chemical nature of the source material, on the conditions under which decomposition takes place, and on the microorganisms which are active in the decomposition process. Trask (1932) found that with near-shore sediments the carbon nitrogen ratio is approximately 8.4, but this ratio would be expected to be greater in deep-sea sediments in which the rate of accumulation of organic matter is probably very slow, thus allowing decomposition under oxidizing conditions to proceed until only the most resistant constituents of the marine humus remain. These, as pointed out by Waksman (1933), are probably lignins and related substances which have a high carbon nitrogen ratio. Waksman found a rather large variation in the carbon nitrogen ratio of four deep-sea samples from the Atlantic, but the average is close to that of soils, namely, 10, and this factor has been used in calculating the organic carbon. The ratio of 1.9 between organic carbon and total organic matter is also that suggested by Waksman.

A study of chart 3, which gives the distribution of nitrogen in the Carnegie deposits, shows that in pelagic deposits the highest contents of nitrogen are found in fine-grained noncalcareous red clays and siliceous oozes, whereas the nitrogen content of normal and ferruginous Globigerina oozes is quite low. The northeast Pacific red clays contain between a third and a half as much nitrogen as the average fine-grained near-shore sediments of the American coast (see Trask, 1932). In general, the amounts of nitrogen (and therefore, presumably, the amounts of carbonaceous and nitrogenous organic matter) are of about the same order of magnitude in red clays and in siliceous oozes, even though the latter are built up, in large part, of the siliceous remains of organisms. This fact supports the suggestion made previously, that the organic matter in pelagic deposits represents an undecomposable residue, perhaps, in part, of continental origin, the amount of which in a sediment is largely a function of the rate of deposition of inorganic material. The very low nitrogen content of south Pacific Globigerina oozes, however, probably is owing not only to dilution by the shells of pelagic foraminifera but also to the small supply of humus from surrounding land and the low plankton population of the surface waters.

Content of Radioactive Material

The distribution of radium in the samples as given by Piggott's determinations (1933) is illustrated in chart 5. A comparison of this chart with chart 3 shows that, in general, the distribution of radium may be correlated with that of organic matter. The highest amounts of radium found by Piggott are in samples 79 and 80--radiolarian oozes from the central Pacific, which underlie the paths of the equatorial currents. Although these samples are not notably high in organic matter, the sea bottom underlying the equatorial currents was shown by Agassiz to be high in living organisms of many kinds, whereas the surface waters were found to be rich in living forms.

The most striking feature of the content of radioactive materials of pelagic bottom sediments, as has been pointed out by Joly (1908), Pettersson (1930), Piggott (1933), and Kalle (1933), is its extreme order of magnitude, many times that of the average continental rocks. Several theories have been advanced to explain this accumulation of radium in deep-sea deposits. Piggott makes the statement that the chemistry involved in the problem is that of uranium rather than of radium, and points out that the oxides of uranium are similar in their behavior to manganese and iron, in that they are insoluble in sea water. Table 9 and charts 5 and 6 show, however, that the distribution of manganese dioxide and radium bear an inverse relation to each other. Pettersson (1930) believes that the radioactive materials are the results of submarine vulcanism and points to the greater abundance of radium in layers of cores taken from the deep sea in which volcanic materials are abundant, and in red clays as contrasted with Globigerina oozes. As to the first point it is possible, as pointed out by Piggott, that the smaller amount of radioactive materials in Globigerina oozes is owing to a differential dilution of a continuing process similar to that taking place with respect to organic matter. It will be noted, furthermore, that the siliceous oozes collected northeast of Japan which contain a great deal of volcanic material have only a moderate radium content. Berget (1930) has suggested that the radium content of marine sediments is owing to organic accumulation, and data by Professor R. D. Evans show that the ash of marine plants does contain moderate amounts of radioactive materials.

Distribution and Amount of ZrO_2

In chart 4 the distribution of ZrO_2 in deep-sea deposits collected by the Carnegie is shown. Except for the northwest Pacific siliceous oozes, which probably originated from the decomposition of volcanic material, and in which the ZrO_2 content is low, the distribution of zirconium is similar to that of organic matter, but there is no close relation between the two, and it is probable that the similarity in distribution may be explained on the basis that the same factors which influence the distribution of nitrogen influence the distribution of zirconium. The contents of between one-tenth and one-fourth of 1 per cent of zirconium dioxide in the Pacific clays are somewhat difficult to explain on the Murray theory that these clays originate from the submarine decomposition of volcanic debris, since zircon is not usually present in such large amounts in volcanic rocks, except in certain nephelite-bearing eruptives. On the other hand, zirconium is probably concentrated in most continental soils and would be expected in deep-sea clays if these were formed by the deposition of fine material carried in suspension or by the wind from land.

Manganese, Phosphate, and Iron

The distribution of manganese is shown in chart 6, from which it may be seen that the highest amounts of manganese are found in Globigerina oozes of intermediate carbonate content from the southeast Pacific. The distribution of phosphate given in chart 7 is similar to

Table 15. Partial chemical analyses of foraminifera from globigerina oozes in per cent

Constituent	Sample number					
	17	19	19	21	23	44
	Station number					
	49	52	dupl.	57	60	83
SiO_2	0.52	0.08	....	0.72	0.56	0.48
Al_2O_3	n.d.	n.d.	0.22	n.d.	n.d.	1.35
$FeO + Fe_2O_3$	1.68	1.13	....	1.43	0.64	0.51
MgO	0.16	0.10	....	0.12	0.14	0.15[d]
CaO	53.12	53.82[a]	53.95	53.47	54.52	54.17
P_2O_5	n.d.	n.d.	....	n.d.	n.d.	?[e]
CO_2	41.69	42.61[b]	43.10	41.95	42.72	42.38
H_2O - 105°	n.d.	n.d.	....	0.51[c]	n.d.	n.d.
Loss on ignition-CO_2	n.d.	n.d.	0.78	n.d.	n.d.	0.87
Total	97.17	97.74	....	98.20	98.58	99.91
CO_2 calculated from CaO	41.70	42.25	42.35	41.97	42.80	42.52

Abbreviation used as follows: n.d. = no determination. Analyses by Sharp-Schurtz Company, Lancaster, Ohio. [a] Duplicate determination checked within 0.02 per cent. [b] Exact check obtained on duplicate determination. [c] Determined some time after the other analyses on remainder of sample, which meanwhile had been kept in a tightly sealed container. [d] Mean of two determinations: individual values 0.14 and 0.16 per cent. [e] "A test for P_2O_5 indicated that some might be present, but the size sample worked upon was so small that we are not quite sure of its presence," communication from Sharp-Schurtz Company.

that of manganese and the relation between manganese and phosphate is shown in figure 2. Particularly in Globigerina ooze there is a fairly close relation between these two substances. From figure 1 it may be seen that in Globigerina oozes the manganese content varies directly with the amount of iron. Crawley (1902) and Heck (1934), among others, have pointed out the close relation between manganese, iron, and phosphate in soils. It is probable that the same conditions with respect to these substances prevail on the sea bottom in areas of pelagic sediments, particularly in the southeast Pacific.

Analyses of Pelagic Foraminifera

Partial chemical analyses of foraminifera separated in the process of mechanical analysis and by treatment with bromoform from five Globigerina oozes are given in table 15. From these it may be seen at once that shells of pelagic foraminifera, at least after partial recrystallization under deep-sea conditions, consist almost entirely of calcium carbonate and contain very little, if any, magnesium carbonate, contrary to the results of Clarke and Wheeler (1922). In four of the five samples analyzed, the amount of calcium found is slightly more than sufficient to balance the amount of CO_2, owing to clayey material present inside the shells which could not be washed out. Analyses of two different separates from sample 19, however, gave an excess of CO_2 over CaO. It is possible that in this highly ferruginous Globigerina ooze some of the calcium has been replaced by ferrous iron during the process of recrystallization of the foraminifera on the sea bottom.

Table 16. Analysis of altered volcanic material from Carnegie sample 11, station 40

Constituent	Value in per cent
SiO_2	16.52
TiO_2	0.05
Al_2O_3	3.95
Total iron as Fe_2O_3	60.80
MnO_2	n. f.
MgO	2.23
CaO	0.81
Na_2O	0.70
K_2O	1.27
Loss on ignition	13.56
Total	99.89
Loss, dried at 105°	1.55

Analysis by Sharp-Schurtz Company, Lancaster, Ohio. Abbreviation used as follows: n.f. = none found.

Spectrographic Analysis

Parts of sixty-seven samples were examined spectrographically by Mr. George Steiger for the following elements: boron, barium, beryllium, bismuth, germanium, tin, and zinc. The results are tabulated in table 17, and certain of them are illustrated in charts 8 and 9. The tests were made using a Gaertner spectrograph, the samples being placed directly in the arc on Acheson graphite electrodes, without previous chemical separation. Blank tests run with the electrodes alone showed no lines of the metals mentioned above. Quantities below a limit between 0.01 and 0.03 per cent cannot be detected spectrographically by the method used without previous chemical separation. Besides determinations of these six metals, plates were made including spectra which will make it possible to determine the presence of silver, arsenic, cadmium, lead, antimony, lithium, and strontium. Mr. Steiger's report on the analyses is as follows:

"Boron is widely distributed in small quantities throughout nature and it might readily be expected in the oceanic muds. Germanium was included in these tests for the reason that this metal although formerly considered very rare has been quite recently shown by several investigators to be widely distributed; this has also been my experience. The present tests have shown that at least in these muds germanium occurs if at all in smaller percentages than it does in many minerals and rocks. There is but little information on the distribution of small percentages of bismuth in rocks and minerals. Beryllium, from recent work, seems to be more widely distributed throughout nature than was formerly supposed.

"The distribution of barium as shown by these tests is of interest. My analyses of oceanic clays collected by the Challenger expedition, published in the Data of Geochemistry (Clarke 1920), gave in the composite of 51 red clays from the deeper parts of the ocean 0.20 per cent BaO, and in the composite of 52 specimens of blue muds from the more shallow parts 0.06 per cent BaO. Most of the samples in the present series, having been taken from under relatively deep water would be expected to run around the 0.20 per cent limit, and the absence or low barium content of some of them cannot be accounted for by shallow water conditions. If volcanic dust be the source of these muds, barium salts being relatively insoluble, their concentration might be expected in muds from the deeper parts of the ocean, other more soluble salts being dissolved on their way down. On the other hand, if the muds have been derived from rocks on adjacent shores, owing to their high specific gravity the barium salts would sink more rapidly and concentrate close to the shore line. Data from the present tests show barium to be concentrated principally in the southeast Pacific, the samples coming from this section without exception not only contain barium, but the individual tests were much stronger, indicating higher percentages. Those of the northeast Pacific come next, nearly all of them contain barium but the tests as a rule were not so strong, while most of those from the western Pacific and from the Atlantic contain little or no (probably less than 0.02 per cent BaO) barium. This segregation is nicely shown by excluding those specimens on which some doubt is placed, reported as "possibly present" and "doubtful." In this way a differential may be had between those specimens of "high" and those of "low" barium content, the division line being around 0.05 per cent BaO. Whether the high barium content of the rocks in the western part of the American continents is responsible for the concentration of barium in the samples from the eastern Pacific is doubtful as it seems a long distance for barium to be carried, but it seems significant that both the land rocks and the bottom sediments high in barium are adjacent to each other."

Table 17. Spectrographic analyses of Carnegie bottom samples

Analyses by George Steiger, United States Geological Survey

Sample	Station	Latitude	Longitude	Depth	Type of sample	Elements tested						
						B	Ba	Be	Bi	Ge	Sn	Zn
		° ′	° ′	meters								
1	6	50 22 N	13 31 W	2604	Globigerina ooze	n.d.	x	-	-	n.d.	-	-
2	7	63 20 N	9 25 W	454	Sand and gravel	n.d.	-	-	-	n.d.	-	-
3	10	59 19 N	34 15 W	3031	Globigerina ooze	n.d.	x	-	-	n.d.	-	-
4	12	51 40 N	49 32 W	2792	Globigerina ooze	n.d.	-	-	-	n.d.	-	-
6	21	15 50 N	37 56 W	4977	Globigerina ooze	n.d.	x	-	-	-	xxxx	x
8	30	12 54 N	56 15 W	4703	Globigerina ooze	n.d.	-	-	-	n.d.	xxxx	-
9	31	14 46 N	63 26 W	1635	Globigerina ooze	n.d.	-	-	-	n.d.	-	-
10	37	5 59 N	82 56 W	3324	Green (coprolitic) mud	n.d.	xxxx	-	-	n.d.	-	-
11	40	1 32 S	82 16 W	1344	Volcanic gravel	n.d.	xxx	-	-	n.d.	-	-
13	43	2 30 S	95 43 W	3352	Globigerina ooze	n.d.	xxxx	-	-	n.d.	-	-
14	44	3 15 S	99 48 W	3423	Globigerina ooze	n.d.	xxxx	-	-	n.d.	-	-
16	47	14 07 S	111 50 W	3080	Globigerina ooze	n.d.	xxxx	-	-	n.d.	-	-
17	49	23 16 S	114 45 W	3098	Globigerina ooze	n.d.	xxxx	-	-	n.d.	-	-
18	51	29 06 S	114 48 W	2898	Globigerina ooze	n.d.	xxxx	-	-	n.d.	-	-
19	52	31 28 S	112 51 W	2851	Globigerina ooze	n.d.	xxx	-	-	n.d.	-	-
20	54	29 17 S	108 54 W	3061	Globigerina ooze	-	xxxx	-	-	-	-	-
21	57	33 59 S	106 43 W	3139	Globigerina ooze	-	xxxx	-	-	-	-	-
22	59	39 51 S	101 04 W	4116	Globigerina ooze	xxx	xxxx	-	-	-	-	-
23	60	40 24 S	97 33 W	4007	Globigerina ooze	-	xxxx	-	-	-	-	-
24	61	38 29 S	94 14 W	3299	Globigerina ooze	-	xxxx	-	-	-	-	-
25	62	34 35 S	91 52 W	3610	Globigerina ooze	-	xxxx	-	-	-	-	-
26	63	32 10 S	89 04 W	3393	Globigerina ooze	-	xxxx	-	-	-	-	-
27	64	31 54 S	88 17 W	3879	Globigerina ooze	xxxx	xxxx	-	-	-	xxx	-
28	65	31 07 S	86 39 W	3626	Globigerina ooze	-	xxxx	-	-	-	-	-
29	67	24 57 S	82 15 W	1089	Globigerina ooze	xxx	xxxx	-	-	-	-	-
30	68	21 28 S	80 26 W	4156	Red clay	-	xxx	-	-	-	xxxx	x
31	69	16 49 S	78 39 W	3657	Red clay	xxx	xxxx	-	-	-	-	-
32	70	13 53 S	77 54 W	4742	Green diatom mud	xx	x	-	-	-	-	-
34	72	9 58 S	82 10 W	4480	Green clayey mud	xx	xxxx	-	-	-	-	-
35	74	11 00 S	87 24 W	4141	Red clay	xx	xxxx	-	-	-	-	-
36	75	14 15 S	92 05 W	3480	Globigerina ooze	-	xxxx	-	-	-	-	-
38	77	14 20 S	103 12 W	4094	Red clay	-	-	-	-	-	-	-
40	79	12 36 S	112 14 W	3090	Globigerina ooze	-	xxxx	-	-	-	xxxx	xx
41	80	12 39 S	117 22 W	3515	Globigerina ooze	-	xxxx	-	-	-	-	-
42	81	13 03 S	121 12 W	2953	Globigerina ooze	-	xxxx	-	-	-	-	-
43	82	14 52 S	126 07 W	3631	Globigerina ooze	-	xxxx	-	-	-	-	-
44	83	17 00 S	129 45 W	3966	Globigerina ooze	-	xxxx	-	-	-	-	-
45	85	17 12 S	136 37 W	3791	Globigerina ooze	-	xxxx	-	-	-	-	-
46	86	17 36 S	141 55 W	2132	Globigerina ooze (?)	xxxx	xxxx	-	x	-	xx	-
47	87	18 05 S	145 33 W	4315	Red clay	-	-	-	-	-	-	-
49	96	6 47 S	172 23 W	5269	Red clay	x	-	-	-	-	-	-
51	108	18 26 N	144 01 E	3573	Volcanic mud	-	-	-	-	-	-	-
53	110	26 20 N	144 24 E	3036	Volcanic globigerina mud	-	-	-	-	-	-	-
54	111	31 00 N	144 16 E	6008	Brown volcanic mud	xxx	-	-	-	-	-	-
56	113	34 44 N	141 04 E	2911	Gray siliceous volcanic mud	xxx	-	-	-	-	-	-
57	115	37 40 N	145 26 E	5396	Radiolarian ooze	xxx	-	-	-	-	-	-
58	116	38 41 N	147 41 E	5545	Radiolarian or diatom ooze	xxxx	-	-	-	-	-	-
59	117	40 20 N	150 58 E	5296	Diatom ooze	-	xxxx	-	-	-	-	-
60	119	45 24 N	159 36 E	5198	Diatom ooze	xxx	x	-	-	-	-	-
61	127	44 16 N	137 37 W	4026	Gray clayey mud	xxxx	-	-	-	-	-	-
62	128	40 37 N	132 23 W	3806	Red clay	xxxx	xx	-	-	-	-	-
64	131	33 49 N	126 20 W	4418	Red clay	-	xxxx	-	-	-	-	-
65	132	31 38 N	128 48 W	4251	Red clay	xxxx	xxxx	-	-	-	-	-
66	133	29 21 N	132 30 W	4426	Red clay	xxxx	-	-	-	-	-	-
69	136	26 13 N	142 02 W	4713	Red clay	xxxx	x	-	-	-	-	-
70	137	24 02 N	145 53 W	5208	Red clay	xxxx	-	-	-	-	-	-
72	142	32 42 N	160 44 W	5787	Red clay	xxxx	-	-	-	-	-	-
73	145	33 27 N	145 30 W	5584	Red clay	xxxx	xxxx	-	-	-	-	-
74	146	31 51 N	140 50 W	4756	Red clay	xxxx	xxxx	-	-	-	-	-
76	148	24 57 N	137 44 W	4835	Red clay	xxxx	xxxx	-	-	-	-	-
77	149	21 18 N	138 36 W	5320	Red clay	xxxx	-	-	-	-	-	-
79	151	12 40 N	137 32 W	4918	Radiolarian ooze	xxxx	xxxx	-	-	-	-	-
80	153	7 45 N	141 24 W	5003	Radiolarian ooze	xxxx	xxxx	-	-	-	-	-
81	156	3 01 N	149 46 W	4953	Globigerina ooze	xxxx	xxxx	-	-	-	xxx	-
82	157	1 48 S	152 22 W	4693	Globigerina ooze	xx	xxxx	-	-	-	-	-
85	160	10 54 S	161 53 W	2614	Globigerina ooze	xxxx	xxxx	-	-	-	-	-
89	Easter Island			......	Volcanic calcareous sand	-	-	-	-	-	xxxx	x

xxxx = element present (amounts greater than approximately .05 per cent). xxx = element probably present (amounts greater than approximately .05 per cent). xx = element possibly present (amounts less than approximately .05 per cent). x = presence of element doubtful (amounts less than approximately .05 per cent). - = element not present in amounts greater than .02 per cent. n.d. = element not determined.

Sixty-seven samples were analyzed for barium and in forty-four of these barium was present in quantities greater than 0.05 per cent; in eight others it was present in amounts less than 0.05 and possibly greater than 0.02 per cent; in fifteen samples barium was not present in detectable quantities. Clarke and Steiger (1914) record 0.086 per cent as the average amount of barium found in 793 analyses of igneous rocks of the United States. Orton (1924) obtained 0.2 mg barium per liter of sea water. It may be seen from table 18 that there is no obvious correlation between barium content and depth, but on the other hand charts 8 and 9 show that there is a relation between the amount of calcium carbonate in a deep-sea sample and the barium content, and that the distribution of barium is almost the opposite of that of boron, at least as far as the Carnegie samples are concerned. Nearly all the Globigerina oozes tested for barium showed more than approximately 0.05 per cent whereas only about half of the red clays showed the presence of this element in corresponding amounts. It appears possible that barium is precipitated, in part at least, as the carbonate in pelagic deep-sea sediments rather than as the sulphate as in the case of the nodules described by Jones (1887, 1888) from off Colombo and by Andrée (1918) from the East Indies. As pointed out by Steiger, one of the striking facts about the distribution of barium is that it is concentrated in the northeast and southeast Pacific off the west coast of North and South America, even at considerable distance from shore.

Of the fifty-two samples analyzed for boron, twenty-four definitely contain this element and in six others it is possibly or doubtfully present. Only seven of the twenty-one Globigerina oozes analyzed contain boron, whereas twenty-three of the twenty-nine noncalcareous sediments contain it. Three possible explanations present themselves for the concentration of boron in the deeper noncalcareous samples:

1. The samples were sent to Mr. Steiger in their original condition without being washed. It is possible that the boron was present in the sea salt remaining in the samples and that the more clayey samples which, as Trask (1932) has shown, would be expected to have a high initial water content and hence to be high in salt, had a correspondingly higher percentage of boron. Investigations of the boron content of sea water by Buch (1933), Wattenburg (1933), and Harding and Moberg (1934), show that boron is present to the extent of about 4.5 mg per liter, and bears a fairly constant ratio to the salinity, namely $B \equiv 0.00013S$ when both quantities are expressed in parts per thousand. Gebbing s (1909) analyses of red clay show that the maximum sea salt content of unwashed samples is about 8 per cent. Thus, if all the boron were present as part of the residual sea salts, it would only amount to about 0.001 per cent, a quantity much too small to be detected.
2. The concentration of boron in deeper sediments may be owing to the solution of non-boron-containing material during the process of settling or on the bottom.
3. It is possible that boron atoms take the place of a small amount of aluminium atoms or are otherwise present in the crystal lattices of the clay minerals which make up a large part of the finer fractions of the sediments. If this were the case, one would expect the red clays, which consist largely of noncalcareous colloidal material, to contain more boron than the Globigerina oozes, which contain much smaller amounts of clay minerals.

It may be seen from the accompanying table 17 that, as pointed out by Mr. Steiger, none of the sixty-seven samples contain enough beryllium or germanium to be detected with the methods used. Only one of the samples contains even doubtfully detectable quantities of bismuth, namely sample 46, which, as will be recalled from the synoptic descriptions of the samples, consists almost

Table 18. Distribution of boron, barium, tin, and zinc in Carnegie samples according to depth

Approximate amount in per cent	Total no. samples	0-1000 meters	1000-2000 meters	2000-3000 meters	3000-4000 meters	4000-5000 meters	5000-6000 meters	> 6000 meters
				Boron				
>0.05	24	..	1	3	3	9	8	..
<0.05 -> 0.02	6	..	..	..	...	4	1	1
<0.02	22	1	..	1	14	5	1	..
Total	52	1	1	4	17	18	10	1
				Barium				
>0.05	44	..	2	6	19	12	5	..
<0.05 -> 0.02	8	..	..	1	2	2	3	..
<0.02	15	2	1	1	2	5	3	1
Total	67	2	3	8	23	19	11	1
				Tin				
>0.05	7	1	..	..	2	3	1	..
<0.05 -> 0.02	1	..	..	1	...	...	...	..
<0.02	59	1	3	7	21	16	10	1
Total	67	2	3	8	23	19	11	1
				Zinc				
> 0.05	...	..	..	..	...	...	...	..
< 0.05 -> 0.02	4	1	..	..	1	1	1	..
< 0.02	63	1	3	8	22	18	10	1
Total	67	2	3	8	23	19	11	1

Table 19. Bottom samples collected in the eastern north Pacific by the U.S.C.G.S.S. Surveyor

Partial chemical analyses by J. G. Fairchild, United States Geological Survey

Constituent	Sample number									
	30	31	32	33	34	35	36	37	39	40
	Values in per cent									
SiO_2	53.3	53.05	52.40	55.09	55.24	57.75	54.78	53.99	28.18	10.84
Total iron as Fe_2O_3	9.74	8.86	8.96	9.36	8.63	7.76	25.52	24.83	5.95	4.19
Al_2O_3	25.39	17.11	17.84	16.46	17.52	18.01			8.07	47.05
CaO		2.07	1.97	1.64	1.94	1.99	1.99	2.06	26.64	
MgO		3.08	3.05	3.30	3.21	3.11	2.91	3.09	1.85	
K_2O		0.94	1.52	1.44	1.03	0.89	1.22	1.06	0.55	
Na_2O		0.70			0.81	0.91				
MnO	tr	tr	....	....	....	....	....	....	....	....
P_2O_5	....	0.09	....	0.11	0.09	0.12	0.10	0.11	0.12	0.10
Total	88.43	85.90	85.74	87.40	88.47	90.54	86.52	85.14	71.36	62.18
Description	gn md	gn md	gn md	gn md	gn md	gn md	gn md	gn md	gl oz	gl oz
Latitude, north	7° 24′	6° 59′	6° 37′	6° 11′	5° 48′	5° 48′	5° 48′	5° 47′	5° 47′	5° 58′
Longitude, west	79° 14′	79° 15′	79° 16′	79° 16′	79° 14′	79° 39′	80° 05′	80° 31′	81° 23′	81° 46′
Depth in meters	3246	3486	3618	3728	3362	2815	3098	3135	1604	812

Constituent	Sample number									
	42	43	44	45	47	48	49	50	51	52
	Values in per cent									
SiO_2	51.05	46.46	44.57	43.48	29.24	43.50	43.29	44.27	51.61	52.64
Total iron as Fe_2O_3	25.34	15.53	22.58	19.93	14.81	21.44	21.97	22.19	25.07	23.24
Al_2O_3		8.20								
CaO	3.08	9.53	10.33	11.71	25.89	11.56	11.58	11.14	3.92	1.92
MgO	3.30	2.43	2.47	2.53	2.13	3.13	3.09	3.10	3.55	3.36
K_2O	0.95	2.98	1.25	0.70	2.96	1.43	1.33	1.14	1.32	0.90
Na_2O		1.07		0.54						0.84
MnO	....	....	....	....	....	....	....	....	1.02	1.54
P_2O_5	0.28	0.07	0.17	0.17	0.13	0.16	0.15	0.14	0.37	0.25
Total	84.00	86.27	81.37	79.06	75.16	81.22	81.41	81.98	86.86	84.69
Description	gn md	gn s	gn md	gn md	gl oz	gn md	gn md	gn md	gn md	gn md
Latitude, north	6° 07′	6° 25′	6° 44′	7° 02′	7° 18′	7° 25′	7° 29′	7° 36′	7° 47′	8° 23′
Longitude, west	82° 05′	82° 42′	83° 20′	83° 56′	84° 29′	84° 43′	84° 52′	85° 06′	85° 28′	86° 39′
Depth in meters	3056	2262	2008	1734	1522	1716	1778	1906	2893	3389

Constituent	Sample number								
	53	54	56	57	58	59	60	61	62
	Values in per cent								
SiO_2	56.43	60.02	58.12	58.96	55.60	53.85	54.17	55.33	55.97
Total iron as Fe_2O_3	23.23	21.00	23.38	22.93	25.31	25.11	24.57	23.35	23.51
Al_2O_3									
CaO	2.02	2.28	1.85	1.62	2.11	2.34	2.79	3.20	3.27
MgO	3.28	2.64	2.60	2.38	2.65	2.87	3.28	2.37	2.97
K_2O	1.66	0.66	1.08	1.33	1.89	1.91	2.94	2.90	3.17
Na_2O			1.00	1.57	1.62	1.34			
MnO	0.51	0.11	....	....	0.31	1.37	0.19	0.56	0.51
P_2O_5	0.34	0.25	0.17	0.24	0.19	0.24	....	....	0.20
Total	87.47	86.96	88.20	89.03	89.68	89.03	87.94	87.71	89.60
Description	gn md	gn md	gn md	gn md	rd cl	rd cl	rd cl	gn md	gn md
Latitude, north	9° 02′	9° 46′	12° 07′	12° 52′	19° 29′	20° 04′	20° 43′	21° 16′	21° 55′
Longitude, west	87° 51′	89° 17′	94° 06′	95° 46′	107° 05′	107° 59′	108° 46′	109° 36′	110° 40′
Depth in meters	3297	3579	4026	4252	3170	3305	2915	3072	3374

entirely of manganese nodules. Gibson (1891) was unable to find any bismuth in his famous analysis of manganese nodules from Challenger station 285, which is about 1000 miles southeast of Carnegie station 86 where sample 46 was collected.

Samples 6 and 8 in the Atlantic, and samples 27, 30, 40, 81, and 89 in the Pacific contain tin, and this element is possibly present also in sample 46. Of these samples, six are classified as Globigerina oozes, one as a red clay from the south Pacific, and one (sample 89) as a calcareous beach sand from Easter Island. No evidence of tin could be detected in sea water by Orton and it has not been detected previously in marine bottom deposits. Orton, however, reports the blood cell of the oyster as containing about 0.05 per cent tin. Goldschmidt (1933) believes that tin should be found as the oxide in the insoluble residues of hydrolytic decomposition, namely clays and silica.

In samples 6, 30, 40, and 89 zinc also is recorded as possibly or doubtfully present, that is in quantities less than about 0.05 and possibly greater than 0.01 per cent.

Clarke and Steiger record 0.0052 per cent of zinc in their analysis of a composite sample of fifty-one red clays dredged by the Challenger and 0.001 per cent in a composite sample of fifty-two terrigenous clays. Bodansky (1920), Orton (1924), and Goldschmidt (1933) report less than 0.1 mg per kilo of the same element in sea water. Bodansky, however, found from 0.0025 grams to 0.341 grams per kg in the ashed tissues of twenty marine animals and concluded that it is a normal constituent of the tissues of these forms. According to Thompson and Robinson (1932) zinc has been detected in the ashes of some sea plants, the ashes of Zostera maritima showing 0.035 per cent. It seems possible, therefore, that the zinc in bottom deposits is the product of the decomposition of marine plants and animals. According to Goldschmidt, however, zinc is associated with iron and manganese hydroxides.

GRAIN DENSITIES, WEIGHT-HUMIDITY AND WEIGHT-TEMPERATURE RELATIONS OF CARNEGIE PACIFIC BOTTOM SAMPLES

P. G. Nutting
United States Geological Survey

Grain Densities

The mean grain densities of the samples sufficient in quantity for the determination are as follows:

Table 20. Mean grain densities of certain samples

Sample no.	Size fraction	Particle size	Mean grain densities
17	clay	< 5 microns	2.841
17	clay	< 5 microns	2.788
Average			2.815
31	colloid	< 1.5 microns	2.642
34	whole sample	....	2.606
69	whole sample	....	2.706
72	whole sample	....	2.765
73	whole sample	....	2.782
77	whole sample	....	2.650

Densities were determined by first grinding the room-dry sample to pass a 300-mesh sieve (50 microns), then drying at 160° C for 24 hours and cooling in a P_2O_5 desiccator. Tetralin (tetrahydronapthalin) was used as pycnometer fluid because of its excellent wetting power for minerals. Fine grinding facilitated the expulsion of air. After weighing in an ordinary 5-cc pycnometer, the clay was wet with tetralin and shaken with it at intervals for 24 hours, then the density determination was completed.

Blank experiments with quartz, both coarsely broken and ground to 50 microns, indicate that the error due to adsorbed air and moisture is less than 0.1 per cent when using the above procedure. The adsorption of tetralin on this class of clay is very slight and produces an error of probably less than 0.25 per cent in the densities, though no method has yet been found for accurately determining it.

Dehydration at 160° C removes sorbed moisture and gases rather completely without breaking down hydrates or carbonates. Organic structural material such as cellulose is but slightly affected. Oxidation is only slightly promoted. The densities of this class of clays, when dehydrated at 160° C, are at or near their maxima. Similar tests on a brown clay soil gave 2.428 room dry, 30 per cent humidity, 2.650 after 24 hours at 160°, and 2.405 after ignition at 800° C in air.

Weight-Humidity Relations

The samples were ground to pass a 150-mesh sieve (0.1 mm) and placed in thin layers in glass dishes in desiccators containing sulphuric acid solutions having eight vapor pressures ranging from 5 to 95 per cent saturated. The initial treatment consisted of drying the samples for two weeks over P_2O_5 (zero humidity) to give the base weight. Temperatures during the experiments varied little from 27°.0 C. About 95 per cent of the change in weight is attained in 24 hours under these conditions, but in all cases at least two weeks was allowed for complete equilibrium to be attained. The weights tabulated below (table 21) are relative to those at zero humidity.

At low moisture contents the vapor pressures of these samples do not differ greatly from the average for ordinary clays (cf. P. G. Nutting, "The adsorbent clays" Bull. 928-C [U.S.G.S.] in press). Further, the percentage increase in vapor pressure is directly proportional to the percentage increase in moisture content of the sample throughout the lower range of humidities.

At higher vapor pressures approaching saturations, these samples show the properties of hygroscopic salts rather than of definite hydrates as all curves turn steeply upward at the highest humidites. If such hydrates as phillipsite, for example, were present each curve would approach a definite maximum as do the curves for the simple oxides SiO_2, Al_2O_3, and Fe_2O_3 (ibid). The energies of association of water with moist clay when such clays are in equilibrium with water vapor of various concentrations are given in a table on page 25 of the paper cited.

Weight-Temperature Relations

The samples were put through a 150-mesh sieve (0.1 mm) and weighed in a light platinum crucible suspended from an arm of a balance in a vertical electric furnace heated to various temperatures for at least 24 hours at each temperature. The weights tabulated in table 22 are in percentages of that at 50° C as a base. Room humidities do not appreciably affect weights taken at temperatures above 70° C.

Samples 17 and 19, high in carbonate, lose weight only slightly out to where CO_2 is given off; 600° C for 17 and 650° for 19. $CaCO_3$ as pure crystalline marble, breaks sharply at 600° C.

The remaining samples 31 to 77 dehydrate very much as do bentonites and glauconites and some other older clays of similar composition. They drop rapidly in weight from room temperature up to 150°, then gradually and evenly out to 440 (77) - 580 (31), followed by a steep drop and then a gradual decrease to 800° C. The data on bentonite given for comparison relate to a very pure one from the Vicksburg formation in central Mississippi. The glauconite is also a pure one from Bonne Terre, Missouri.

These curves are entirely different in character from the dehydration curves for analcite (cf. P. G. Nutting, "Standard thermal dehydration curves of minerals," Professional Paper [U.S.G.S.] 197-E, p. 202) or for the zeolites, chabazite, or phillipsite. In the lower range of temperatures, these zeolites change in weight only slowly at first as the higher hydrate starts to break up. At room temperature the curves for both are horizontal instead of steep, as are those for bentonites and the bottom samples.

Chabazite shows no breaks at higher temperatures as additional water is expelled, but phillipsite exhibits a sharp drop at 140° and another at 630° C, the latter corresponding to one molecule of H_2O rather closely and being not unlike the characteristic breaks in the curves for the bottom samples studied and for the bentonites. If either chabazite or phillipsite has formed and is present, it must form such a minor percentage of the whole as not to be evident as breaks in the dehydration curves.

Discussion of Nutting's Report

In attempting to distinguish between various types of clay minerals from their dehydration curves, three important points are to be noted: (1) the temperature at which a break occurs in a curve; (2) the amount of water lost during this sharp drop in the water content, which indicates the number of molecules of essential water in

Table 21. Vapor pressure versus moisture content

(Ratio of moisture content at the humidity indicated to that at zero humidity)

Relative humidity in per cent	19 colloid	31 colloid	69 all	72 all	73 all	77 colloid	77 all
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	1.0065	1.0110	1.0072	1.0092	1.0080	1.0170	1.0126
10	1.0131	1.0178	1.0125	1.0131	1.0148	1.0295	1.0218
20	1.0185	1.0310	1.0220	1.0184	1.0246	1.0502	1.0336
30	1.0235	1.0422	1.0288	1.0238	1.0324	1.0677	1.0424
40	1.0300	1.0531	1.0372	1.0295	1.0420	1.0846	1.0522
50	1.0348	1.0651	1.0475	1.0368	1.0528	1.1024	1.0623
60	1.0424	1.0818	1.0609	1.0445	1.0676	1.1268	1.0741
70	1.0568	1.1032	1.0825	1.0558	1.0898	1.1646	1.0872
80	1.0848	1.1385	1.1226	1.0768	1.1335	1.2276	1.1070
90	1.1476	1.2218	1.2022	1.1220	1.2376	1.3500	1.1776
95	1.2248	1.3218	1.2978	1.1676	1.4168	1.5458	1.2878

Table 22. Percentage of water lost at the temperature indicated

Sample no.	100°	150°	200°	300°	400°	450°	500°	550°	600°	650°	700°	800°
17	1.33	2.08	2.59	3.85	4.67	5.62	6.25	10.86	22.16	36.30	36.81	36.87
19	0.89	1.53	2.10	4.02	4.72	5.10	5.68	6.89	10.78	26.08	36.10	36.22
31	13.20	18.30	22.22	24.97	28.63	29.08	29.48	30.00	33.66	34.31	34.51	34.64
34	2.88	3.51	4.05	4.95	4.95	6.40	7.93	8.92	9.37	9.73	9.82	9.91
69	0.94	1.40	1.68	2.25	2.90	3.37	4.40	5.61	5.99	6.27	6.36	6.45
72	1.21	1.59	1.87	2.43	3.08	3.64	4.48	5.51	6.16	6.26	6.44	6.63
73	2.29	2.94	3.30	4.04	4.68	5.50	6.79	7.52	7.89	8.07	8.17	8.26
77	0.47	0.85	1.13	1.88	2.63	3.76	4.69	5.26	5.63	5.82	6.01	6.10
Mississippi bentonite	6.99	9.12	9.46	9.97	10.49	10.74	11.08	12.79	13.73	14.15	14.49	14.75
Chabazite	2.93	7.59	11.95	15.90	18.20	19.07	19.62	20.09	20.49	20.73	20.89	20.89
Phillipsite	1.42	6.77	8.44	11.70	13.78	14.20	14.45	14.54	14.62	15.96	16.37	16.46
Glauconite	0.84	1.12	1.30	1.67	2.14	2.70	3.72	5.12	5.95	6.42	6.79	6.98

the crystal lattice of the mineral; and (3) the amount of water lost at temperatures below the break in the curve, which indicates the amounts of absorbed water and, thus, something of the crystal structure.

In figure 6 are given the dehydration curves for kaolinite and halloysite, taken from a paper by Ross and Kerr (1933), and for glauconite and a Mississippi bentonite containing montmorillonite, taken from Nutting's report. It will be noticed that the amount of water lost by halloysite below the break in the curves is much greater than in kaolinite, and that the loss in the bentonite is about twice that of halloysite, corresponding with the well-known ability of bentonite to absorb large quantities of water. There is a sharp break in the halloysite curve between 420° and 500°, whereas the even sharper break in kaolinite occurs at temperatures close to 500°. About 10 per cent of water is lost between these temperatures. In the bentonite curve there is a much more gradual break between 500° and 600° in which only about 3 per cent of water is lost.

The breaks in the curves for samples 34, 69, 72, 73, and 77 begin at about 400° to 500°, but the amount of water lost is, in every case, about 3 per cent, the same as in bentonite, and the breaks are of the same general character, being neither as abrupt nor as large as those of the halloysite or kaolinite curves. There is one important difference, however, between the dehydration curves for the samples mentioned and that of montmorillonite, as exemplified by the Mississippi bentonite. This is in the amount of water lost below 400°, which in no case exceeds 6 per cent, and for samples 69, 72, and 77 is about 3 per cent, as contrasted with the loss of about 11 per cent in bentonite. In terms of crystal structure, this means that in the lattice packages of the mineral involved the atomic layers cannot be stretched apart as widely by the absorption of water as in montmorillonite.

Professor W. P. Kelley, who has seen these curves, states in a personal communication that they are very similar to those obtained in his laboratory for certain California soils previously mentioned which contain a clay mineral similar to, but not identical with, beidellite. The dehydration curves thus corroborate the conclusion that the chief clay mineral in Pacific deep-sea clays is beidellite-like in type.

The break in the curve of sample 31 between 550° and 600° is owing to the presence of calcium carbonate. Below 500°, however, the curve is quite different from those of the other clays and probably indicates a more complex mineralogical composition.

MECHANICAL ANALYSES

Pipette Analyses

Method

Fourteen samples, including six Globigerina oozes, six red clays from the northeast Pacific, and two south Pacific clays, were mechanically analyzed by the pipette method, first introduced by Robinson (1922), Jennings, Thomas, and Gardner (1922), and Krauss (1925). This has been adopted as the international method for soil analyses, and has been used on a great many sediments from the Baltic Sea by Gripenberg (1934). The procedure of analysis followed closely that outlined by Krumbein (1932) as modified by Rittenhouse (1933). The sample to be analyzed, usually weighing from 10 to 20 grams in the moist condition, was carefully quartered, and a part of 3 to 6 grams was placed in an 8-ounce sterilizer bottle, which contained about 3 ounces of water. The bottle was shaken for a period of 8 to 24 hours, after which the material was poured through a sieve with meshes of about 0.07 mm. The residue remaining on the sieve was washed until clean, dried on a sand bath, and separated into fractions by hand sieving with the use of a series of standard sieves for mechanical analyses. The part which had passed through the sieve was washed nearly free of salt by repeated centrifuging and, after a period of further shaking in the sterilizer bottles, was allowed to stand overnight to see if flocculation would occur. With red clays washing and shaking were sufficient often to bring about apparent dispersion. Three drops of 28 per cent ammonia were added to the samples which were found to have flocculated on standing overnight, and shaking was continued. In some cases further washing by itself brought about dispersion, whereas even after repeated washing and shaking with ammonia, certain Globigerina oozes, notably samples 22, 27, and 44 could not be dispersed. In these cases no attempt was made to effect satisfactory dispersion by other means or with other peptizing agents, and further mechanical analysis was abandoned. Although such sodium salts as the phosphate, citrate, oxalate, and carbonate are said to effect a greater degree of dispersion than ammonia, the latter was used, principally because the colloidal fractions of the samples analyzed were later to be utilized for chemical and X-ray analyses. The ammonia was probably nearly completely driven off during drying.

When a sample was apparently dispersed, as evidenced by the absence of any fluffy, flocculated mass at the bottom of the bottle after standing, as well as by the appearance of the material under microscope, it was transferred to a half-liter Pyrex graduate and the volume of the suspension was brought up to 500 cc. The graduate was then placed in a water bath, either in a dark constant-temperature room or, in the case of the first analyses, merely away from direct light. One or two pipette samples were withdrawn while the suspension was being thoroughly shaken, and these were used as a measure of the weight of material in suspension. Subsequent samples were withdrawn at increasing time intervals, with 10 and 20 cc automatic pipettes, from measured depths in the suspension, usually 10 or 5 cm. The pipetted samples were first dried on a water bath and then at 105° for several hours, or were dried on a sand bath.

The pipette method rests on the assumption that in a dilute suspension, each particle sinks to the bottom with its own particular velocity independently of other particles. If a thoroughly shaken suspension in which the particles are uniformly distributed is set at rest, all particles having a settling velocity greater than h/t will have settled below the depth $\underline{h}$ at the end of the interval of time $\underline{t}$, whereas all particles of lesser velocity will retain their initial concentration at this depth, since each one of them will have settled below the surface through a distance smaller than $\underline{h}$. Consequently, if a thin horizontal layer of the suspension is removed from the depth h, at the end of time t, the weight of suspended material in it will be a measure of the amount of particles in the suspension having settling velocities less than h/t. Similar measurements of the proportion of particles of various settling velocities will be obtained as often as the process of sampling is repeated.

The fact that particles settling through a medium such as water soon attain constant velocities proportional to the sizes of the particles is expressed in Stokes' law which, in terms of diameters in microns and velocities in microns per second of spherical particles settling in pure water, may be expressed as

$$V = 10^{-4} \times \frac{g(\sigma - 1)}{18\eta} D^2$$

in which g = the acceleration of gravity, σ = the density of the settling spherical particles, and η = the coefficient of viscosity of water in dyne seconds/cm^2. The diameters of the spherical particles may be obtained from the simplified expression $D = C\sqrt{V}$, where C is a constant whose value is essentially dependent on the temperature and the grain densities of the particles. Values of C for differences in density of the settling particles and water from 1.0 to 2.0, and for temperatures between 0 and 30° C are shown in figure 10. The equation gives only the particle diameters of spherical particles, and Stokes' law is not precise for particles which are not spherical. Waddell (1934) has shown, however, that the actual size of even a very flat particle, that is, the radius of a sphere of the same volume as the particle, can be determined with fair accuracy from Stokes' law for particles less than about 0.1 micron in size. Odén (1915, p. 222) has proposed that the difficulty attending the determination of actual particle sizes may be eliminated by the concept of the equivalent radius of a settling particle which is defined as "the radius of a perfect sphere of the same material which will sink at the same average rate as the particle in question, the latter being supposed to retain during its fall a certain orientation with respect to its line of motion." Various other workers, including Atterberg (1905), Mohr (1910), Holmes (1921), Wentworth (1926), and Galliher (1932), have set up empirical relations for the conversion of settling velocities into particle diameters, and these are shown graphically in figure 9, together with the diameter-velocity relation calculated from Stokes' law for particles of density 2.6 settling in pure water at a temperature of 20° C.

Rubey (1930) states that in the sediments investigated by him, the constituent clay particles have thicknesses only about one-seventh of their length and breadth, and that, consequently, the settling velocities of the particles should be equal to those of spheres of diameters between one-third and two-thirds of the maximum diameters of the clay particles. There is shown in figure 9 a curve of the average relation between settling velocity and observed maximum diameters of the particles in the analyzed Carnegie sediments. Although the individual observed points on which the curve is based are rather widely variable, it may be seen that the average maximum diameters of these particles are approximately five-thirds as great as those of perfect spheres of the same settling velocities, a fact which is in close agreement with Rubey's findings.

Stokes' law is applicable only for particles less than about 0.1 mm in size. Beyond this diameter the more complex relation for particles and settling velocities given by Oseen must be used. In the present investigation, however, only particles less than 0.07 mm were analyzed by the pipette method, the coarser materials being analyzed by sieving. The applicability of Stokes' law to extremely fine-grained so-called colloidal particles less than 1 micron in size has been the subject of considerable controversy, but Mason and Weaver (1924) and Johnston and Howell (1930), among others, have shown that the Brownian movement of extremely small particles takes place equally in all directions, and that particles subject to Brownian movement have a residual downward velocity which is given by Stokes' law. This holds true except for the extremely narrow zone just above the bottom of a colloidal suspension. In this zone there is a concentration gradient, as shown by the experimental work of Perrin (1908, 1911), which maintains a steady state. The fact that in most colloidal solutions the suspended particles do not settle out is owing primarily to the presence of slight convection currents caused by inequalities of temperature. When the temperature is maintained constant, it has been found that settling does occur.

Presentation of Results. The data reduced to standard grade sizes obtained in the pipette analyses are shown in table 23, which gives the interpolated percentages for the various size grades of the classification of Udden (1914) and Wentworth (1922). The data are also illustrated graphically in figures 13 to 27, in which the observed settling velocities, as well as the calculated equivalent diameters, are plotted as histograms and cumulative curves. In table 24, the values for the statistical constants employed by Trask (1932), namely the median and quartile diameters, the coefficients of sorting and of skewness, the logarithm of the skewness, and the parts of sand (greater than 50 microns), silt (50 to 5 microns), and clay (less than 5 microns) are shown. The median diameter indicates the mid-point by weight in the size distribution, whereas the quartiles indicate the minimum particle diameters of the parts making up less than 25 per cent, and less than 75 per cent of the cumulative distribution of the sample. The coefficient of sorting, which is defined as $S_0 = \sqrt{(Q_1/Q_3)}$, indicates the degree of spreading or sorting of the particles in a sediment. The better a sediment is sorted, the smaller is the coefficient of sorting. Trask found in the one hundred and seventy sediments analyzed by him that the average coefficient of sorting was close to 3.0, whereas in 25 per cent of his samples S_0 was smaller than 2.5, and in 75 per cent it was smaller than 4.5, the extremes being 1.26 and 9.4.

The dissymmetry of the size distribution curve, that is, the position of the mode or peak of the distribution and its distance from the median, is measured by the coefficient of skewness, which is defined by the equation

$$Sk = \frac{Q1 \times Q3}{M^2}$$

If the mode lies on the fine side of the median diameter, Sk will be greater than 1.0 and log Sk will be positive; if the mode is coarser than the median, Sk will be less than 1.0 and log Sk will be negative. For sediments of symmetrical size distribution, Sk will vary about 1.0 and log Sk will be close to 0; whereas the more Sk diverges from 1.0 and log Sk from 0, the farther the mode lies from the median. In fifty per cent of the samples ana-

Table 23. Mechanical analyses by the pipette

<table>
<tr><th rowspan="2">Sample no.</th><th colspan="7">Percentage in size grades</th></tr>
<tr><th>> 1000</th><th>1000-500</th><th>500-250</th><th>250-125</th><th>125-62.5</th><th>62.5-31.3</th><th>31.3-15.6</th></tr>
<tr><td>19</td><td>0.1</td><td>2.8</td><td>12.3</td><td>8.0</td><td>12.8</td><td>12.0</td><td>3.5</td></tr>
<tr><td>21</td><td>....</td><td>1.0</td><td>10.8</td><td>8.4</td><td>13.2</td><td>8.8</td><td>5.0</td></tr>
<tr><td>23</td><td>....</td><td>0.1</td><td>4.6</td><td>8.3</td><td>8.8</td><td>6.0</td><td>6.8</td></tr>
<tr><td>31</td><td>....</td><td>0.1</td><td>1.6</td><td>1.6</td><td>2.3</td><td>2.2</td><td>2.4</td></tr>
<tr><td>34</td><td>....</td><td>tr</td><td>tr</td><td>0.2</td><td>0.9</td><td>(1.0)</td><td>1.9</td></tr>
<tr><td>40</td><td>....</td><td>3.2</td><td>6.0</td><td>5.9</td><td>8.0</td><td colspan="2">16.7</td></tr>
<tr><td>43</td><td>....</td><td>7.3</td><td>12.5</td><td>5.0</td><td>4.4</td><td>5.0</td><td>6.1</td></tr>
<tr><td>49</td><td>....</td><td>tr</td><td>0.3</td><td>1.0</td><td>1.0</td><td>0.5</td><td>0.5</td></tr>
<tr><td>69</td><td>....</td><td>....</td><td>.....</td><td colspan="4">tr</td></tr>
<tr><td>70</td><td>....</td><td>....</td><td>.....</td><td colspan="2">tr</td><td>(0.9)</td><td>1.2</td></tr>
<tr><td>72</td><td>....</td><td>....</td><td>.....</td><td>....</td><td>1.3</td><td>1.3</td><td>1.4</td></tr>
<tr><td>73</td><td>....</td><td>....</td><td>.....</td><td colspan="4">0.1</td></tr>
<tr><td>74</td><td>....</td><td>....</td><td>.....</td><td colspan="3">tr</td><td>0.6</td></tr>
<tr><td>77</td><td>....</td><td>....</td><td>.....</td><td colspan="2">tr</td><td>(0.8)</td><td>3.5</td></tr>
<tr><td>81</td><td>....</td><td>tr</td><td>2.4</td><td>4.3</td><td>8.0</td><td>6.2</td><td>5.7</td></tr>
<tr><td colspan="6">Average of samples 69, 70, 73, 74, and 77</td><td>0.35</td><td>1.06</td></tr>
</table>

Table 24. Statistical constants calculated from pipette analyses

Sample no.	Q1	M	Q3	So	log Sk	Sk	Sand	Silt	Clay
	In microns						In per cent		
19	113.0	21.3	1.86	7.80	-0.333	0.463	40.0	19.7	40.3
21	97.8	10.4	1.87	7.24	+0.228	1.69	36.0	22.3	41.7
23	43.8	4.70	1.34	5.72	+0.423	2.65	24.2	25.2	50.6
31	4.37	1.51	0.525	2.89	+0.009	1.02	6.7	16.0	77.3
34	2.79	0.95	0.280	3.16	-0.063	0.865	1.2	14.3	84.5
40	54.0	8.03	4.02	3.67	+0.526	3.36	25.8	41.0	33.2
43	124.0	7.55	1.96	7.95	+0.630	4.27	30.8	24.6	44.6
49	4.35	1.97	1.42	1.75	+0.201	1.59	2.4	19.8	77.8
69	2.74	1.12	0.370	2.72	-0.091	0.810	tr	11.0	89.0
70	2.90	1.10	0.351	2.87	-0.075	0.842	0.5	14.5	85.0
72	3.33	1.25	0.420	2.82	-0.047	0.898	1.8	14.2	84.0
73	2.61	1.12	0.352	2.72	-0.137	0.730	tr	12.7	87.3
74	2.85	1.16	0.284	3.17	-0.221	0.601	tr	13.3	86.7
77	2.42	1.01	0.323	2.74	-0.116	0.766	0.2	12.5	87.3
81	18.0	3.35	0.845	4.62	+0.134	1.36	16.6	26.4	57.0
Average of samples 69, 70, 73, 74, and 77	2.704	1.102	0.336	2.844	-0.126	0.750	0.14	12.80	87.06

lyzed by Trask, log Sk varied between -0.18 and +0.12, the extremes being -1.12 and +1.03.

The statistical constants advocated by Trask have been adopted by Stetson (1933) and Gripenberg (1934) in their studies of fine-grained sediments from near Spitzbergen and the Baltic, respectively. There is thus a considerable body of comparable published data expressed in terms of these quantities. Furthermore, the constants are based entirely on the middle half of the size distribution and thus are particularly applicable to analyses of extremely fine-grained samples such as red clays, in which it is not practicable to obtain the complete size distribution.

On the other hand, each of the three methods of presentation of the data from mechanical analyses, namely, by graphic representation, by tabulation of the percentages in various grade sizes, and by tabulation of the statistical constants of the size distribution, possesses certain advantages. For statistical treatment the constants, particularly the median diameter, may be used as single, easily comparable characteristics of a sediment. In interpreting the statistical constants, however, a more or less regular size distribution must be assumed. Irregularities in the size distribution, such as the presence of secondary maxima, can only be indicated by a listing of the percentages in the various size grades, or by a graphical presentation of histograms and of cumulative curves, the latter being essentially the integrals of the true frequency curves. The graphical method has the advantage of being easily comparable, and the cumulative curves may be constructed from determinations of particle sizes at irregularly spaced intervals.

Accuracy. The accuray of the pipette method, as indeed of all sedimentation methods, is dependent on the fulfillment of the following experimental conditions, which are listed by Fisher and Odén (1924):

"1. Complete dispersion of sediment particles and prevention of any tendency to coagulation.

"2. Uniform distribution of every class of particles at starting time t = 0.

method of certain *Carnegie* bottom samples

(Size grades in microns)

15.6-7.81	7.81-3.91	3.91-1.95	1.95-.977	.977-.488	.488-.244	Remainder	Total
3.4	7.4	11.7	12.6	11.0	.....	2.5	100.1
4.8	9.9	12.5	11.3	.....	.....	14.3	100.0
8.4	9.4	14.1	14.6	.....	.....	18.9	100.0
4.2	12.6	16.5	17.8	15.1	8.7	14.8	099.9
4.5	11.1	13.5	16.3	13.8	14.7	22.2	100.1
10.7	26.6	12.9	3.6	.....	.....	6.4	100.0
9.1	9.0	16.6	16.6	7.2	.....	1.2	100.0
10.0	14.4	23.1	.....	.....	.....	49.3	100.1
4.2	10.7	19.6	19.2	15.9	12.4	18.0	100.0
15.6		16.6	18.9	15.5	(14.2)	17.2	100.1
6.6	10.9	16.0	20.2	(15.0)	.....	27.3	....
4.0	13.2	16.4	20.4	14.3	13.7	18.0	100.1
5.1	12.0	18.0	19.5	14.0	7.6	23.2	100.0
1.7	10.5	14.5	20.0	16.4	12.4	20.2	100.0
10.3	10.5	11.6	13.3	.....	.....	27.7	100.0
4.56	10.84	17.02	19.60	15.22	12.06	19.32	100.03

"3. Constant and uniform temperatures so that no convection current or other disturbances occur during sedimentation.

"4. A sufficiently dilute concentration so that the particles may fall independently and that the density of the fluid displaced by the particles is not appreciably different from that of water."

To the above assumptions should be added two more, namely: 5. that the sediments consist of "ultimate particles of definite size, no matter what their actual dimensions, and that analysis of the suspension dispersed into these ultimate sizes leads to one and only one distribution curve" (Gripenberg, p. 56).

6. The density of the settling particles is known.

There are several sources of error which affect the accuracy of the mechanical analyses. These are as follows:

1. Errors of collection and preservation of samples. The random nature of the bottom samples obtained with snappers, and the great distance between the samples, means that the representativeness of such materials with regard to the bottom deposits of any given area is unknown. Besides this essential limitation of the sampling technique, the mechanical composition of the material collected may be altered by washing while it is being hauled to the surface and by alterations during storage.

2. Errors of dispersion. The purpose of dispersion is to destroy all aggregates of ultimate particles without affecting the size of the particles themselves, but no criteria exist to indicate when this process has been accomplished. Although it is often possible to obtain reproducible results with any one method of dispersion, it is known that the addition of various peptizing agents results in the production of differing sedimentation curves (see Galliher, 1933 and Richter, 1931). The subject is exceedingly complex, but it is probable that the concept of ultimate particle size should be abandoned and that a statement of the distribution curve of colloidal particles in a sediment is valid only for a given set of base exchange ions in the outer layer of the colloidal micelles, and of dissolved ions in the dispersing medium, as suggested by the work of Gedroiz (1931) and Mattson (1929). The most satisfactory procedure of dispersion, then, would be that which maintained as closely as possible the original set of base exchange ions in the colloidal micelles.

3. Errors caused by the initial current resulting from stirring in the settling tube. That this error is rather pronounced is shown by the relatively large variations found in the 62.5- to 31.3-micron size grades of the multiple analyses given in table 25. According to Fisher and Odén, the error due to such initial currents becomes negligible only after 53 minutes.

4. Convection currents in the settling tube, due to changes of temperature during prolonged settling, result in mixing and therefore in an apparent increase of the very fine grades at the expense of the maximum sizes affected by the mixing. The magnitude of this error is unknown, but it probably amounts to several per cent, as differences in temperature between the walls and the center of the settling cylinder of even a few hundredths of a degree probably give rise to currents equal in magnitude to the settling velocities of particles less than a fraction of a micron in diameter.

5. The difficulties attending the calculation of particle size from observed settling velocites already have been discussed in part. In addition to the fact that the particles are not spherical, and hence do not exactly obey Stokes' law, differences in the densities of the settling micelles due to (1) variations in the specific gravity of the mineral particles and (2) to the varying amounts of water adhering to them, give rise to inaccuracies in the determination of equivalent diameters. An examination of the data given in Dr. Nutting's report on the mean grain densities of the samples shows that these vary about 0.1 unit in any given type of deposit. From figure 10 it may be calculated that at 20° and at a density of 2.7, an error of 0.2 in the determination of density results in a 6 per cent difference in calculated diameter and a percentage error of 1.5 per cent in the distribution curve of the samples analyzed. Changes of temperature result in changes in the viscosity term of Stokes' law and hence also affect the determination of particle size. It may be calculated from figure 10 that with a grain density of 2.7, a change in temperature from 25° to 20° results in an error exactly similar to an error of 0.2 in

Table 25. Multiple analyses by the pipette method of fractions less than 70 microns in particle diameter

(Data reduced to standard size grades)

Sample 31. Duplicate analyses on parts dispersed separately

Equivalent particle diameter in microns	Per cent by weight of particles in size grade			Cumulative per cent of particles larger than diameter indicated		
	A	B	Deviation (A - B)	A	B	Deviation (A - B)
70				0.0	0.0	
	0.7	4.3	-3.6			
31.3				0.7	4.3	-3.6
	3.5	1.4	+2.1			
15.6				4.2	5.7	-1.5
	5.0	4.0	+1.0			
7.81				9.2	9.7	-0.5
	13.3	13.4	-0.1			
3.91				22.5	23.1	-0.6
	16.5	18.5	-2.0			
1.95				39.0	41.6	-2.6
	19.4	18.3	+1.1			
0.98				58.4	59.9	-1.5
	16.4	15.6	+0.9			
0.49				74.8	75.5	-0.7
	9.5	9.0	+0.5			
0.24				84.3	84.5	-0.2
	15.7	15.6	+0.1			
Total	100.0	100.1				

Settling in dark "constant-temperature" room was continued for about 95 hours. Ten and six samples were taken from A and B respectively, at irregular intervals and at depths below surface of suspension between 10 and 3 cm (for settling velocities see fig. 11). Temperatures varied between 14°5 and 12°3 C, but rate of change of temperature was less than 0°04 per hour.

Average deviation of percentages in each size grade = 1.3 per cent; σ = standard deviation of percentages in each size grade = 1.2 per cent; P.E. = probable error of percentages in each size grade = 0.8 per cent. Without first value, average deviation = 1.0 per cent; σ = 0.9 per cent; P.E. = 0.6 per cent. Average deviation of cumulative percentages = 1.4 per cent; σ = 1.4 per cent; P.E. = 0.9 per cent. Without first value, average deviation = 1.1 per cent; σ = 1.0 per cent; P.E. = 0.7 per cent.

Sample 19. Triplicate analyses on parts dispersed separately

Equivalent particle diameter in microns	Per cent by weight of particles in size grade					Cumulative per cent of particles larger than diameter indicated				
	A	B	C	Average	Average deviation	A	B	C	Average	Average deviation
70						0.0	0.0	0.0		
	9.8	15.2	12.8	12.6	1.9					
31.3						9.8	15.2	12.8	12.6	1.9
	8.4	3.9	4.7	5.7	1.8					
15.6						18.2	19.1	17.5	18.3	0.6
	5.8	5.3	6.0	5.7	0.3					
7.81						24.0	24.4	23.5	24.0	0.3
	12.3	12.5	12.8	12.5	0.2					
3.91						36.3	36.9	36.3	36.5	0.3
	20.3	19.1	20.3	19.8	0.6					
1.95						56.6	56.0	56.6	56.4	0.3
	23.3	17.6	22.4	21.2	2.3					
0.98						79.9	73.6	79.0	77.5	2.6
	20.1	21.6	13.6	18.4	3.2					
0.49						100.0	95.2	92.6	95.9	2.7
	0.0	4.8	7.4	4.1	2.7					
Total	100.0	100.0	100.0	100.0						

For A and B, settling in dark "constant-temperature" room, at temperatures between 17°6 and 16°6 C was continued for about 45 hours; for C, settling was continued for 73 hours at temperatures between 13°4 and 12°4 C. In all three experiments 8 samples were taken at irregular intervals, and at depths below surface of suspension between 10 and 4 cm. Settling velocities are shown in fig. 11.

density, namely a 6 per cent increase in the calculated particle diameter, and a percentage error of 1.5 per cent in the distribution curve of the samples analyzed. Robinson (1926, 1927), among others, has suggested that because of the difficulties in determination of particle size, the data of mechanical analyses should be presented in terms of settling velocities. In samples which contain appreciable amounts of sand grades, however, this procedure cannot be followed satisfactorily, and even when the data are presented in terms of particle diameters, considerable uncertainty arises in the joining of the two parts of the distribution curves. As pointed out by Krumbein, a concept of equivalent radius is implied in the mechanical analysis by sieving of irregularly shaped sand grains, as the results of sieving are based on the minimum and mean dimensions of the particles. The rate of sedimentation, on the contrary, is dependent on the maximum and mean dimensions of the particles.

6. The error due to the concentration of the settling solution is negligible, according to Fisher and Odén (1924), if the concentration is less than 2 per cent.

7. There are certain errors inherent in the pipette method itself which arise in the withdrawal of the pipette sample. These are owing to (1) the inaccuracy in measuring the depth of samples, (2) a certain amount of mixing which accompanies the introduction of the pipette into the suspension,and (3) the fact that the pipette does not withdraw a horizontal stratum of extreme thinness as required by theory, but rather taps a spherical zone. Kohn (1928) and Keen (1931) have shown that the errors due to this last cause are practically negligible.

In an attempt to determine empirically the magnitude of the errors in the pipette analyses, duplicate and triplicate analyses were carried out on samples 31 and 19, respectively. The results are given in table 25. The two parts of sample 31, a red clay from the south Pacific containing 20 per cent calcium carbonate, remained dispersed throughout the period of the experiment. The deviation in duplicate determinations of the fraction greater than 31.3 microns in particle size was 3.6 per cent, an error probably arising in the initial sampling. For the remaining size grades the average deviation between duplicate determinations was 1.0 per cent and the probable error of a single determination was 0.6 per cent. The average deviation of the cumulative percentages was slightly greater. These results may be compared with those given by Gripenberg, who obtained an average deviation between duplicate determinations of 0.8 per cent. A calculation from the data given by Rittenhouse shows a probable error for a single determination of 0.54 per cent. It should be emphasized that the measures of variation or error given above are expressed as percentages of the total amount of material in the sample analyzed, and not of the amount of material in the size grades. Correns and Schott (1932) have published comparative data on mechanical analyses by the method of Atterberg, a modified Odén method, and the pipette method. Although the results of duplicate analyses are presented only graphically by these authors, a study of their figures shows that deviations between duplicate analyses by the pipette method are of about the same order of magnitude as those given above. The general agreement between different methods of analyses is also quite good.

The agreement between the triplicate determinations in sample 19 is very satisfactory for grade sizes between 15.6 and 2 microns. Below this point, however, the analyses show a marked discrepancy which probably is owing to differing degrees of dispersion between the three parts analyzed, and to slow coagulation.

Results. As already stated, the results of the pipette analyses are given in table 23 which lists the percentages in each size grade, and in table 24 which gives the statistical constants for each sample. The analyses may be conveniently placed in two groups, those of clays low in calcium carbonate, and those of Globigerina oozes. Figures 13 to 21 give histograms and cumulative curves in terms of both settling velocities and equivalent diameters for the nine clays analyzed, namely, numbers 31, 34, 49, 69, 70, 72, 73, 74, and 77; the figures for the Globigerina oozes, numbers 19, 21, 23, 40, 43, and 81 are grouped in figures 22 to 27.

The most striking fact shown by the analyses of the clays is the essential uniformity of the particle size distribution of these samples, with the exception of no. 49. The shape of the curve for this sample almost certainly indicates that coagulation occurred during analysis, and this was confirmed by the appearance of stratified layers in the suspension. Sample 31, doubtless owing to the presence of 20 per cent calcium carbonate, is somewhat more coarse-grained than the other clays, and sample 72, which contains a greater amount of siliceous organic remains than most north Pacific red clays, also has a slightly greater median diameter. The average median diameter of the remaining clays, nos. 34, 69, 70, 73, 74, and 77 is close to 1.05 microns, and the deviations between the percentages found in each size grade are almost within the limits of error of the method of analysis, the deviation of the percentages in nos. 69, 70, 73, 74, and 77 from the average for these samples being 1.20. The coefficient of sorting of these clays averages about 2.9, ranging from 3.17 in sample 74 to 2.72 in sample 73. The clays thus show a fair degree of sorting. The skewness is small in every sample except no. 74 which shows a moderate skewness toward the coarse side, perhaps caused by convection currents during analysis. The average cumulative curve for samples 69, 70, 73, 74, and 77 is shown in figure 12, compared with results for other marine clays obtained by Galliher (1932), Rubey (1930), Stetson (1933), Trask (1932), and Gripenberg (1934). The general parallelism between all the curves is easily seen, but it will be noticed that the only sediments as fine-grained as these clays are those obtained from the Baltic Sea by Gripenberg. On the other hand, the marine Middle Oligocene clay from Malliss, analyzed by Correns and Schott (1932), is even more fine-grained than any of the Pacific clays, as are many soils. Odén (1915), in his analysis of a Challenger sample from the Atlantic, pointed out the fine-grained nature of red clay. The curve given by Odén for a Challenger red clay from the south Pacific is very similar to that obtained for Carnegie sample 49 from the same area, and probably also represents coagulation during or preceding analysis.

The curves for the Globigerina oozes, samples 19, 21, 23, 40, 43, and 81, are much more complex in type. Well-developed double maxima in the sand and clay grades are shown in the histograms of samples 19 and 43, and to a lesser extent of the remaining samples, except no. 40. Double maxima are also strikingly shown in the analyses by the Bureau of Soils' method given below. Odén likewise found curves showing two maxima in his analyses of Globigerina oozes from the Atlantic and Pacific. A few analyses, given in table 26, of the calcium

Table 26. $CaCO_3$ content of different size grades in certain calcareous samples

Sample no.	Size grade and $CaCO_3$ per cent of grade (A) and of sample (B)									
	.25 - .12 mm		.12 - .07 mm		.07 - .03 mm		.03 - .005 mm		< .005 mm	
	A	B	A	B	A	B	A	B	A	B
17*	94.1	6.0	95.8	8.9	94.7	8.1	57.9	9.6	74.9	25.6
20 top	.....	.....	.....	....	.....	.....	61.2	20.9	65.6	22.4
20 bottom	.....	.....	.....	.....	.....	.....	77.8	38.3	53.7	11.9
24	93.2	17.6	.....	....	94.7	16.7	89.8	17.6	83.2	19.0
40	.....	.....	.....	....	.....	.....	84.0	29.5	57.5	19.1
53	.....	.....	39.9	2.6	35.6	6.8	51.8	10.7	61.5	23.7
82	.....	.....	.....	....		5.0	93.7		80.8	53.5

*Although the method used is accurate only for comparison purposes, the sum of the $CaCO_3$ found, plus that estimated microscopically for the remaining sand grades, agrees well with the value of total $CaCO_3$ given in table 1, for all samples except no. 17. The discrepancy in this sample is owing to the fact that the part used in chemical analysis did not contain as great amounts of volcanic glass fragments as did the part which was mechanically analyzed.

carbonate content in the different size grades of certain Globigerina sediments were carried out by a titration method similar to that described by Trask (1932). The results indicate the presence in some samples of double maxima in the proportions of calcium carbonate in the different size grades. This is shown particularly well in sample 17, a volcanic ferruginous ooze from the southeast Pacific. The sand grades of this sample contain approximately 95 per cent calcium carbonate and the clay grades about 75 per cent. The silt grades, on the other hand, contain only 58 per cent $CaCO_3$. The top part of sample 20 similarly shows less $CaCO_3$ in the silt grade than in the clay, and $CaCO_3$ increases in a regular manner from the sand to the clay in sample 53. In the remaining samples--20 (bottom), 24, 40, and 82--the calcium carbonate, as is to be expected, decreases with decreasing particle size. If all the calcium carbonate in these sediments comes from the breaking up of the shells of foraminifera, it is difficult to understand the size distribution of $CaCO_3$ in samples 17, 20, and 53. A possible explanation for this distribution is that the fine-grained calcium carbonate has a different origin from that of the sand grades.

In general, the median particle diameters of deep-sea sediments vary directly with the amounts of calcium carbonate in them. This relation is well shown by the samples from the south Pacific which were analyzed by the pipette method, as may be seen from figure 28 in which the logarithms of the median diameters of samples 19, 21, 31, 34, 40, 43, and 81 are plotted against the respective contents of calcium carbonate. Correns has pointed out a similar relation for the deep-sea sediments of the south Atlantic.

Bureau of Soils' Method

Besides the precise analyses by the pipette method described above, forty-one mechanical analyses by the older method of the United States Bureau of Soils were carried out by A. H. Barker and the author. The results as percentages in various size grades are given in table 27 and are plotted in figures 31 to 36. The method used is quite familiar and it need only be pointed out that the errors involved are of a far greater order of magnitude than those of the pipette method. For coarse-grained samples, however, the method is fairly satisfactory.

In table 28 the magnitude of the errors due to sieving and quartering in the mechanical analyses of the sand grades of two Globigerina oozes, nos. 19 and 21, is shown. The probable error due to sieving was found to vary between 0.2 and 0.5 per cent; that due to quartering is close to 0.4 per cent. The probable error of a single determination by sieving of the percentages in any sand size grade thus varies between 0.4 and 0.6 per cent. That these differences are of little significance in the interpretation of the analyses may be seen from figures 29 and 30, in which histograms are shown of the most widely differing of the multiple analyses of the sand grades of these two samples. Compare, in this connection, the results obtained by Wentworth (1927).

In figure 31 are shown the histograms from mechanical analyses, both by the Bureau of Soils' method and the pipette method, of thirteen Globigerina oozes from the south Pacific which show double maxima in the size distribution, one in the sand and the other in the clay grade. It has been pointed out already that this size distribution may reflect a similar distribution of the calcium carbonate content.

The remaining Globigerina oozes, for which histograms are shown in figure 32, may be divided into four groups as follows: (1) a group of six samples of high $CaCO_3$ content in which there is a single maximum in the sand grades owing to the preponderance of unbroken shells of pelagic foraminifera; (2) a group of four samples of intermediate calcium carbonate content in which there is a single maximum in the fine grades owing to the presence of much finely divided calcium carbonate as well as of fine-grained noncalcareous material; (3) three samples--nos. 15 and 17, Globigerina oozes from the south Pacific, and no. 53, a volcanic Globigerina mud from the northwest Pacific--which contain a relatively large amount of volcanic debris of gravel or sand size in addition to pelagic foraminifera and fine material, hence are poorly sorted; (4) a group of three samples which were not satisfactorily dispersed because of the presence of large amounts of iron and manganese oxide. These are included simply to indicate the appearance of such unsatisfactory mechanical analyses of Globigerina oozes.

Histograms for all the samples of north Pacific clay which were mechanically analyzed either by the pipette or the Bureau of Soils' methods are shown in figure 33. The difficulty of interpretation of the analyses made by

Table 27. Mechanical analyses of certain Carnegie bottom samples by the method of the United States Bureau of Soils

Sample no.	Diameter in mm											
	8	8 - 4	4 - 2	2 - 1	1 - .5	.5 - .25	.25 -.12	.12 - .07	.07 - .03	.07 - .005	.03 - .005	< .005
	Percentage in size grades											
10	....	.....	.....	.....	......	3.4	5.0	1.6	.....	1.3	.....	88.8
11	....	35.0	42.3	17.8	3.7	1.2		.....	.....	.....	.....	.....
13	....	.....	.....	.....	0.2	4.0	7.5	8.7	.....	11.8	.....	67.9
14	....	.....	.....	.....	0.1	7.5	5.3	3.6	.....	3.3	.....	80.1
15	....	57.3	.....	.....	3.6	9.7	11.3	6.3	7.6	.....	4.2	.....
16	....	.....	.....	.....	8.5	16.4	11.6	8.7	.....	7.6	.....	47.2
17	9.8	3.4	2.8	0.3	2.2	6.4	6.4	9.3	8.6	.....	16.6	34.2
18	....	.....	.....	.....	3.1	10.5	9.6	11.0	.....	7.9	.....	58.0
20 top	....	.....	.....	.....	2.1	8.0	6.0	6.4	9.1	.....	34.2	34.2
20 bottom	....	.....	.....	.....	1.4	6.8	6.7	10.6	3.2	.....	49.2	22.1
22	....	.....	.....	.....	0.3	1.3	2.2	3.0	.....	48.6	.....	44.6
24	....	1.4	.....	.....	0.3	9.1	18.9	10.3	17.6	.....	19.6	22.8
25	....	.....	.....	.....	0.4	6.0	6.9	7.8	.....	32.5	.....	46.5
26	....	.....	.....	.....	1.9	17.1	14.9	8.4	.....	28.5	.....	29.3
27	....	.....	.....	.....	tr	2.8	6.2	0.9	.....	76.3	.....	13.7
29	....	.....	.....	.....	1.3	20.2	28.7	22.2	.....	22.5	.....	5.1
35	....	.....	.....	.....	tr	0.3	1.9	4.7	.....	10.8	.....	82.2
36	....	.....	.....	.....	4.9	19.9	7.0	5.2	.....	13.4	.....	49.6
37	....	.....	.....	.....	22.1	43.1	19.3	11.5	4.0			
41	....	.....	.....	.....	10.2	16.5	8.1	9.0	.....	15.9	.....	40.4
42	....	.....	.....	tr	20.4	37.2	19.0	19.9	3.5			
44	....	.....	.....	.....	0.2	2.4	17.8	11.3	.....	57.2	.....	11.1
45	....	.....	.....	.....	10.8	21.6	11.1	8.1	.....	26.5	.....	21.9
51	....	.....	.....	0.3	0.4	2.9	8.0	8.9	35.4	.....	24.1	20.0
53	....	.....	.....	0.1	0.4	6.8	8.1	6.5	19.1	.....	20.6	38.5
54	....	.....	.....	.....	0.1	0.3	1.7	4.6	27.3	.....	41.8	24.3
56	....	.....	.....	.....	0.1	0.8	2.3	7.0	.....	26.9	.....	62.9
57	8.6	.....	.....	0.1	0.1	0.3	3.1	5.6	.....	13.2	.....	69.0
58	....	.....	.....	.....	0.1	0.3	2.9	5.8	.....	17.4	.....	73.4
59	....	.....	.....	.....	tr	0.2	1.3	2.0	.....	19.6	.....	76.8
60	....	.....	.....	.....	0.3	0.2	1.3	2.2	.....	40.4	.....	55.6
61	....	.....	.....	.....	.....	tr	tr	0.2	.....	8.7	.....	91.0
62	....	.....	.....	.....	tr	0.1	0.4	0.5	.....	2.5	.....	96.5
64	....	.....	.....	.....	.....	tr	tr	0.1	.....	6.2	.....	93.6
65	....	.....	.....	.....	.....	tr	tr	tr	.....	3.3	.....	96.7
66	....	.....	.....	.....	.....	tr	tr	tr	.....	3.2	.....	96.8
79	....	.....	.....	.....	0.2	0.2	1.7	2.9	.....	4.5	.....	90.5
80	....	.....	.....	.....	0.3	1.1	5.1	3.8	.....	4.1	.....	85.7
82	....	.....	.....	.....	3.6	11.5	8.2	5.3	.....	5.3	.....	66.2
85	....	.....	.....	.....	3.8	10.6	15.8	16.2	.....	8.3	.....	45.3
88	....	.....	.....	.....	0.2	1.0	2.6	6.9	.....	4.7	.....	84.6
89	....	.....	11.3		50.0	37.1	1.6	tr	.....	.....	.....	.....

the older method for fine-grained samples is well shown in this figure. These analyses, however, do confirm the conclusions as to the uniform nature and extreme fineness of grain of the mechanical composition of north Pacific clays which were stated in the discussion of the pipette analyses.

Histograms for the five detrital muds and red clays of the south Pacific which were analyzed, are shown in figure 34. The double maxima in the size distribution of sample 10 are owing to the presence of coprolitic pellets. The remaining four analyses were made by the pipette method and have been discussed previously.

Analyses of the five more or less volcanic siliceous muds and oozes collected northeast of Japan, samples 56 to 60, which have been shown to be nearly identical in chemical composition, are illustrated in figure 35. The progressive decrease in the amount of sand-size material reflects the change in physical composition of these sediments, corresponding to increasing distance from shore, from a deposit with a high content of volcanic debris such as that of no. 56, to an argillaceous diatom ooze containing very little volcanic material, such as sample 60.

Three analyses of volcanic sediments and two of near-shore sediments are also shown in figure 35. The large average diameter of the material in sample 11 probably indicates that this is a residual deposit from which the fine material has been removed by currents. In samples 51 and 52 the relatively large amounts of material between 1/16 and 1/32 mm diameter are owing to the presence of many small skeletons of radiolaria and frustules of diatoms.

Table 28. The magnitude of the errors owing to sieving and quartering in the mechanical analysis of sand grades

Size grades in mm	First part			Second part			Third part			Fourth part			Grand average
	A	B	Average	A	B	Average	A	B	Average	A	B	Average	
Sample 19 divided into four parts, and each part sieved twice													
Percentages in size grades													
> 1	0.31	0.31	0.31	0.20	0.20	0.20	0.29	0.29	0.29	0.07	0.07	0.07	0.22
1 - .5	8.57	8.92	8.74	8.59	8.36	8.48	8.32	8.31	8.31	8.84	9.18	9.01	8.64
.5 - .25	39.80	39.48	39.64	39.75	39.82	39.79	40.82	40.61	40.71	41.45	41.51	41.48	40.41
.25 - .12	25.72	26.75	26.23	26.03	26.68	26.35	25.11	24.93	25.02	26.53	26.01	26.27	25.98
.12 - .07	20.51	19.37	19.94	19.97	19.20	19.59	18.79	19.15	18.97	18.49	18.44	18.46	19.24
< .07	5.08	5.17	5.12	5.46	5.73	5.59	6.67	6.72	6.69	4.61	4.78	4.69	5.53
Total	99.99	100.00	....	100.00	99.99	....	100.00	100.01	....	99.99	99.99	....	....
Total weight in grams	1.633	....	....	1.502	....	....	1.394	....	....	1.368	....	....	....
Deviations between duplicate determinations in each part													
> 1	....	0.00	....	....	0.00	....	....	0.00	....	....	0.00	....	....
1 - .5	....	-0.35	....	....	+0.23	....	....	+0.01	....	....	-0.34	....	....
.5 - .25	....	+0.32	....	....	-0.07	....	....	+0.21	....	....	-0.06	....	....
.25 - .12	....	-1.03	....	....	-0.65	....	....	+0.18	....	....	+0.52	....	....
.12 - .07	....	+1.14	....	....	+0.77	....	....	-0.36	....	....	+0.05	....	....
< .07	....	-0.09	....	....	-0.27	....	....	-0.05	....	....	-0.17	....	....
Average deviation = 0.29 per cent; σ_1 = standard deviation = 0.33 per cent; P.E.$_1$ = 0.22 per cent = probable error owing to sieving.													
Deviations from grand average of the averages of each part													
> 1	....	+0.09	....	....	-0.02	....	....	+0.07	....	....	-0.15	....	....
1 - .5	....	+0.10	....	....	-0.16	....	....	-0.33	....	....	+0.37	....	....
.5 - .25	....	-0.77	....	....	-0.62	....	....	+0.30	....	....	+1.07	....	....
.25 - .12	....	+0.25	....	....	+0.37	....	....	-0.96	....	....	+0.29	....	....
.12 - .07	....	+0.70	....	....	+0.35	....	....	-0.27	....	....	-0.78	....	....
< .07	....	-0.41	....	....	+0.06	....	....	+1.16	....	....	-0.84	....	....
Average deviation = 0.44 per cent; σ_2 = 0.57 per cent; P. E.$_2$ = 0.38 per cent = probable error owing to quartering; σ = standard deviation of a single determination $= \sqrt{\sigma_1^2 + \sigma_2^2}$ = 0.66 per cent; P. E. = probable error of a single determination = 0.44 per cent.													
Sample 21 divided into two parts, and each part sieved twice													
Percentages in size grades													
1 - .5	3.74	3.63	3.69	4.39	4.20	4.30	....	....	....	....	....	....	3.99
.5 - .25	42.06	42.44	42.25	43.87	43.31	43.59	....	....	....	....	....	....	42.92
.25 - .12	35.51	33.53	34.52	35.10	35.96	35.53	....	....	....	....	....	....	35.02
.12 - .07	17.99	19.58	18.79	16.00	15.88	15.94	....	....	....	....	....	....	17.36
< .07	0.70	0.82	0.76	0.65	0.66	0.66	....	....	....	....	....	....	0.71
Total	100.00	100.00	....	100.01	100.01	....	....	....	....	....	....	....	....
Total weight in grams	....	0.856	....	....	0.775	....	....	....	....	....	....	....	....
Deviations between duplicate determinations in each part													
1 - 5	....	+0.11	....	....	+0.19	....	....	....	....	....	....	....	....
.5 - .25	....	-0.38	....	....	+0.56	....	....	....	....	....	....	....	....
.25 - .12	....	+1.98	....	....	-0.86	....	....	....	....	....	....	....	....
.12 - .07	....	-1.59	....	....	+0.12	....	....	....	....	....	....	....	....
< .07	....	-0.12	....	....	-0.01	....	....	....	....	....	....	....	....
Average deviation = 0.59 per cent; σ_1 = 0.69 per cent; P. E.$_1$ = 0.46 per cent = probable error owing to sieving.													
Deviations from grand average of each set of determinations													
1 - .5	0.25	0.36	....	0.40	0.21	....	....	....	....	....	....	....	....
.5 - .25	0.86	0.48	....	0.95	0.39	....	....	....	....	....	....	....	....
.25 - .12	0.49	1.49	....	0.08	0.94	....	....	....	....	....	....	....	....
.12 - .07	0.63	2.22	....	1.36	1.48	....	....	....	....	....	....	....	....
< .07	0.01	0.11	....	0.06	0.05	....	....	....	....	....	....	....	....
Average deviation = 0.64 per cent; σ = standard deviation of a single determination = 0.90 per cent; P. E. = probable error of a single determination = 0.60 per cent. $\sigma_2 = \sqrt{\sigma^2 - \sigma_1^2}$ = 0.57 per cent; P. E.$_2$ = 0.38 per cent = probable error owing to quartering.													

X-RAY ANALYSIS

Discussion of Method

In order to obtain information on the mineralogical composition of the fine fractions of the sediments, X-ray diffraction patterns of the silt, clay, and colloidal grades of a number of samples were made by the method of Debye and Scherrer (1916) and Hull (1917). Mr. W. H. Dore kindly co-operated in this part of the study. The materials were ground in an agate mortar, packed into thin-walled glass tubes having inside diameters of the order of 0.5 mm and exposed for 24 hours in an X-ray diffraction apparatus supplied by the General Electric Company. A Coolidge tube with a molybdenum target was used as the source of X-rays, and the rays were passed through a zirconium oxide screen, so that their effective wave length was 0.712 angstrom unit. The photographic films on which the diffraction patterns were recorded were placed in cassettes of 8-inch radius at the center of which were located the tubes containing the specimens. Incident X-ray beams were directed through a narrow slit (0.02 by 0.5 in.) on these tubes, and images of the slit were produced on the film by the undeflected beam and by the various beams deflected by the powdered particles.

The Debye-Scherrer method[1] of X-ray analysis of finely powdered crystalline substances depends on the fact that the constituent grains of such fine powders are, in reality, minute crystals which are in random arrangement. Even in a small amount of finely powdered crystalline material there will be some crystalline fragments so arranged with respect to the X-ray beam that they will produce reflections in phase on a suitably placed photographic film corresponding to each interplanar spacing.

Since no two minerals have exactly the same atomic structure, the diffraction pattern of an unknown mineral may be employed for its identification by comparison of the pattern with those of known substances.

In a mixture of two or more crystalline minerals the patterns of each mineral remain the same, but the patterns are superimposed on each other. Some of the lines of one pattern often coincide with some of the lines of the other patterns and the greater the number of compounds, the greater the probability of overlapping or coincidence of lines. If the number of compounds is not too great, however, there are usually some lines which are characteristic of each compound in the mixture and are not shown by the remainder of the substances. In a mixture the general intensity of each pattern is diminished because of dilution, and coincidences of lines cause some difference in relative intensity.

As the quantity of any crystalline substance in a mixture decreases, so does the intensity of its pattern. First the less intense lines disappear, and then the stronger ones, until a point is reached when the strongest lines can no longer be seen. According to Brownmiller and Bogue (1930) quantities of material less than 2 or 3 per cent can rarely be identified even under the most favorable conditions; Hendricks and Fry (1930) state that in the case of clay minerals, amounts less than 10 per cent are not indicated in the diffraction patterns. The minimum amount of material necessary for identification is a function of the simplicity of structure and degree of symmetry of the crystals, also of their size and shape. Sodium chloride, for example, can be readily detected, owing to its high symmetry and simple structure, even when present in very small amounts.

On the other hand, noncrystalline or amorphous substances, the atoms of which occupy more or less random positions, do not give definite patterns, hence cannot be recognized except by a more or less general fogging of the film, even when present in large amounts.

Nagelschmidt (1934) has pointed out the special difficulties attending the application of the X-ray method, when applied to fine-grained sediments and soils. These arise from the following causes:

1. Certain of the minerals occurring in clays have low symmetry, and their X-ray diagrams therefore have many lines.
2. The crystal structure of many of the minerals of fine-grained sediments is very similar and their powder diagrams are correspondingly difficult to distinguish.
3. A broadening of the diffraction lines and increase in diffused radiation takes place when crystal particles are smaller than 0.05 micron, as they are in many clays.
4. The crystal structures of certain minerals occurring in fine-grained sediments are not accurately known, hence a theoretical prediction of the applicability and limits of the method for purposes of quantitative identification is not possible at present.

The precision of measurement of the interplanar spacings increases as the magnitude of the spacing decreases. In their investigation of the constituents of Portland cement, Brownmiller and Bogue, using a machine similar to that used in this investigation, found an extreme error of less than 1 per cent for interplanar spacings of 2.990 angstroms and 0.4 per cent for interplanar spacings of 1.202 angstroms. Nagelschmidt, using a more modern type of machine and copper-K-radiation, obtained a maximum deviation of 1 per cent in measurements of interplanar spacings of 4 angstroms, and 0.1 per cent for interplanar spacings of 1 angstrom. Measurements of weak lines and of diffuse lines are of greater inaccuracy than these figures would indicate.

Measurements were made on the centers of narrow lines; for broad lines the measurements in brackets given in the tables are for both edges of the lines. These broad lines probably often consist of two or more narrow lines, but molybdenum radiation is said by Nagelschmidt to be of too short a wave length to give satisfactory resolution for lines that are close together. The intensity of the lines was determined visually.

The results of the X-ray analyses are given in table 29. Part A of this table gives the measured interplanar spacings found in eighteen fine fractions of fifteen calcareous sediments. The silt and clay grades obtained in mechanical analyses by the Bureau of Soils' method and the parts of definite particle size, ranging from less than 3 to less than 1 micron obtained in the pipette method of mechanical analyses were investigated. Part B of table 29 gives the measured interplanar spacings of seventeen samples of low calcium carbonate content, including 11 red clays, 1 green (coprolitic) mud, 1 green clayey mud, 2 volcanic muds, 1 diatom ooze, and 1

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[1] For other discussions of the application of X-ray methods to the study of colloidal fractions of sediments and soils, see Kelley, Dore, and Brown (1931), and Nagelschmidt (1934).

Table 29-A. Interplanar spacings of the finer fractions of certain Carnegie bottom samples

Samples of high $CaCO_3$ content

Sample no., station no., size, d_{hkl}, and intensity of characteristic spacings											
14		16		17		17		19		20	
44		47		49		49		52		54 (top)	
Clay		Clay		Silt		Colloid		<1 micron		Clay	
d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.
8.1	?										
7.1	vvw	7.15								7.15	?
		5.9 5.7	tr							5.9 5.7	tr
4.42	vvw	4.53	vvw			4.50	vw	4.47	vw	4.53	vvw
4.0	vvw	4.27	vvw			4.20	vw			4.20	vvw
3.82	mw	3.87	mw	3.82	w	3.83	w	3.83	w	3.87	mw
3.60	vw	3.60	vw							3.58	vw
3.45	vw	3.43	w	3.40	vw	3.46 3.33	w			3.44	tr
3.31	vw							3.33	vw		
		3.20	vvw							3.20	vvw
3.08 2.98	vs	3.06 3.00	vs	3.05 2.97	vs	3.08 2.99	vs	3.09 2.99	vs	3.06 3.0	vs
		2.92	vvw					2.89	vw		
2.83 2.79	mw	2.82	mw	2.81	vw	2.84	vw			2.82	m
		2.70	vvw							2.70	vvw
		2.62	vvw							2.62	vvw
2.49	ms	2.49	ms	2.48	ms	2.51 2.45	ms	2.49	ms	2.49	m
2.39	vw	2.39	vvw							2.39	vvw
2.28	s	2.28	ms	2.28	ms	2.30 2.26	ms	2.29	s	2.28	ms
		2.22	w								
		2.09	ms	2.08	ms	2.10 2.07	ms	2.10	s		
		2.04	vw							2.04	vw
2.00	w	1.99	m	1.923 1.90	s	1.93 1.90	s			1.99	m
1.915	s	1.915	s					1.92	s	1.915	s
1.875	s	1.87	s	1.875 1.855	s	1.88 1.86	s	1.88	s	1.87	s
1.82	vw										
1.79	?	1.79	?							1.795	vvw
1.705	vvw	1.70	vw	1.71	vw	1.73 1.70	w			1.70	vw
1.63	m	1.625	w							1.625	w
1.60	ms	1.60	ms	1.597	m	1.61 1.59	m	1.61	ms	1.60	ms
1.52	ms	1.53 1.51	ms	1.51	m	1.53 1.51	m	1.52	ms	1.53 1.51	ms
1.475	w	1.47	w	1.47	w	1.473	w	1.475	w	1.47	w
1.44	m	1.44	m	1.433	m	1.438	m	1.44	m	1.44	m
1.415	mw	1.42	w	1.413	mw	1.41	w				
1.36	w	1.36	w	1.355	vw	1.36	w				
1.34	w	1.335	mw	1.33	vw	1.33	w				
1.295	mw	1.295	m	1.29	w	1.29	mw	1.30	w	1.295	m
		1.26	w							1.26	mw
1.239	m			1.237	w	1.24	w	1.24	w		
		1.205	w							1.205	w
1.176	mw	1.175	mw	1.17	mw	1.18	mw	1.18	w	1.175	w
1.15	m	1.15	mw	1.15	mw	1.150	mw	1.153	w	1.15	mw
1.14	w	1.14	w							1.14	w
1.12	vw	1.125	vvw							1.125	vvw
1.06	vw	1.06	vw							1.06	vw
1.042	m	1.04	mw	1.040	mw	1.043	mw	1.042	w	1.04	mw
1.008	mw	1.01	mw	1.008	w	1.010	w	1.012	w	1.01	mw
0.982	w	0.983	w	0.978	vw	0.982	w	0.987	w	0.983	w
0.962	vw	0.962	w	0.961	w	0.963	w	0.961	w	0.962	w
0.939	w	0.940	w	0.940	w	0.949	w	0.938	w	0.940	w
0.922	vvw	0.923	w							0.923	w
0.893	w	0.895	vw	0.895	vw	0.890	vw				
0.888	vw	0.887	vw								
		0.876	vw								
		0.868	vvw							0.868	vvw
0.855	w	0.860	vvw			0.855	vw			0.860	vvw

Table 29-A. Interplanar spacings of the finer fractions of certain Carnegie bottom samples--Continued

Samples of high $CaCO_3$ content--Continued

Sample no., station no., size, d_{hkl}, and intensity of characteristic spacings											
21 57 <1 micron		22 59 Clay		23 60 <1 micron		25 62 Silt		27 64 Clay		40 79 <3 microns	
d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.
					(?foggy)			8.1	vvw		
		7.2	vw	7.2	tr			7.1	vvw		
		6.7	?								
6.2?	vw	6.3	vw	6.0	vw			6.05	vw		
		5.7	vvw			5.8	vvw				
		5.35	vvw								
		5.15	vvw								
		4.51	w	4.5	vw	4.51	w	4.42	w	4.38	vw
		4.20	w			4.20	vvw	4.20	vw		
3.89	m	3.90	mw	3.85	w	3.90	m	4.01	vw		
3.77		3.80				3.80		3.82	mw	3.83	w
		3.61	vw			3.61	vw	3.60	vw		
		3.41				3.41	mw	3.45	vw	3.43	vw
		3.30	mw	3.33	vw	3.30	mw	3.31	vw		
		3.20	vw			3.20	vw			3.23	m
3.08		3.10		3.09		3.14		3.07		3.04	
2.96	vvs	3.00	vs	3.01	vs	2.98	vs	2.99	vs	2.98?	m
		2.91	vw			2.91	vw	2.82		2.86	
2.80	vw	2.81	mw	2.82	vw	2.81	w	2.78	vs	2.775	vs
		2.70	w			2.70	w			2.68	vw
		2.58	w								
2.50	ms	2.51	ms	2.49	m	2.51	ms	2.49	ms	2.49	w
2.44		2.47				2.47		2.42	w		
								2.34	w	2.40	vw
2.30	s	2.32	s	2.28	ms	2.32	s	2.28	s	2.28	w
2.24		2.265				2.265				2.22	w
2.10	s										
2.06				2.08	ms					2.09	w
										2.015	
1.922		2.00	w			2.00	w	2.00	ms	1.975	vs
1.898	s	1.92	s	1.92	s	1.92	s	1.915	s	1.91	mw
1.88	s	1.87	s	1.87	s	1.87	s	1.875	s	1.87	mw
1.85											
1.80	w	1.81	vw	1.82	vw	1.81	vw	1.82	vw		
								1.79	vvw		
1.70	w	1.73	mw	1.70	w	1.73	w	1.705	w	1.69	mw
		1.70				1.70				1.63	
		1.63	w			1.63	w	1.63	m	1.61	s
1.610	ms	1.605	ms	1.597	m	1.605	ms	1.60	ms	1.595	vw
1.578											
1.518	ms	1.535	ms	1.51	m	1.535	ms	1.52	ms	1.515	vw
1.500		1.51				1.51					
1.46	w	1.476	w	1.465	w	1.472	mw	1.475	w	1.47	vvw
1.437	m	1.44	ms	1.435	mw	1.44	ms	1.44	m	1.44	w
1.420										1.415	ms
1.410	mw	1.42?	m	1.412	m	1.42?	m	1.415	m	1.40	
		1.38	vvw			1.38	vvw	1.379	tr		
1.350	w	1.355	w			1.355	w	1.36	vw		
1.325	w	1.336	w	1.332	w	1.336	w	1.34	vw	1.332	vvw
1.285	mw	1.294	mw	1.290	mw	1.294	m	1.295	mw	1.29	w
								1.26	ms	1.258	s
1.23	mw	1.24	mw	1.235	w	1.24	m	1.239	vw		
		1.20	vw			1.20	vw			1.205	vw
1.172	m	1.18	mw	1.17	mw	1.18	m	1.176	mw	1.174	vw
		1.153	ms	1.148	mw	1.153	m	1.15	m	1.153	s
1.141	m							1.14	w	1.139	
		1.122	vw			1.122	vw	1.12	vw		
		1.111	vvw			1.111	vvw				
		1.072	vvw			1.072	vvw	1.08	vw	1.079	w
		1.062	vvw			1.062	vvw	1.06	vw		
1.038	ms	1.045	ms	1.042	mw	1.045	ms	1.042	mw	1.040	vw
1.006	mw	1.011	m	1.009	w	1.011	m	1.008	w		
0.980	w	0.982	mw	0.980	w	0.982	ms	0.982	vw	0.999	mw
0.958	w	0.965	m	0.959	w	0.965	m	0.962	vw	0.962	vw
0.933	w	0.941	m			0.941	m	0.939	w	0.938	ms
0.923	vvw	0.92	vw			0.92	vw	0.922	vvw		
		0.895	w			0.895	w	0.893	w	0.89	w
0.888	vw							0.888	vw		
		0.858	w			0.858	w	0.855	w	0.850	mw

Table 29-A. Interplanar spacings of the finer fractions of certain Carnegie bottom samples--Concluded

Samples of high $CaCO_3$ content--Concluded

Sample no., station no., size, d_{hkl}, and intensity of characteristic spacings											
40 79 Silt		40 79 Clay		43 82 Colloid		53 110 Clay		81 156 <1 micron		82 157 Clay	
d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.
				6.1	w	6.1	w	6.0	vw		
4.53	vw			4.48	w	4.48	w	4.5	vw	4.5	vvw
				4.20	vw	4.20	vw				
3.83	mw	3.88	w	3.80	m	3.80	m	3.85	w	3.85	m
3.40	vw									3.40	vw
				3.33	w	3.33	w	3.33	vw		
3.10 2.98	vs	3.04	vs	3.08 2.95	vs	3.08 2.95	vs	3.09 3.01	vs	3.07 3.01	vs
2.81	mw	2.83	s					2.82	vw	2.81	mw
				2.69	vw	2.69	vw			2.68	vvw
				2.58	w	2.58	w				
2.49	ms	2.5	m	2.47	ms	2.47	ms	2.49	m	2.49	ms
										2.41	vw
				2.37	vw	2.37	vw				
2.28	s	2.3	ms	2.27	s	2.27	s	2.28	ms	2.29	s
										2.21	vw
										2.15	vw
		2.1	ms	2.08	s	2.08	s	2.08	ms	2.09	s
		2.0	s	1.98	mw	1.98	mw	2.00	vw	2.00	w
1.91	s	1.93	s	1.91	s	1.91	s	1.92	s	1.92	s
1.87	s	1.88	s	1.865	s	1.865	s	1.87	s	1.875	s
				1.80	vw	1.80	w	1.82	vw	1.82	vvw
										1.775	vw
				1.70	vw						
				1.67	w	1.70	vvw	1.70	w	1.70	vw
		1.63	w	1.62	mw	1.62	mw			1.63	mw
1.61 1.59	ms	1.61	vw	1.60	ms	1.60	ms	1.597	m	1.605	ms
1.53 1.505	ms	1.525	m	1.515	ms	1.515	ms	1.51	m	1.52	ms
1.47	w	1.48	w	1.47	mw	1.47	mw	1.465	w	1.47	mw
1.435	ms	1.44	m	1.44	ms	1.44	ms	1.435	mw	1.44	ms
1.415	w	1.41	w	1.418	mw	1.418	mw	1.412	w	1.42	m
										1.379	vw
				1.35	vw	1.35	vw			1.355	w
1.332	w	1.34	vvw	1.33	w	1.33	w	1.332	w	1.338	m
1.29	mw	1.295	vw	1.29	m	1.29	m	1.290	mw	1.295	m
		1.27	w	1.26	vw	1.26	mw			1.285	w
1.232	mw	1.24	vvw	1.23	mw	1.23	mw	1.235	w	1.23	mw
				1.20	vw	1.20	vw				
1.174	mw	1.18	mw	1.175	mw	1.175	mw	1.170	mw	1.179	mw
1.153 1.139	m	1.15	ms	1.149	ms	1.149	ms	1.148	mw	1.15	m
				1.139	w	1.139	w			1.14	w
1.12	w										
				1.077	vvw	1.077	vvw				
				1.06	vw	1.06	vw				
1.040	vw	1.047	m	1.041	ms	1.041	ms	1.042	mw	1.042	m
1.009	mw	1.014	vw	1.008	mw	1.008	mw	1.009	w	1.01	mw
0.981	w	0.985	vvw	0.98	w	0.98	w	0.980	w	0.983	w
										0.976	vw
0.961	w	0.965	vvw	0.96	w	0.96	w	0.959	w	0.963	w
0.938	mw	0.940	vvw	0.94	mw	0.94	mw			0.938	w
										0.915	vw
0.89	w	0.892	vvw	0.893	mw	0.893	mw				
				0.878	vw	0.878	vw				
0.856	w										

Table 29-B. Interplanar spacings of the finer fractions of certain *Carnegie* bottom samples

Samples of low $CaCO_3$ content

Sample no., station no., size, d_{hkl}, and intensity of characteristic spacings											
10 37 Clay		30 68 Whole sample		31 69 < .5 micron		34 72 < 30 microns		34 72 < .3 microns		35 74 Clay	
d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.
		7.2	vw			7.0	vvw				
						6.35	vvw				
4.5	s	4.5	mw	4.52 4.39	s	4.48	ms	4.53 4.38	s	4.5	s
4.25	mw	4.23	w			4.25	w			4.21	vw
4.03	mw	4.02	w	4.0	vw	4.01	w			4.03	vvw
3.76	w					3.73	vw			3.73	vw
3.33	vs	3.32	w	3.31	w	3.37 3.29	vs	3.32	mw	3.32	s
3.20	m	3.2	m	3.18	w	3.18	ms	3.16?	w	3.2	w
3.0	w	3.0	mw								
						2.98	vw			2.98	vw
2.81	m	2.81	vs							2.81	ms
2.57	ms	2.57	mw	2.56	ms	2.60 2.53	s	2.60 2.54	s	2.57	ms
2.45	vw	2.45	vw			2.44	w	2.44	w	2.45	vw
2.38	vw	2.40	vw	2.40	tr			2.36	w	2.40	vw
2.27	w	2.29	w			2.27	w			2.29	w
2.18	vw			2.25	w			2.25	vw		
2.13	w	2.12	mw	2.12	w	2.13	mw	2.10	vw	2.12	mw
1.995	m	2.00	vs			1.99	w	1.98	w	2.00	ms
1.91	vw	1.92	vw								
		1.88	vw	1.88	mw			1.89	vvw		
1.815	w	1.81	w	1.81	vw	1.82	m	1.81	vvw	1.81	ms
1.71	vw	1.71	w	1.70	w			1.71	w		
1.68	w					1.67	mw			1.67	w
1.64	w	1.635	s					1.64	w	1.635	w
1.535	mw	1.54	w	1.60?	vvw	1.54	ms			1.54	w
1.51 1.49	m	1.50	mw	1.495	mw	1.50	ms	1.510 1.493	s	1.50	mw
1.45	vw			1.44	vw						
1.40	w	1.41	s								
1.38	mw	1.375	w			1.375	s	1.358?	tr	1.375	w
1.29	vw	1.29	vw	1.30	mw	1.289	m	1.29	ms	1.29	vw
1.26	w	1.26	s			1.247	w			1.26	w
								1.242	mw		
						1.20	w				
						1.18	w				
1.15	vw	1.16	w			1.153	w			1.15	w
						1.080	vw				
						1.047	vw				
						1.012	vvw				
						0.989	tr				
		0.938	w								
		0.92	w								
		0.91									
		0.873									

Table 29-B. Interplanar spacings of the finer fractions of certain *Carnegie* bottom samples--Continued

Samples of low $CaCO_3$ content--Continued

Sample no., station no., size, d_{hkl}, and intensity of characteristic spacings

49 96 < 1.6 microns		51 108 Clay		56 113 Clay		60 119 Clay		62 128 Clay		69 136 < .3 micron		70 137 < .5 micron	
d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.
7.1	vvw					7.2	w	7.15	w			7.1	w
6.35	vvw					6.4	w	6.4	vw				
						5.75	w	5.75	tr				
5.1	tr					{5.20		5.00	vw			5.0	vvw
						4.85	vvw						
4.45	m	4.5	vw	4.5	vw	4.5	m	4.5	m	{4.59	s	{4.56	s
										4.39		4.39	
4.20	?	4.29	vvw	4.26	vvw	4.22	mw	4.22	mw				
4.0	vvw	4.03	vw	4.03	w	4.0	mw	4.0	mw				
3.76	vvw	3.83	vw	{3.79	mw	3.72	vw	{3.79	vw			3.70	tr
3.50	vw	3.58	vvw									{3.37	ms
3.33	mw	3.33	vw	3.33	vs	3.32	vs	3.32	vs	3.33	mw	3.28	
3.17	w	3.20	w	3.20	ms	3.19	ms	3.19	ms	3.16?	w	3.20	mw
		3.03	vs	3.03	ms			3.02	s				
												2.99	vvw
		2.89	tr										
2.80	w	2.80	vs	2.80	m	2.81	mw	2.81	mw			2.80	tr
2.57	s			2.57	ms	2.56	ms	2.56	s	{2.60	s	{2.60	vs
										2.53		2.53	
2.45	mw	2.48	ms	{2.46	m	2.45	mw	2.45	mw	{2.42	mw	2.44	w
2.40	mw			2.37	w	2.39	w	2.39	w	2.35	w	2.37	w
		2.28	s	2.29	mw	2.29	w	2.28	mw				
{2.26	vvw					{2.21	tr?			2.23	vw	2.25	w
2.12	vw	2.09	ms	2.10	mw	2.11	m	2.12	m	2.11	vw	2.12	w
2.00	vw	1.99	vs	1.99	m	1.99	ms	1.99	ms	1.98	w	{2.01	w
												1.98	
1.91	vvw	1.915	s	1.91	w	1.935	w	1.915	w				
		1.87	s	1.87	w	1.875	w	{1.87	w				
1.81	w	1.815	w	1.81	m	1.815	m	1.815	m	1.81	vvw	1.82	w
		1.78	vw										
1.70	w	1.70	w	1.71	vw	1.70	w			1.71	w	1.71	mw
1.65	vw			1.66	w	1.66	w	1.66	w				
		1.62	s	{1.615	vw	1.625	w	1.625	w	1.64	w	1.64	mw
1.535	vvw	1.60	mw	1.54	ms	1.54	ms	1.54	ms			1.54	w
		1.51	mw							{1.51	s		
1.495	m	1.47	w	1.50	ms	1.497	ms	1.497	ms	1.49			
		1.44	mw	1.45	w	1.45	vw	1.45	vw			1.45	vw
1.41	w	1.405	m	1.41	w	1.405	w	1.405	w			1.415	tr
1.375	w			1.37	m	1.37	m	1.37	m	1.358?	tr	1.37	w
1.295	w	1.29	mw	1.29	w	1.29	vw	1.29	mw	1.290	ms	{1.30	mw
												1.285	
1.253	vw	1.26	ms	1.26	mw	1.255	w	1.255	w			1.246	w
		1.23	w	1.22?	vvw					1.242	mw		
1.205	tr	1.205	w	1.20	vvw	1.195	vw	1.195	w				
		1.18	w	1.18	vw	1.178	w	1.178	w				
		1.15	m	1.15	w	1.15	mw	1.15	mw				
								1.078	vvw				
		1.04	mw	1.038	vw			1.045	vvw				
		1.01	w	1.01	vw			1.01	vvw				
		0.99	w?										
		0.979	vw	0.983	vvw			0.98	vvw				
		0.962	w	0.959	vvw			0.96	vvw				
		0.94	mw	0.939	vvw			0.938	vvw				
		0.89	mw	0.89	vw								
		0.86	w	0.86	vw?								

Table 29-B. Interplanar spacings of the finer fractions of certain Carnegie bottom samples--Concluded

Samples of low $CaCO_3$ content--Concluded

Sample no., station no., size, d_{hkl}, and intensity of characteristic spacings

72 142 <1 micron		73 145 <30 microns		73 145 <.3 micron		74 146 <.3 micron		77 149 <4.5 microns		77 149 <.3 micron		79 151 Clay	
d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.
		7.1	v					8.2	?				
		7.1	vw					7.1	vvw				
		6.4	vw					6.35	vvw				
		6.0	vw										
								5.75	tr				
								5.4	tr				
		4.98	vw					5.0	tr				
4.57	s	4.57	ms	4.57	s	4.58	s	4.45	ms	4.58	s	4.43	ms
4.38		4.37		4.38		4.38				4.38			
		4.20	m					4.20	vvw			4.2	w
		4.00	vw					4.0	vvw			4.0	vvw
		3.72	w					3.70	vvw			3.70	vvw
3.38	ms	3.39	vvs	3.38	mw			3.50	vw				
3.27		3.27		3.27		3.32	mw	3.32	vs	3.32	mw	3.31	vs
3.18	w	3.18	ms	3.19	vvw	3.20	vw	3.19	mw	3.20	vw	3.17	m
		3.00	w										
2.97	tr	2.93										2.93	w
		?2.89											
		2.80	w					2.80	w			2.79	mw
2.59	vs	2.60	s	2.59	vs	2.61	vs	2.70	?	2.61	vs	2.56	s
2.54		2.53		2.54		2.53		2.57	s	2.53			
2.40	w	2.44	m	2.40	w	2.40	w	2.45	mw	2.40	w	2.43	w
		2.37	m					2.40	mw			2.36	vw
		?2.29	mw										
2.24	w	2.25		2.24	w	2.25	vw	2.26	w	2.25	vw	2.25	w
2.13	w	2.12	m	2.13	w	2.10	vw	2.12	w	2.10	vw	2.10	m
1.98	w	2.02	mw	1.98	w	2.00	w	2.00	w	2.00	w	1.97	m
		1.96											
								1.91	vw				
		1.88	vw									1.87	w
1.81	w	1.828	ms	1.81	vvw	1.82	w	1.81	mw	1.82	w	1.81	m
		1.802											
		1.69	w	1.69	w			1.71	w	1.71	w	1.70	w
						1.69	w	1.65	vw	1.69	w	1.66	w
		1.64	w	1.65	w							1.62	tr
		1.547	s					1.535	w			1.535	mw
1.51	s	1.530		1.51	s	1.513	s			1.513	s	1.50	ms
1.49				1.49		1.490		1.495	s	1.490			
		1.45	w					1.446	vw				
		1.413	w					1.41	w			1.41	vw
1.37	w	1.385	s	1.37	tr?	1.37	vvw	1.375	mw	1.37	vvw	1.37	ms
		1.365											
1.29	m	1.305	mw	1.29	m	1.313	m	1.295	mw	1.313	m	1.285	w
		1.282				1.298				1.298			
		?1.256	w					1.253	vw			1.255	w
1.24	w	1.243		1.24	w								
		1.20	vvw					1.195	vvw				
		1.178	w					1.18	tr			1.17	vw
		1.149	vw									1.143	vw
		1.103	vvw										
		1.077	vw									1.08	vvw
		1.042	w										
		1.009	vw										
		0.984	vw									0.975	vvw
		0.958	vw										
		0.942	vw										
		0.910	vvw										
		0.889	vw										
		0.862	vvw										

Symbols refer to intensity of characteristic spacings for substances indicated: vs = characteristic spacings are very strong in pattern; s = strong; mw = moderately weak; w = weak; vw = very weak; vvw = very, very weak; tr = trace; ? = spacings are possibly present or some spacings are missing; m = moderate; ms = moderately strong.

radiolarian ooze. Twenty analyses of the silt and clay grades and of fine parts of maximum particle size ranging from 30 to 0.3 microns from the pipette analyses are shown.

Patterns Used for Comparison

For comparison, powder diagrams were made of certain substances which may occur in deep-sea sediments and the interplanar spacings of certain other substances which may also occur were taken from the literature or were obtained from data prepared by Mr. W. H. Dore. The data for sixteen such substances are represented in table 30.

Part A of table 30 gives data for the interplanar spacings of sodium chloride, quartz, hyalite, calcite, aragonite, hydrous ferric oxide (bog iron ore), psilomelane, pyrolusite, and phillipsite. In general, only observed values are listed, although the calculated values and the Miller indices of the interplanar spacings are given for quartz, calcite, and aragonite. In some of the other substances listed these theoretical values are not known with any degree of certainty.

The measurements given for sodium chloride were made with the instrument used in the present investigation, and thus serve as a check on the accuracy of the method.

For quartz, the measurements given by Nagelschmidt and made with copper radiation, together with the calculated interplanar spacings and indices given by him, are compared with measurements prepared by Mr. Dore with molybdenum radiation. In general, the agreement between the two sets of measurements, both with regard to numerical values and intensities, is good.

The values given for hyalite were obtained by Mr. Dore from samples of banded opal donated by Professor N. L. Taliaferro. Two sets of measurements--one on undried material having a water content of 8.2 per cent, refractive index of 1.444, and specific gravity of 2.028, and the other on material dried for 150 hours at 160°, having no water, a refractive index of 1.386, and a specific gravity of 1.860--gave identical results. The pattern is probably that of cristobalite, even though the appearance of the substance indicates a low temperature of formation. Dwyer and Mellor state that opals associated with sedimentary rocks show only a broad band corresponding with either alpha or beta cristobalite. The crystals in sedimentary opal are said to be less than 0.01 micron in diameter. These facts are of interest in this investigation because of the presence in many of the bottom samples of the opaline skeletons of siliceous organisms, namely diatoms, radiolaria, and sponges.

The measured and calculated values and the indices given by Nagelschmidt for calcite are listed. Besides these, measurements made by Mr. Dore and the writer on known calcite and on shells of foraminifera separated from the sand grades of sample 44 are reported. The foraminifera give a pattern identical with that of calcite except for the presence of one very weak aragonite line and of the strongest line of sodium chloride.

The pattern given for aragonite is that of a crystal from Bilin, Czechoslovakia, which was identified optically as aragonite. For comparison, needles of $CaCO_3$ precipitated from sea water by Revelle and Fleming (1934), which the writer had previously identified tentatively by optical means as aragonite, as well as the very small needles identified by Merwin from Vaughan's sample 177 from the Bahamas (see Vaughan, 1924), were studied and the results are also presented in table 30-A. The X-ray results confirm the optical determinations, both the experimentally precipitated needles and the fine material from the Bahaman sample giving aragonite patterns.

It is believed that many deep-sea sediments, particularly certain Globigerina oozes, contain free hydrous ferric oxide. Accordingly, a sample of limonitic iron ore donated by Professor Adolf Pabst was studied, and the measured interplanar spacings are given in table 30-A. Unfortunately the interplanar spacings shown in the pattern of this substance coincide with those of other minerals known to be present in deep-sea samples.

The data given for psilomelane and pyrolusite are taken from Smitheringale (1929), who also gives data for manganite, hausmannite, braunite, bementite, and wad.

Twinned crystals and aggregates of phillipsite were separated from the fine sand grade of sample 44 by hand picking and the use of heavy liquids. The X-ray pattern obtained is presented in table 30-A, together with a pattern given by a phillipsite crystal from Australia, identified goniometrically by Dr. Adolf Pabst. The virtual identity of the patterns confirms Rénard's optical and chemical determinations of the zeolite in deep-sea clays as phillipsite.

The interplanar spacings given by various authors for the platy minerals glauconite and muscovite, and the clay minerals kaolinite, halloysite, montmorillonite, and beidellite-nontronite, are presented in table 30-B. The similarity in crystal structure and habit of these minerals is reflected in the coincidences of many of their interplanar spacings. The presence or absence of only a few lines is diagnostic for any one of the minerals. Gruner (1932, 1933) has discussed the crystal structure of kaolinite; and Hoffman, Endell, and Wilm (1933) have discussed that of montmorillonite.

The data for glauconite are based on measurements by Dr. E. M. Thorp. Three of the patterns given for muscovite are taken from Nagelschmidt (one of these is from the work of Noll, 1932); the remaining muscovite pattern represents data prepared by Mr. Dore.

Date for kaolinite, the hydrous aluminum silicate containing little or no bases and in which the silica sesquioxide ratio is 2 to 1, were obtained from Nagelschmidt, Gruner, Ross and Kerr (1931, 1934), and Hendricks and Fry (1930). Four of the patterns for halloysite, similar to kaolinite in chemical composition but containing more water, are taken from Nagelschmidt, one from Kelley, Dore, and Brown, one from Hendricks and Fry, and one from Ross and Kerr. In addition, the pattern of a soil colloid of halloysite type given by Hendricks and Fry is presented. Four patterns, two of which are from Nagelschmidt, one from Hendricks and Fry, and one from Kerr (1932), are given for montmorillonite, the hydrous magnesium aluminum silicate in which the silica sesquioxide ratio is about 4 to 1, together with that of a soil colloid stated by Hendricks and Fry to be of montmorillonite type. For nontronite and beidellite, the isomorphous hydrous iron alumina silicates in which the silica sesquioxide ratio is about 3 to 1, data prepared by Mr. Dore are presented. In addition, several patterns are given for bentonites which

Table 30-A. Interplanar spacings which may occur in X-ray diagrams of deep-sea sediments

Other than clay minerals

NaCl		Quartz						Hyalite		Calcite			
1		2 (Nagelschmidt)		3 (Nagelschmidt)		4 (Dore)		5		6 (Nagelschmidt)		7 (Nagelschmidt)	
		measured		calculated						measured		calculated	
d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	index	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	index
								4.30	s				
		4.24	s	4.22	(100)	4.24	w						
								4.10	vs				
										3.84	m	3.84	(110)
3.23	mw	3.35	vs	3.34	(101)	3.35	vs						
						3.30							
										3.02	vs	3.02	(112)
2.82	vvs												
		2.45	m	2.45	(110)	2.45	mw	2.50	ms	2.49	s	2.48	(10$\bar{1}$)
		2.285	m	2.275	(102)	2.28	w			2.272	s	2.274	(102)
2.24	vvw	2.236	w	2.229	(111)	2.235	vw						
		2.129	m	2.121	(200)	2.125	w						
								ca.2.05	vw	2.082	s	2.084	(200)
2.00	vs	1.981	m	1.974	(201)	1.98	w						
										1.914	vs	1.916	(202)
										1.866	vs	1.870	(123)
		1.814	s	1.813	(112)	1.82	m						
1.70	w	1.667	m	1.667	(202)	1.67	w						
1.63	s									1.618	w		
		1.539	s	1.536	(121)	1.54	w	ca.1.61	w	1.595	m	1.594	(12$\bar{1}$)
										1.515	s	1.511	(224)
										1.470	w		
		1.447	w	1.448	(113)	1.455	vvw	ca.1.44	w				
										1.437	m	1.435	(11$\bar{2}$)
1.413	m	1.412	vw	1.414	(300)					1.420	w		
		1.376	s	1.377	(122)	1.375	s	ca.1.36	vw	1.355	vw		
										1.333	w		
		1.284	w	1.283	(104)	1.29	w			1.293	m	1.291	(134)
1.264	ms	1.253	m	1.251	(302)	1.26	vvw						
		1.225	vw	1.224	(220)	1.23	vvw	ca.1.24	vvw				
		1.196	m	1.196	(123)	1.20	vvw						
		1.178	m	1.179	(114)	1.18	vvw	ca.1.19	vw	1.176	m	1.175	(235)
1.153	ms	1.150	w	1.149	(131)	1.16	vvw			1.153	m		
										1.139	w	1.140	(225)
		1.078	m	1.077	(132)	1.08	vvw						
		1.044	w	1.044	(105)	1.05	vvw						
						1.04				1.043	m		
		1.011	vw	1.0105	(223)	1.02	vvw			1.010	m		
0.998	vw					0.99	vvw						
						0.960	vvw			0.963	m	0.960	(14$\bar{1}$)
0.94	w												
		0.916	w	0.9155	(232)	0.92	vvw						
		0.897	vw	0.898	(006)								

Table 30-A. Interplanar spacings which may occur in X-ray diagrams of deep-sea sediments--Continued

Other than clay minerals--Continued

Calcite--Concluded				Aragonite						
8 (Dore)		9 Foraminifera from Carnegie sample 44		10 Precipitated from sea water			11 Needles from near Bahamas		12 From Bilin, Czecho-slovakia	
d_{hkl}	int.	d_{hkl}	int.	index	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.
3.85	vw	3.85	w		3.9	w	3.9	w		
		3.41[a]	vw	(111)	3.4	vs	3.4	vs	3.4	vs
				$(\bar{3}02)$	3.23	s	3.22	s	3.25	s
3.06 3.00	vs	3.08 2.98	vs		3.02	w	3.00[c]	ms	3.10 3.00	w
		2.82[b]	vw							
				$(\bar{2}22)$	2.70	vs	2.70	vs	2.70	vs
				(012)	2.58	w	2.58	w	2.58	w
				(220)						
2.49	mw	2.48	m	(100)	2.49	s	2.49	s	2.48	s
				(022) (210)	2.4 2.3	vs	2.4 2.3	vs	2.40 2.30	vs
2.28	m	2.27	ms	(230)						
					2.25	w	2.25	w		
				(211)	2.18	mw	2.18	mw	2.18	w
2.10	m	2.08	ms	(110)	2.10	m	2.10	m	2.10	ms
				(040)	1.975	vs	1.975	vs	1.97	vs
1.92	ms	1.91	vs							
1.87	ms	1.87	s	(202)	1.875	vs	1.875	vs	1.87	vs
				$(\bar{4}62)$	1.81	s	1.81	s	1.805	s
				(603) (222)	1.75 1.72	vs	1.75 1.72	vs	1.75 1.713	vs
					1.625	vw	1.625	vw	1.62	w
1.60	m	1.60	ms	$(\bar{2}03)$	1.56	w	1.56	w	1.55	mw
1.52	m	1.515	ms		(1.50	w)	(1.50	w)	(1.489	w)
					1.50	w	1.50	w	1.489	w
1.475	w	1.47	w		1.47		1.47		1.46	mw
1.445	w									
1.425	w	1.43	ms						1.425	vvw
					1.41		1.41		1.401	m
1.345	vw	1.355	vvw		1.36		1.36		1.35	m
		1.33	vvw							
1.295	w	1.285	vw						1.29	vw
				$(\bar{6}05)$	1.26		1.26		1.257	w
1.24	vw	1.23	vw		1.24		1.24		1.230	mw
					1.20		1.20		1.20	w
1.18	w	1.17	vw		1.181		1.181			
1.155	w				1.163		1.163		1.16	mw
		1.145	w							
					1.122		1.122		1.12	w
					1.108		1.108		1.10	vw
									1.076	tr
					1.050		1.050		1.053	tr
1.045	w	1.04	ms		1.03		1.03		1.03	w
1.015	vw	1.005	w		1.002		1.002		1.00	w
0.985	vw	0.981	w		0.973?	tr	0.973?	tr	0.975	
0.960	vw	0.955	vw		0.958		0.958		0.956	w
0.942	vw	0.940	vw		0.932		0.932			
					0.922		0.922		0.923	w

Table 30-A. Interplanar spacings which may occur in X-ray diagrams of deep-sea sediments--Concluded

Other than clay minerals--Concluded

Bog iron ore		Psilomelane		Pyrolusite		Phillipsite				
13		14 (Smitheringale)		15 (Smitheringale)		16 From Melbourne, Australia			17 From Carnegie sample 44	
d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	index	d_{hkl}	int.	d_{hkl}	int.
							8.2	vw	8.2	w
							8.1			
							7.2	ms	7.2	ms
							6.35	w	6.4	w
							5.3	w	5.3	w
							5.0	ms	5.0	ms
							4.3	vw	4.3	vw
4.2	m						4.19	ms	4.19	ms
							4.09		4.09	
							3.68	vvw	3.68	vvw
		3.35^d	vw							
							3.26	m	3.26	m
							3.19	vs	3.18	vs
							3.13	?		
		3.12	vw	3.12	s					
							2.93	m	2.94	m
							2.75	m	2.76	m
2.7	w	2.73	w				2.70	s	2.69	s
2.56	vw	2.58	vvw				2.54	w	2.55	w
2.45	ms	2.43	m	2.41	m					
							2.39	w	2.39	w
2.28	w	2.275	vvw				2.32	w	2.32	w
				2.20	vw		2.23	w	2.24	w
2.16		2.15	vw				2.15	vw	2.13	w
				2.10	w		2.05	vw	2.05	vw
				1.970	vw		1.96	mw	1.96	mw
		1.83	vw				1.90	vw	1.90	vw
		1.82					1.819	vvw	1.823	w
1.73	ms	1.72	vw				1.720	ms	1.720	ms
1.67							1.68	w		
		1.63	w	1.620	s					
1.55	mw	1.56	vw	1.555	s					
		1.51	vvw							
1.50	vw			1.50	?					
1.45	vw									
		1.425	vvw	1.435	vw					
		1.355	vw	1.385					1.360	w
							1.324	w	1.323	w
		1.31	vvw	1.30						
							1.27	mw	1.27	mw
				1.245	?		1.232	vw		
				1.20	?		1.204	vw	1.220	vw
							1.168	w	1.168	w
				1.12	vw		1.129	w	1.128	vw
				1.09	vvw					
							1.070	vvw	1.073	vvw
				1.052	vw					
				1.032	vw		1.032		1.032	
				0.998	vw					
				0.979	vw					
				0.955	vw					
				0.926	vvw					

Table 30-B. Interplanar spacings which may occur in X-ray diagrams of deep-sea sediments

Clay-like minerals, soils, and bentonites

Glauconite				Muscovite							
1		2		3		4		5		6	
(Thorp)				(Nagelschmidt)				(Noll)		(Dore)	
				Location unknown		From Auvergne					
d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.
				4.97	s	4.95	m	5.00	w	4.99	vw
				4.47	s	4.46	s	4.47	w	4.45	s
										4.10	vw
				3.88	w	3.88	vw	3.90	w	3.85	mw
3.62	vw	3.60	tr	3.69	w	3.69	w	3.69	w	3.70	w
				3.50	w	3.50	w	3.49	w	3.48	mw
3.45	w	3.45	w								
3.33	w	3.33	vw	3.34	vs	3.32	s	3.33	s	3.34	m
3.17	w	3.17		3.20	w	3.18	w	3.20	w	3.20	mw
3.02		3.02		3.00	m	2.98	w	2.99	m	3.00	w
				2.89	m	2.87	m	2.86	ms	2.87	mw
2.78	ms-w	2.78	w	2.77		2.76		2.79	w	2.79	vw
2.60	ms	2.60	ms								
2.569	?	2.569	?	2.57	vs	2.56	vs	2.56	s	2.58	vs
										2.54	
2.45	ms-w	2.45	ms-w	2.47	w	2.46	w	2.46	vw	2.45	mw
2.38		2.38		2.375	m	2.372	w	2.374	w	2.38	m
						2.308	w				
2.25	mw	2.25	mw								
				2.212	w	2.210	vw	2.202	w	2.25	w
2.145	mw	2.145	mw	2.129	m	2.129	m	2.128	w	2.13	ms
				2.061	vw	2.058	vw	2.060	vw	2.06	vw
								1.998	s		
2.00	tr	2.00	?	1.995	s	1.990	s	1.972	vw?	2.00	
1.935	w	1.935	?							1.95	w
1.89	?	1.89	?								
1.84	vw	1.84	vw	1.813	vw	1.813	vw	1.816	vw		
				1.735	vw			1.734	vw		
1.655	mw	1.655	mw	1.645	s	1.645	s	1.644	ms	1.65	m
				1.598	vw			1.600	vw	1.60	w
1.53	w-ms	1.53	w-ms	1.561	vw			1.533	vw	1.55	w
1.50		1.50		1.522	vw			1.524	w		
				1.499	s	1.498	s	1.498	s	1.50	s
										1.37	vw
				1.352	m	1.355	m	1.352	ms	1.34	
1.313	w	1.313	vw	1.336	m	1.326		1.338	ms		
1.295		1.295		1.295	m	1.292	w	1.294	ms	1.295	
				1.242	w	1.241	vw	1.248	ms	1.245	

Table 30-B. Interplanar spacings which may occur in X-ray diagrams of deep-sea sediments--Continued

Clay-like minerals, soils, and bentonites--Continued

Kaolinite											
7		8		9		10		11		12	
(Nagelschmidt)				(Gruner)		(Ross and Kerr)				(Hendricks and Fry)	
From Schneeberg		From Zwickan									
d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.
7.15	vs	7.14	vs	7.06	10			7.2	m	7.15	s
4.46	vs	4.45	s	4.39	6	4.46	10	4.40	vs	4.39	mw
4.17	s	4.16	s	4.21	3	4.19	10	4.20	ms	4.18	vw
3.86	m	3.83	m	3.76	4	3.87	5			3.912	vw
3.61	vs	3.60	vs	3.57	10	3.61	6	3.58		3.585	vs
3.36	w	3.37	w	3.35	1	3.42	5	3.31	s		
3.09	vw	3.11	vw	3.08	0.5	3.07	2				
2.782	vw	2.780	vw	2.760	1	2.789	1				
2.570	s	{2.54	s	2.556	5	(2.512)	9	2.53	ms or s	2.565	s
2.502	s			2.491	5			2.49	ms	2.492	ms
2.355	vs	{2.32	s	2.373	2	2.344	10			2.345	s
2.297	s			2.341	8						
				2.272	5	2.305	4			2.290	m
2.205	vw	2.208	vw	2.200	0.5	2.205	1	2.205	1	2.19	vw
1.996	m	1.997	m	1.983	4	2.005	4	1.99	m	1.985	mw
1.953	w	1.950	vw	1.930	1					1.927	vw
				1.893	1						
1.848	w	1.850	w	1.839	2	1.860	1	1.860	1	1.84	vw
1.794	w	1.793	w	1.785	1					1.78	vw
{1.670	vs	{1.666	s	{1.658	7	1.666	6	1.666	6	1.657	w
1.623	m	1.625	m	1.610	4	1.621	2	1.621	2	1.618	w
1.591	vw	1.586	vw	1.585	1						
1.547	w	1.549	w	1.536	3	1.549	2	1.549	2	1.535	vw
1.493	s	1.493	s	1.486	8	1.487	6	1.487	6	1.485	s
1.455	vw			1.452	2	1.455	2	1.455	2	1.446	vw
				1.430	1						
1.396	vw			1.389	0.5	1.382	1	1.382	1		
1.375	vw			1.371	0.5						
1.344	m	1.345	w	1.340	3	1.347	5	1.347	5	1.330	vw
1.311	m	1.309	m	1.306	4	1.303	2	1.303	2	1.303	mw
1.287	m	1.288	w	1.284	3	1.283	3	1.283	3	1.277	mw
				1.264	1						
{1.243	m	{1.245	w	{1.235	3	1.233	4	1.233	4	1.228	vw
										1.207	vw

Table 30-B. Interplanar spacings which may occur in X-ray diagrams of deep-sea sediments--Continued

Clay-like minerals, soils, and bentonites--Continued

Halloysite											
13		14		15		16		17		18	
		(Nagelschmidt)						(Kelly, Dore, and Brown)		(Hendricks and Fry)	
From Elbingerode		From Beuthen		From Tarnowitz		From Argentina					
d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.
7.48	m	7.48	vvw	7.43	m	7.49	w				
4.44	vs	4.42	vs	4.44	vs	4.42	vs	4.45	vs	4.41	
3.62	w	3.72	m	3.61	s	3.60	w	3.65	m		
3.35^d	w	3.31									
2.60	s	2.59	s	2.57	s	2.59	s	2.60	m	2.560	s
2.33		2.33		2.36		2.33		2.35		2.508	ms
										2.50	vw
										2.337	ms
		2.22	vw	2.23	vw						
				2.013	w	2.019	vw				
1.70	m	1.70	m	1.71	s	1.70	m	1.69	w	1.680	mw
1.64		1.63		1.63		1.62				1.637	mw
1.487	s	1.485	s	1.491	vs	1.486	s	1.48	s	1.480	vs
1.290	w	1.289	w	1.291	m	1.289	w	1.29	vw	1.278	mw
1.237	w	1.236	w	1.239	m	1.236	w	1.24	vw	1.229	m

Table 30-B. Interplanar spacings which may occur in X-ray diagrams of deep-sea sediments--Continued

Clay-like minerals, soils, and bentonites--Continued

Halloysite--Concluded				Montmorillonite									
19 (Ross and Kerr)		20 (Hendricks and Fry) soil colloid		21 (Nagelschmidt) From Montmorillon		22 (Nagelschmidt) From Unterrupsroth		23 (Hendricks and Fry)		24 (Kerr)		25 (Hendricks and Fry) soil colloid	
d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.
7.42	4			7.18[e]	w								
				5.06	m	5.05	s						
4.42	10	4.41		4.46	vs	4.45	vs	4.493	s	4.49		4.44	s
				4.25	w	4.26	vw			4.05			
3.97	5					3.74	vw						
3.63	6	3.584		3.57[e]	m								
						3.34[d]	vw						
				3.05	m	3.03	vs	3.063	vw				
		2.587	vw										
2.560	4	2.567	s	2.536	vs	2.534	vs	2.551	vs			2.56	s
		2.510	ms					2.478	vw	2.48			
		2.50	vw										
2.365	5	2.328	s	2.340	w	2.341	vw						
		2.284	m			2.24	vw						
		2.18	vw	2.188	vw	2.16	vw						
		1.988	mw					1.869	vw				
1.685	4	1.674	mw	{1.689	m	{1.689	m	1.685	w	1.67		1.697	w
		1.639	mw	1.648		1.652							
		1.528	mw										
1.510	10	1.480	vs	1.490	vs	1.489	vs	1.491	vs	1.47		1.501	mw
		1.45	w									1.493	vs
		1.36	vw										
1.295	2	1.275	mw	1.285	m	1.288	m	1.286	mw	1.29		1.290	w
1.250	2	1.231	m	1.239	m	1.239	m	1.238	mw	1.250		1.243	w
		1.185											
				0.972	w	0.974	w			0.976			

Table 30-B. Interplanar spacings which may occur in X-ray diagrams of deep-sea sediments--Concluded

Clay-like minerals, soils, and bentonites--Concluded

Nontronite		Beidellite		Bentonite						Natural soil colloids			
26		27		27		28		29		30		31	
(Dore)		(Dore)				(Dore)				(Dore) no. 431		no. 7083	
d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.	d_{hkl}	int.
5.0	vw	4.95	w	5.0	w	5.0	w	4.95	w				
4.50	vs	4.50	vs	4.45	vw	4.45	vw	4.50	vs	4.50	s	4.50	s
										4.05	w		
								3.60	m				
		3.30^d	w					3.30^d	m	3.33^d	m	3.33^d	m
				3.02	m	3.02	m	3.05	m	3.20	m	3.20	mw
								2.89	?				
2.62 2.54	m	2.57	vs	2.58 2.50	vs	2.58 2.50	vs	2.58 2.50	vs	2.62 2.54	s	2.62 2.54	s
										2.42	m	2.42	m
		2.38	vw?					2.38	s				
				2.25	vw	2.25	vw	2.25 2.10	m	2.27	vw	2.27	vvw
										2.15	vw	2.15	?
								1.99 1.94	w	2.00	vw	2.00	vvw
								1.81^d	vvw	1.84^d	vvw	1.84^d	?
1.725	w	1.68	m	1.69	m	1.69	m	1.69	ms	1.70 1.60	ms	1.70 1.66	ms
								1.63	ms				
										1.53	m	1.53	m
1.52	s	1.49	m	1.50 1.48	vs	1.50 1.48	vs	1.50	vs	1.50	s	1.50	s
										1.37^d	vw	1.37^d	vvw
1.305	w	1.29	w	1.29	m	1.29	m	1.30	s	1.30	vw	1.30	vw
1.26	w	1.24	w	1.24		1.24		1.24	w	1.25	vvw	1.25	vvw
				1.115	vw	1.115	vw	1.19	vw				
				1.020	vw	1.020	vw	1.115	vw				
		0.970	vvw	0.970	vw	0.970	vw	1.010	?				
								0.970	vvw				

[a] Probably an aragonite line. [b] NaCl line. [c] Partly calcite line. [d] Probably a quartz line.
[e] Probably a kaolinite or halloysite line.

Symbols refer to intensity of characteristic spacings for substances indicated: vs = characteristic spacings are very strong in pattern; s = strong; m = moderate; ms = moderately strong; mw = moderately weak; w = weak; vw = very weak; vvw = very, very weak; tr = trace; ? = spacings are possibly present or some spacings are missing.

Table 31. Constituents of the fine fractions of samples of high carbonate content as revealed by X-ray powder diagrams

Sample no.	NaCl	Calcite	Aragonite	Phillipsite	Quartz	Clay mineral
14 clay	mw	dom	?	n f	vw	vvw
16 clay	mw	dom	w	vvw	n f	vvw
17 silt	?	dom	?	n f	n f	n f
17 colloid	?	dom	?	n f	w?	vw
19 <1 micron	n f	dom	n f	n f	vw	vw
20 clay	m	dom	vvw	n f	n f	vvw
21 <1 micron	?	dom	n f	n f	n f	n f
22 clay	mw	dom	mw?	vw	w	w
23 <1 micron	?	dom	n f	n f	vw	vw
25 silt	w	dom	vw	?	w	w
27 clay	s	dom	vw?	tr	w	w
40 <3 microns	vs	dom	vw	n f	n f	vw
40 silt	?	dom	n f	n f	n f	vw
40 clay	s	dom	n f	n f	n f	n f
43 colloid	?	dom	n f	n f	w	w
53 clay	?	dom	n f	n f	w	w
81 <1 micron	vw	dom	n f	n f	vw	vw
82 clay	mw	dom	vvw	n f	n f	vvw

Symbols refer to intensity of characteristic spacings for substances indicated: dom = characteristic spacings are dominant in pattern; vs = very strong; s = strong; m = moderate; mw = moderately weak; w = weak; vw = very weak; vvw = very, very weak; tr = trace; ? = spacings are possibly present or some spacings are missing; nf = spacings not observed.

contain montmorillonite beidellite clay minerals and quartz, and for two California soils, previously mentioned, containing a beidellite-like mineral and quartz.

The prominent lines exhibited by all clay minerals are those at 4.4 to 4.5, about 2.55, 1.7, 1.5, 1.29, and 1.24 angstroms. The distinctive lines of muscovite are those at 3.7, 3.5, 3.333 (the most prominent line of quartz), 3.20, 3.00, 2.87, and 2.13 angstroms. The kaolinite minerals, including halloysite, exhibit characteristic lines at 7.4 to 7.1 and 3.6 angstroms, whereas kaolinite itself may be distinguished from halloysite by the occurrence of a strong line at approximately 4.2 angstroms and a moderate line at 3.87 to 3.83 angstroms (there is a weak muscovite line at 3.85 to 3.90 angstroms). The weak kaolinite lines at 3.07 to 3.11 and 2.76 to 2.79 are also absent from halloysite. Halloysite differs from kaolinite principally in the presence of wider and more diffuse lines. This difference is said by some workers to be owing to the finely divided nature of halloysite, in which the individual grains are usually of colloidal dimensions. Nagelschmidt states that the X-ray diagrams of halloysite are like those which would be expected from kaolinite if the particles of the latter were smaller and only the strong lines remained. That kaolinite is usually relatively coarse-grained is shown by the work of Vinther and Lasson (1933), who found by sedimentation analyses that only 1 to 9 per cent of kaolin particles from various sources have particle diameters less than 0.1 micron, whereas other clays had as much as 55 per cent of the particles smaller than 0.1 micron. On the other hand, Ross and Kerr, basing their opinion on optical and dehydration data as well as X-ray analyses, believe that halloysite is a mineral distinct from kaolinite.[1]

The minerals of the montmorillonite, beidellite, nontronite group may be distinguished from those of the kaolinite group by the presence of lines at 4.95 to 5.05, and 3.03 to 3.06 angstroms. Both these lines, however, are close to muscovite spacings. The essential characteristic of the minerals of this group is the presence of only a few lines, namely the basic spacings, previously mentioned, of all clay minerals. In this respect, they are similar to halloysite but differ from it in the two lines mentioned and in the absence of the broad line at 2.5 angstroms which characterizes halloysite.

Recent investigations by Ross and Kerr and others have shown that the clay minerals of higher silica sesquioxide ratio of the montmorillonite, beidellite, nontronite group are far more common in soils and fine-grained sediments than is kaolinite. Hendricks and Fry, in their examination of soil colloids, found that the minerals of these colloids belong in one of three groups (1) montmorillonite beidellite, (2) montmorillonite and quartz, and (3) halloysite. Bentonite, which is formed from the alteration of volcanic ash, has been found to consist of montmorillonite together with some quartz in certain cases (see Kelley, Dore, and Brown and Ross and Kerr).

Samples of High $CaCO_3$ Content

The patterns obtained from the Carnegie samples, compared with those of known substances, are illustrated in figures 36 and 37. Figure 36 shows the interplanar spacings of certain Globigerina oozes, together with those of calcite, aragonite, phillipsite, and bog iron ore; the minerals identified in the various samples of Globigerina ooze are listed in table 31. The presence of sodium

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[1] Mehmel (1935) has made an X-ray study of the crystal structure of halloysite which he claims is distinct from that of kaolinite.

Table 32. Intensities of quartz lines for different size fractions of northeast Pacific red clays

Sample no.	Maximum size in microns	Interplanar spacings in angstroms			$SiO_2/Al_2O_3 + Fe_2O_3$	
		3.33	1.81	1.37	Whole sample	colloid
73	30.0	vvs	ms	s	3.95	2.65
77	4.5	vs	mw	mw	4.01	2.54
72	1.0	ms	w	w	4.10	2.34
70	0.5	ms	w	w	3.85	.....
77	0.3	mw	w	vvw	.....	.....
74	0.3	mw	w	vvw	.....	.....
73	0.3	mw	vvw	tr?	.....	.....

Symbols refer to intensity of characteristic spacings for substances indicated: vs = characteristic spacings are very strong in pattern; vvs = very, very strong; s = strong; ms = moderately strong; mw = moderately weak; w = weak; vvw = very, very weak; tr = trace; ? = spacings are possibly present or some spacings are missing.

chloride in many of the Globigerina oozes is owing to imperfect washing of the samples. Owing to the high symmetry of this substance, very small amounts of it give disproportionately strong diffraction lines. The lines of calcite are dominant in every sample, whereas only very small amounts of aragonite were detected in a few of the samples. Phillipsite was found definitely in only three of the analyzed calcareous samples--nos. 16, 22, and 27--and possibly also in no. 25. Quartz was present in samples 14, 17, 19, 22, 23, 25, 27, 43, 53, and 81. The presence of the typical clay line at 4.45 angstroms indicated the existence of a clay mineral in all samples except the silt grade of sample 17 and the part less than 1.0 micron in size of sample 21. In general, the patterns given by the true colloidal materials obtained from samples 17, 19, 21, 23, and 81 exhibit fewer lines than those given by coarser separates such as those from samples 16, 22, and 27, which indicates a simpler constitution of the former. A few lines in samples 22 and others could not be identified.

Samples of Low $CaCO_3$ Content

Figure 37 shows the patterns of interplanar spacings obtained from certain red clays, nos. 70, 72, 73, 74, and 77, compared with those of quartz, muscovite, kaolinite, and montmorillonite, and of soil colloids 431 and 7083 given by Kelley, Dore, and Brown.

The increasing complexity of structure and composition with increasing particle size is well shown in the noncalcareous samples, the analyses for coarser size grades showing in every case many more lines than those of colloidal particle size. The presence of many well-defined lines even in the finest-grained samples shows conclusively that at least a considerable part of these materials are definitely crystalline and not "amorphous" as was thought to be the case by Murray.

Examination of table 29 and of the graph shows conclusively that quartz is present in every noncalcareous sample examined, the three most prominent quartz lines at 3.33, 1.81, and 1.37 angstroms being present in every sample. It may be seen that the amount of quartz decreases directly with the particle size, a conclusion which is confirmed by a comparison of chemical analyses of certain whole samples with analyses of the colloidal fractions of the same samples. This is illustrated in table 32 which shows the intensity of the three principal quartz lines (3.33, 1.81, and 1.37 angstroms) given by the coarse and fine fractions of samples 70 to 77, inclusive, together with the silica sesquioxide ratios of the entire samples and of the colloidal fractions. It will be noticed that this ratio varies from approximately 4 in the entire samples to about 2.5 in the colloidal fractions; correspondingly, the quartz lines vary from strong to weak with decreasing particle size.

Nagelschmidt concluded (from a comparison of his X-ray examination of marine Middle Oligocene clay from Maliss in Mecklenburg with the chemical and optical investigations of Schlünz [1933] on the same material) that quartz, in comparison with the other minerals which occur in clay, is easily detected because of the relatively strong reflecting power of its crystal lattice. Powdered quartz less than 0.6 micron in diameter showed no widening of the lines or decrease in intensity. On the other hand, the powder diagram of the fraction less than 0.05 micron in particle diameter of the Maliss clay contained no quartz lines, even though chemical analyses showed 15 per cent free silica. Nagelschmidt suggests that the silica in this fraction may be amorphous.

Owing to imperfect washing, small quantities of sodium chloride are present in samples 10, 30, 35, 49, 51, 56, 60, 62, 70, 79, the fraction less than 30 microns in particle size of sample 73, and the fraction less than 4.5 microns in particle size of sample 77. Calcite is found in samples 10, 30, 51, 56, and 62. Phillipsite is definitely present in small quantity in the fraction less than 4.5 microns in particle size of sample 77, and is probably present in samples 30, 49, 60, 62, 70, and the fraction less than 30 microns in size of sample 73, but the apparent absence of the strong phillipsite line at 2.70 angstroms makes its determination in these samples uncertain. It should be pointed out, however, that with the apparatus used, the detection of the presence of weak lines occurring near strong ones is difficult, especially in patterns of materials which give diffused lines and more or less generally darkened films.

The fine fractions less than 1 micron in particle diameter of samples 31, 34, 69, 70, 72, 73, 74, and 77 have patterns agreeing very closely, both in intensity and numerical values of the spacings, with the patterns given by Kelley, Dore, and Brown for colloids from two California soils, nos. 431 and 7083. Optical studies by Professor A. O. Woodford of the clay mineral in soil 431 gave the following indices, $\alpha = 1.554$, $\beta = 1.569$, $\gamma = 1.569$, and for no. 7083 the indices are α=1.567, β=1.586, γ=1.587. According to Professor W. P. Kelley, the dehydration curves of these two soil colloids indicate that the clay mineral in them is closely related to, but slightly different from, beidellite. This difference is confirmed both for the soil colloids and for the deep-sea clays by a comparison of the X-ray patterns with those given in table 30 for montmorillonite, beidellite, nontronite, and bentonite. Besides the quartz lines at 3.33, 1.81, and 1.37 angstroms, these samples also contain lines at about 3.2, 2.42, and 2.0 angstroms, which are not found in the clay minerals mentioned, and they usually do not contain the characteristic line of beidellite and montmorillonite at about 5 angstroms. It is interesting to note in this connection that Dr. C. S. Ross, from the results of optical examination, identified the clay mineral in sample 62 as being similar to the beidellite-nontronite group.

Correns believes, from the results of an X-ray investigation of the deep-sea samples collected by the Meteor expedition,that certain of these contain muscovite and kaolinite in addition to calcite. Nagelschmidt's results show that the fine fraction of the Maliss clay contains muscovite and halloysite, in addition to quartz and calcite; Denison, Fry, and Gile (1929), and Volk (1933) are of the opinion that soil colloids often contain muscovite. An examination of table 29-B will show that many of the characteristic muscovite and kaolinite (or halloysite) lines are present in at least some of the samples, and it is therefore possible that these minerals are present in certain deep-sea clays of the Pacific. The possible presence of phillipsite, the lines of which coincide with many of the diagnostic lines of muscovite and kaolinite, makes the determination of the latter minerals very uncertain. On the other hand, if the colloidal materials in deep-sea clays originate as continental soils, it would be expected that several clay minerals are present in them, and furthermore in different oceanic basins the principal clay mineral in the deposits would reflect the dominant conditions of soil formation on surrounding land.

DISTRIBUTION OF CALCIUM CARBONATE IN THE AREA INVESTIGATED BY THE CARNEGIE

Observed Relations

In table 36 are given most of the determinations available of the calcium carbonate contents of bottom samples collected in the region traversed by the Carnegie. The results of 596 determinations are given. Of these over one hundred have not been published previously, namely, those of the Carnegie and of the U.S.C. and G.S.S. Surveyor bottom samples. The remainder have been compiled from the results of the Challenger (Murray and Rénard, 1891) and the Albatross (Murray and Lee, 1909); the descriptions given by Murray (1902, 1906) of certain samples collected by the British surveying ships Britannia, Egeria, Penguin, and Waterwitch and the U.S.S. Tuscarora; and the numerous determinations published by Trask (1932) on samples collected by him or obtained from other sources.

The data are grouped according to latitude and depth for each 10-degree interval of latitude north and south of the equator, and for the following depth intervals: 0 to 1000 meters, 1000 to 2000, 2000 to 3000, 3000 to 4000, 4000 to 5000, and over 5000 meters. The name of the collecting ship when known, the published reference, the type of deposit, and the location, depth, and calcium carbonate content, are given for each sample. These data are summarized and illustrated in tables 33 and 34 and figures 38 to 41, which give the average calcium carbonate contents of all the samples of sediments and of the pelagic sediments alone, for the various depth divisions within each latitude interval, and for each depth division of all latitudes taken together. The frequency distribution of calcium carbonate contents within each latitude and depth division is summarized in table 35, wherein the numbers of samples for each division having percentage contents of $CaCO_3$ of 0 to 10 per cent, 10 to 20 per cent, 20 to 30 per cent, etc. are shown.

Areal Distribution. Chart 10, constructed from table 36, shows the probable areal distribution of calcium carbonate in the region investigated by the Carnegie. The actual content of calcium carbonate of each of the samples given in table 36 also is shown. The chart was constructed in the following manner. The available determinations of calcium carbonate (given in table 36) were plotted first and then the lines of equal calcium carbonate content as given by Murray and Lee were drawn on the chart. In addition, all sonic sounding values of less than 2000 fathoms obtained by the U.S.S. Ramapo (H.O. Publ. 210 a, c) in the north Pacific and certain soundings of the Carnegie were plotted. With the aid of Hanzawa's chart (1928) of the areal distribution of the various types of bottom sediments in the northwest Pacific, and of the small scale Hydrographic Office sheets showing the depths of other soundings in the north and the southeast Pacific, the lines of equal calcium carbonate content given by Murray and Lee were modified to correspond to the data plotted on the chart. Contour lines for 5, 15, 30, 50, and 75 per cent of calcium carbonate are shown. The areas having more than 30 per cent $CaCO_3$ are indicated by crosshatching, as described in the legend accompanying the chart.

Although no information is available about the nature of the sediments surrounding most of the islands in the south and northwest Pacific, the areas around these islands, following Murray and Lee, have been assumed to contain sediments having more than 30 per cent $CaCO_3$. Also, known depths less than 2000 fathoms in the north Pacific have been assumed to be underlain by sediments containing more than 15 per cent $CaCO_3$.

In the Pacific north of latitude 10° there is very little difference in the general character of the chart from that given by Murray and Lee. South of this latitude several important changes have been made. The areas of more than 30 per cent $CaCO_3$ content surrounding the Caroline Islands and the Marshall Islands, between longitudes 140° and 180° east, and latitudes 0 to 12° north, have been joined together as a result of Hanzawa's work in this region. Similarly, the three areas of $CaCO_3$ content over 50 per cent in the southeast Pacific have been grouped into one area and greatly enlarged. Although the investigations of the Carnegie added considerably to

Table 33. Average calcium carbonate content of bottom samples in the area investigated by the *Carnegie*, according to latitude and depth

Latitude	Depth in meters	All samples		Pelagic samples	
		No. of samples	Average per cent $CaCO_3$	No. of samples	Average per cent $CaCO_3$
0° - 10° S	0-1000	1	12.0	...	.....
	1000-2000	5	27.2	1	75.0
	2000-3000	2	68.0	2	68.0
	3000-4000	18	46.4	15	54.0
	4000-5000	18	45.6	16	51.3
	>5000	6	10.7	6	10.7
10 - 20 S	0-1000	...	.....	...	.....
	1000-2000	14	56.4	9	74.4
	2000-3000	23	50.4	16	66.5
	3000-4000	25	65.2	22	72.4
	4000-5000	30	18.1	27	19.9
	>5000	6	17.0	5	16.0
20 - 30 S	0-1000	...	.....	....	.....
	1000-2000	1	94.0	1	94.0
	2000-3000	3	46.3	2	63.5
	3000-4000	13	53.4	13	53.4
	4000-5000	11	17.9	11	17.9
	>5000	1	0.0	1	0.0
30 - 40 S	0-1000	...	.....	...	.....
	1000-2000	...	.....	...	.....
	2000-3000	4	57.8	3	74.7
	3000-4000	11	59.2	10	63.6
	4000-5000	6	16.7	5	18.8
	>5000	...	.....	...	.....
40 - 50 S	0-1000	...	.....	...	.....
	1000-2000	...	.....	...	.....
	2000-3000	2	54.0	1	82.0
	3000-4000	...	.....	...	.....
	4000-5000	2	37.5	2	37.5
	>5000	...	.....	....	.....
0 - 10 N	0-1000	11	32.0	2?	(46.0)
	1000-2000	12	22.3	5	31.0
	2000-3000	10	31.3	4	57.8
	3000-4000	28	24.4	13	49.4
	4000-5000	31	51.0	28	55.9
	>5000	6	24.2	6	24.2
10 - 20 N	0-1000	3	47.3	...	.....
	1000-2000	4	11.2	...	.....
	2000-3000	2	32.5	2	32.5
	3000-4000	10	1.9	7	0.4
	4000-5000	13	13.9	10	17.6
	>5000	7	1.0	7	1.0
20 - 30 N	0-1000	8	16.4	...	.....
	1000-2000	3	6.0	...	.....
	2000-3000	3	12.3	2	17.5
	3000-4000	14	10.8	11	8.3
	4000-5000	13	1.9	13	1.9
	>5000	12	0.8	12	0.8
30 - 40 N	0-1000	27	4.7	...	.....
	1000-2000	9	12.8	...	.....
	2000-3000	2	13.0	1	22.0
	3000-4000	7	11.3	1	56.0
	4000-5000	25	1.6	20	1.8
	>5000	24	0.6	23	0.4

Table 33. Average calcium carbonate content of bottom samples in the area investigated by the Carnegie, according to latitude and depth--Concluded

Latitude	Depth in meters	All samples		Pelagic samples	
		No. of samples	Average per cent $CaCO_3$	No. of samples	Average per cent $CaCO_3$
° °					
40 - 50 N	0-1000	7	1.5	...	.....
	1000-2000	7	1.2	...	.....
	2000-3000	2	4.0	...	.....
	3000-4000	1	7.0	1	7.0
	4000-5000	1	1.0	...	.....
	>5000	2	0.5	2	0.5
50 - 60 N	0-1000	28	5.8	...	.....
	1000-2000	15	5.3	...	.....
	2000-3000	12	1.3	...	.....
	3000-4000	26	0.2	...	.....
	4000-5000	6	0.0	...	.....
	>5000	3	0.3	...	.....

Table 34. Average calcium carbonate content of pelagic bottom samples of all latitudes in the area investigated by the Carnegie, according to depth

Depth in meters	No. of samples	Average per cent $CaCO_3$
0-1000	2?	(46)
1000-2000	16	62.1
2000-3000	33	60.2
3000-4000	93	48.7
4000-5000	132	26.0
>5000	62	5.1
Total	338	
Average	....	33.58

the knowledge previously obtained by the Challenger and the Albatross of the sea bottom in the southeast Pacific, there are still areas covering many thousands of square miles in which no soundings of any kind have been made. Until quite recently, one of these unexplored regions was that between 120° and 140° west longitude and 10° north and 15° south latitude. Murray and Lee considered that this area contains very little calcium carbonate, even though all the bottom samples collected by the Albatross on both sides of it were rich in lime. It will be noticed that on chart 10 the sediments of this region are represented as having more than 50 per cent calcium carbonate. Both points of view were purely speculative, however, until the circumnavigating trip of the Danish ship Dana, during which echo soundings were made at frequent intervals across the center of this questionable area from latitude 5° south, longitude 120° west, to latitude 9° south, longitude 140° west. (See Dana Report no. 1, 1934). A representative series of these soundings is plotted in the author's figure 42. At the eastern side of the course the depth is about 4300 meters, corresponding to an Albatross sounding in this location of 4298 meters. The depth then gradually increases to an average maximum of about 4700 meters and afterwards decreases to about 4200 meters near the Marquesas Islands. A study of figure 42 will show that in this region the percentage of $CaCO_3$ in depths between 4000 and 5000 meters is usually well over 60 per cent, so that it is probable that the average $CaCO_3$ content of the whole area is greater than 50 per cent, as indicated on chart 10.

In general the results of later work show that the areas of high $CaCO_3$ content in the southeast Pacific are much larger than had previously been supposed. For example, the two areas given by Murray and Lee as having more than 75 per cent $CaCO_3$ in latitudes 3° to 19° south and 38° to 51° south, and longitudes 113° to 124° west and 86° to 129° west, respectively, are probably continuous, if the Carnegie samples collected between them may be taken as representative. Similarly, the small area indicated by Murray and Lee in latitudes 5° to 7° north and longitudes 160° to 163° west has been considerably extended.

On the other hand, those regions which are underlain by deposits having between 15 and 50 per cent calcium carbonate usually form only rather narrow borders around regions in which carbonate content is high. In other words, the boundaries between regions of high and low carbonate are relatively sharp when considered on a small scale chart. There are two notable exceptions to this statement. A region of intermediate calcium carbonate content between 30 and 50 per cent lies across the equator between longitude 96° west and the South American coast. According to Schott (1934) the Peruvian Current here swings westward to become the Southern Equatorial Stream and, as will be shown below, areas underlying these currents tend to be low in calcium carbonate. A second large region of calcium carbonate content between 30 and 50 per cent lies between the Caroline and Gilbert archipelagoes. Since no $CaCO_3$ determinations are available, the 30 per cent $CaCO_3$ contour is here based on the boundary given by Hanzawa (1928) for Globigerina ooze. It is probable that many of the Globigerina oozes of this region contain more than 50 per cent $CaCO_3$.

Table 35. Frequency of occurrence of samples having the percentage content of $CaCO_3$ indicated, according to latitude and depth intervals

Depth interval in meters	$CaCO_3$ in per cent																
	0-10		10-20		20-30		30-40		40-50		50-60		60-70	70-80	80-90	90-100	
	t	p	t	p	t	p	t	p	t	p	t	p	p	p	p	t	p
0° - 10° N																	
0-1000	1	...	4	..	..	1	3	..	..	..	..	..	..	1	..	1	..
1000-2000	2	...	1	2	4	..	..	1	..	2	..	..	..	..	..	..	..
2000-3000	2	...	3	..	..	1	..	2	..	..	..	..	..	..	2	..	..
3000-4000	15	1	..	2	..	1	..	2	..	1	..	..	1	3	2	..	..
4000-5000	2	5	1	..	..	1	..	..	..	1	..	1	8	9	3	..	..
>5000	...	3	..	..	..	1	..	..	..	1	..	..	..	1	..	..	..
10° - 20° N																	
0-1000	...	...	..	..	..	..	1	..	..	..	2	..	..	..	..	..	..
1000-2000	2	...	1	..	1	..	..	..	..	..	..	..	..	..	..	..	..
2000-3000	...	1	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..
3000-4000	2	7	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..
4000-5000	3	7	..	..	..	...	..	..	..	1	..	1	1	..	..	..	..
>5000	...	7	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
20° - 30° N																	
0-1000	2	...	3	..	1	..	2	..	..	..	..	..	..	..	..	..	..
1000-2000	3	...	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
2000-3000	1	1	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..
3000-4000	2	8	..	..	..	3	..	..	1	..	..	..	..	..	..	..	..
4000-5000	...	12	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..
>5000	...	12	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
30° - 40° N																	
0-1000	22	...	4	..	1	..	..	..	..	..	..	..	..	..	..	..	..
1000-2000	4	...	2	..	2	..	1	..	..	..	..	..	..	..	..	..	..
2000-3000	1	...	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..
3000-4000	6	...	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..
4000-5000	5	18	..	2	..	..	..	..	..	..	..	..	..	..	..	..	..
>5000	1	23	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
40° - 50° N																	
0-1000	7	...	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1000-2000	7	...	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
2000-3000	2	...	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
3000-4000	...	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
4000-5000	1	...	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
>5000	...	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
50° - 60° N																	
0-1000	20	...	5	..	2	..	1	..	..	..	..	..	..	..	..	..	..
1000-2000	13	...	1	..	..	..	1	..	..	..	..	..	..	..	..	..	..
2000-3000	11	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
3000-4000	26	...	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
4000-5000	6	...	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
>5000	3	...	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
0° - 10° S																	
0-1000	...	...	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1000-2000	2	...	1	..	1	..	..	..	..	..	..	..	..	1	..	..	..
2000-3000	...	...	..	..	..	..	..	..	..	..	..	1	..	..	1	..	..
3000-4000	2	...	1	1	..	..	..	2	..	2	..	3	3	4	..	..	..
4000-5000	2	3	..	1	..	1	..	..	..	..	..	2	3	3	2	..	1
>5000	...	4	..	1	..	..	..	..	..	1	..	..	..	..	..	..	..
10° - 20° S																	
0-1000	...	...	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1000-2000	...	...	..	..	4	..	1	..	..	..	..	1	..	6	1	..	1
2000-3000	2	...	1	1	4	..	..	1	..	2	..	1	2	1	5	..	3
3000-4000	2	...	..	..	..	1	1	2	..	..	..	1	1	9	4	..	4

Table 35. Frequency of occurrence of samples having the percentage content of $CaCO_3$ indicated, according to latitude and depth intervals--Concluded

Depth interval in meters	$CaCO_3$ in per cent																
	0-10		10-20		20-30		30-40		40-50		50-60		60-70	70-80	80-90	90-100	
	t	p	t	p	t	p	t	p	t	p	t	p	p	p	p	t	p
									10° - 20° S--Concluded								
4000-5000	2	14	1	3	..	3	..	1	..	3	..	1	1	1	..	..	..
>5000	...	4	..	..	1	..	..	..	..	..	..	..	..	..	1	..	..
									20° - 30° S								
1000-2000	...	...	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1
2000-3000	...	...	1	..	..	..	..	1	..	..	..	..	..	..	..	..	1
3000-4000	...	1	..	1	..	..	..	1	..	1	..	2	4	3	..	..	..
4000-5000	...	6	..	1	..	1	..	1	..	1	..	..	..	1	..	..	..
>5000	...	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
									30° - 40° S								
2000-3000	1	...	..	..	..	..	..	..	..	..	..	1	..	..	2	..	..
3000-4000	...	...	1	1	..	..	..	..	..	2	..	..	2	2	2	..	1
4000-5000	1	2	..	..	..	2	..	..	..	1	..	..	..	..	..	..	..
									40° - 50° S								
2000-3000	...	...	..	..	1	..	..	..	..	..	..	..	..	..	1	..	..
4000-5000	...	1	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..

The following abbreviations are used: t indicates terrigenous; p, pelagic samples.

Along the South and Central American coasts, in the eastern part of the path of the Peruvian Current, there is a band of varying width which is low in $CaCO_3$. It is extended westward as a wide, curved tongue at about 20° south in the Bowers Basin of Agassiz (1906), and at longitudes 100° to 105° west joins a narrow region of low $CaCO_3$ between 5° and 25° south, which includes the Bauer Deep discovered by the Carnegie. This tongue is bounded on the southeast by the sediments of the Merriam Ridge, which are high in calcium. Another region of low carbonate content surrounds the Galápagos Islands, even though the bottom here is relatively shallow and plateau-like in character. A marked diminution of carbonate content occurs in a small area at about 100° west longitude and 40° south latitude, and is probably to be correlated with a depth depression. Between the Tuamotu Archipelago and the high $CaCO_3$ area, which lies across the equator at 160° west, there is a re-entrant area of low $CaCO_3$ content. A similar re-entrant area lies between 17° and 25° south, west of longitude 140°, and a third larger area lies between 30° and 42° south, west of longitude 125° west.

These areas may be regarded as salients of a broad band of deposits poor in calcium carbonate extending, according to the map of Murray and Lee, from 50° south to 10° north where it joins the low area covering almost the entire north Pacific. In the south this band lies, in general, between longitudes 150° and 176° west; toward the north it becomes narrower and is shifted to the westward between the meridians of 164° and 166° west on the east side, and 180° to 174° east on the west side.

A comparison of chart 10 with a bathymetric chart of the Pacific shows that the areas of high calcium carbonate generally lie in the shallower depths, less than 4000 meters, except near the equator. The rather sharp, relatively straight northern boundary of the high calcium carbonate area of the southeast Pacific between longitudes 90° and 155° west almost exactly parallels the average southern limit of the Counter Equatorial Current and does not follow the depth contours. (Compare also with Schott's map [1934] of salinity in the Pacific, from which it may be seen that this boundary follows closely the 34.5 per mille isohaline.)

Relations Between $CaCO_3$, Depth, and Latitude. Figures 38, 39, and 40 show the distribution for each ten degrees of latitude of average calcium carbonate contents with respect to depth. In most cases two curves are plotted, one for all samples within a given latitude division, and another which includes only the pelagic samples. The number of samples entering into each average value is given in the figures. The average carbonate value for a given depth interval is plotted at the mid-point, halfway between the two limiting depths; for example, the average depth of samples collected at depths less than 1000 meters has been assumed to be 500 meters, and the average depth of samples over 5000 meters has been assumed to be 5500 meters.

In latitudes 0° to 10° south the calcium carbonate content of all samples, both pelagic and terrigenous, markedly increases from an average of 12 per cent between 0 and 1000 meters to 68 per cent between 2000 and 3000 meters, and then as sharply decreases to an average value of 11 per cent for samples at depths greater than 5000 meters. In contrast, the curve for pelagic samples alone shows a regular decrease with depth at all levels. The difference between the two curves is owing to the relatively low carbonate content of terrigenous samples of moderate depth. Between latitudes 0° and 10° north the curve for all samples combined is comparatively straight to depths between 3000 and 4000 meters at about 22 to 32 per cent calcium carbonate, and then shows an increase to an average of 51 per cent at depths between 4000 and 5000 meters, after which there is a decrease to about 24 per cent for depths greater than

Table 36. Distribution of calcium carbonate in the area investigated by the *Carnegie*, according to latitude and depth

Station[1]		Reference[2]	Type of sample[3]	Latitude	Longitude	Depth in meters	$CaCO_3$ in per cent
			0° - 10° N				
			0-1000 meters				
Albatross	2794	T	gy f g s	7°37′N	78°47′W	113	15
	2796	T	gn st	8 05 N	78 51 W	60	15
	2799	T	gn st cl	8 44 N	79 09 W	54	30
	3354	T	gn cl	7 10 N	80 50 W	588	3
	3384	T	br gy cl	7 32 N	79 14 W	835	10
	5519	T	rd cl (?)	8 47 N	123 31 E	331	20
Challenger	210	M and R	gn mud	9 25 N	123 45 E	686	36
	210a	M and R	bu mud	9 15 N	124 38 E	338	17
	214	M and R	bu mud	4 33 N	127 06 E	915	34
Britannia	625	M	ca s	3 54 N	159 25 W	466	99
Surveyor	40	....	glob oz	5 58 N	81 46 W	812	(73)
			1000-2000 meters				
Albatross	3353	T	gy cl	7°06′N	80°34′W	1270	4
	3363	T	br gy cl	5 43 N	85 50 W	1765	30
	3372	T	br gy cl	4 49 N	86 11 W	1390	15
	5614	T	rd cl ?	0 31 N	126 32 E	2000	18
	4630	M and L	gn s	6 53 N	81 42 W	1017	5
	4631	M and L	gn mud	6 26 N	81 49 W	1419	25
Surveyor	39	....	glob oz	5 47 N	81 23 W	1604	47
	45	....	gn mud	7 02 N	83 56 W	1734	20
	47	....	glob oz	7 18 N	84 29 W	1522	45
	48	....	gn mud	7 25 N	84 43 W	1715	20
	49	....	gn mud	7 29 N	84 52 W	1778	20
	50	....	gn mud	7 36 N	85 06 W	1906	19
			2000-3000 meters				
Albatross	H 1118	T	glob oz	2°53′N	86°24′W	2965	36
	H 1119	T	glob oz	1 13 N	86 02 W	2450	30
	2806	T	rd gy cl	0 30 N	88 38 W	2705	25
	3361	T	gn cl	6 10 N	83 06 W	2680	12
	3375	T	glob oz	2 34 N	82 29 W	2200	85
	3376	T	glob oz	3 09 N	82 08 W	2060	80
Surveyor	35	....	gn mud	5 48 N	79 39 W	2815	3
	43	....	gn s	6 25 N	82 42 W	2262	17
	44	....	gn mud	6 44 N	83 20 W	2008	18
	51	....	gn mud	7 47 N	85 28 W	2893	7
			3000-4000 meters				
Albatross	H 1126	T	(radiol oz)	4°44′N	93°02′W	3560	10
	H 1127	T	(radiol oz)	8 26 N	95 30 W	3645	8
	3374	T	br gy st and glob	2 35 N	83 53 W	3320	25
	3382	T	gn cl	6 21 N	80 41 W	3275	1
	H 2627	T	(rd cl)	0 36 N	82 45 W	3450	15
	4505	M and L	glob oz	3 12 N	84 57 W	3118	38
	4541	M and L	glob oz	4 55 N	112 27 W	3976	68
	204	M and L	glob oz	1 52 N	173 15 E	3943	74
	219	M and L	glob oz	8 02 N	167 43 E	3985	82
	220	M and L	glob oz	8 38 N	167 37 E	3470	86
	243	M and L	glob oz	6 47 N	152 11 E	3954	73
Challenger	198	M and R	volc mud	2 55 N	124 53 E	3932	0
	213	M and R	bu mud	5 47 N	124 01 E	3749	2
	216	M and R	glob oz	2 46 N	133 58 E	3064	49
	216a	M and R	glob oz	2 56 N	134 11 E	3658	35
	224	M and R	glob oz	7 45 N	144 20 E	3384	79
Carnegie[1]	10	....	gn mud	5 59 N	82 56 W	3324	3
Surveyor	30	....	gn mud	7 24 N	79 14 W	3246	4
	31	....	gn mud	6 59 N	79 15 W	3486	3
	32	....	gn mud	6 57 N	79 16 W	3617	3
	33	....	gn mud	6 11 N	79 16 W	3727	2
	34	....	gn mud	5 48 N	79 14 W	3398	3
	36	....	gn mud	5 48 N	80 05 W	3098	3
	37	....	gn mud	5 47 N	80 31 W	3135	3
	42	....	gn mud	6 07 N	82 05 W	3056	5
	52	....	gn mud	8 23 N	86 39 W	3389	3
	53	....	gn mud	9 02 N	87 51 W	3297	3
	54	....	gn mud	9 46 N	89 17 W	3579	3

Table 36. Distribution of calcium carbonate in the area investigated by the Carnegie, according to latitude and depth--Continued

Station[1]		Reference[2]	Type of sample[3]	Latitude	Longitude	Depth in meters	$CaCO_3$ in per cent
0° - 10° N--Concluded							
4000-5000 meters							
Albatross	4742	M and L	glob oz	0°03′N	117°16′W	4243	64
	4540	M and L	glob oz	3 26 N	115 54 W	4024	69
	13	M and L	radiol oz	9 57 N	137 47 W	4920	1
	15	M and L	glob oz	4 35 N	136 54 W	4724	65
	16	M and L	glob oz	2 38 N	137 22 W	4463	71
	17	M and L	glob oz	0 50 N	137 54 W	4505	65
	197	M and L	glob oz	0 30 N	173 35 E	4062	83
	206	M and L	glob oz	2 27 N	173 09 E	4124	83
	208	M and L	glob oz	3 57 N	172 00 E	4547	78
	209	M and L	glob oz	4 25 N	171 13 E	4582	77
	210	M and L	glob oz	4 54 N	170 21 E	4470	74
	211	M and L	glob oz	5 20 N	169 43 E	4410	81
	213	M and L	glob oz	6 34 N	169 13 E	4779	66
	226	M and L	glob oz	9 55 N	168 56 E	4080	75
	232	M and L	glob oz	8 50 N	170 26 E	4062	77
	236	M and L	glob oz	6 34 N	170 59 E	4540	73
	237	M and L	glob oz	6 11 N	170 25 E	4547	69
	238	M and L	glob oz	5 48 N	169 01 E	4433	75
	240	M and L	glob oz	6 49 N	156 36 E	4527	63
	241	M and L	glob oz	6 51 N	154 39 E	4633	70
	244	M and L	glob oz	8 06 N	151 08 E	4033	67
	199	M and L	volc mud	5 44 N	123 34 E	4755	1 (T)
Carnegie[1]	81	....	glob oz	3 01 N	149 46 W	4953	40
Challenger	202	M and R	bu mud	8 32 N	121 55 E	4664	tr
	211	M and R	bu mud	8 00 N	121 42 E	4070	15
	215	M and R	rd cl	4 19 N	130 15 E	4664	0
	221	M and R	rd cl	0 40 N	148 41 E	4847	tr
	222	M and R	rd cl	2 15 N	146 16 E	4481	7
	223	M and R	glob oz	5 31 N	145 13 E	4252	52
	267	M and R	radiol oz	9 28 N	150 49 W	4938	tr
	269	M and R	radiol oz	5 54 N	147 02 W	4664	20
>5000 meters							
Albatross	14	M and L	glob oz	6°41′N	137°00′W	5077	44
	245	M and L	rd cl	9 31 N	149 36 E	5002	9
Challenger	268	M and R	radiol oz	7 35 N	149 49 W	5304	tr
	270	M and R	glob oz	2 34 N	149 09 W	5350	71
Britannia	664	M	radiol oz	8 15 N	157 08 W	5048	21
Carnegie[1]	80	....	radiol oz	7 45 N	141 24 W	5003	tr
10° - 20° N							
0-1000 meters							
Challenger	204a	M and R	gn mud	12°43′N	122°09′E	183	56
	204b	M and R	gn mud	12 46 N	122 10 E	210	50
	209	M and R	bu mud	10 14 N	123 54 E	174	36
1000-2000 meters							
Albatross	3419	T	gn cl	16°35′N	100°03′W	1228	9
Challenger	204	M and R	bu mud	12 28 N	122 15 E	1289	11
	205	M and R	bu mud	16 42 N	119 22 E	1920	22
	207	M and R	bu mud	12 21 N	122 15 E	1280	3
2000-3000 meters							
Albatross	H 1820	T	rd cl	19°03′N	110°51′W	2980	0
	near Guam	T	(glob oz)	18 06 N	143 17 E	2680	65
3000-4000 meters							
Albatross	H 1129	T	gy cl	14°33′N	98°14′W	3400	0
	H 1808	T	rd cl	18 23 N	114 18 W	3600	0
	H 1803	T	rd cl	19 35 N	114 52 W	3700	0
	H 1809	T	rd cl	18 24 N	113 48 W	3665	0
	H 1810	T	rd cl	18 25 N	113 15 W	3625	0
	H 1812	T	rd cl	18 29 N	112 12 W	3385	0
	H 1814	T	rd cl	18 35 N	111 21 W	3230	0

Table 36. Distribution of calcium carbonate in the area investigated by the Carnegie, according to latitude and depth--Continued

Station[1]		Reference[2]	Type of sample[3]	Latitude	Longitude	Depth in meters	$CaCO_3$ in per cent
10° - 20° N--Concluded							
3000-4000 meters--Concluded							
Challenger	206	M and R	bu mud	17°54′N	117°14′E	3841	tr
Carnegie[1]	51	....	volc mud	18 26 N	144 01 E	3573	16
Surveyor	58	....	rd cl	19 29 N	107 05 W	3169	3
4000-5000 meters							
Albatross	H 1128	T	(radiol oz)	11°45′N	97°03′W	4110	3
	11	M and L	rd cl	14 38 N	136 44 W	4840	1
	223	M and L	glob oz	10 49 N	167 15 E	4516	64
	224	M and L	glob oz	10 30 N	167 42 E	4730	55
	225	M and L	glob oz	10 15 N	168 06 E	4772	45
Challenger	226	M and R	rd cl	14 44 N	142 13 E	4207	6
	227	M and R	rd cl	17 29 N	141 21 E	4527	tr
	228	M and R	rd cl	19 24 N	141 13 E	4481	tr
	263	M and R	volc mud	17 33 N	153 36 W	4847	0 (T)
Carnegie[1]	78	....	rd cl (?)	16 15 N	137 06 W	4553	<1
	79	....	radiol oz	12 40 N	137 32 W	4918	1
Surveyor	56	....	gn mud	12 07 N	94 06 W	4025	3
	57	....	gn mud	12 52 N	95 46 W	4252	2
>5000 meters							
Albatross	7	M and L	rd cl	18°19′N	134°57′W	5269	1
	12	M and L	radiol oz	12 07 N	137 18 W	5273	1
	246	M and L	rd cl	10 34 N	148 25 E	5474	5
Challenger	225	M and R	radiol oz	11 24 N	143 16 E	8185	tr
	265	M and R	radiol oz	12 42 N	152 01 W	5304	tr
	264	M and R	rd cl	14 19 N	152 37 W	5487	tr
	266	M and R	radiol oz	11 07 N	152 03 W	5030	tr
20° - 30° N							
0-1000 meters							
Trask, Brit. Museum		T	gy st	28°06′N	122°20′E	67	10?
Albatross	2823	T	gn st cl	24 16 N	110 22 W	48	30
	2830	T	gn st cl	23 33 N	110 37 W	120	36
	2834	T	gn st cl	26 14 N	113 13 W	87	25
	2835	T	gy f g s	26 43 N	113 34 W	10	3
	2838	T	gn st cl	28 12 N	115 09 W	80	15
	3007	T	gy cl	25 28 N	110 51 W	660	0
	5303	T	gy cl	21 44 N	114 48 E	65	12
1000-2000 meters							
Albatross	3429	T	gn cl	22°31′N	107°01′W	1670	8
	H 1830	T	gy cl	27 37 N	111 09 W	1100	2
	3431	T	gy cl	23 59 N	108 40 W	1808	8
2000-3000 meters							
Albatross	H 1796	T	(rd cl or glob oz)	24°51′N	115°43′W	2385	30
	3433	T	gy cl	25 26 N	109 48 W	2230	2
Surveyor	60	T	rd cl	20 43 N	108 46 W	2915	5
3000-4000 meters							
Albatross	H 1779	T	rd cl	29°57′N	117°58′W	3245	20
	H 1788	T	rd cl	27 47 N	117 36 W	3865	20
	H 1789	T	rd cl	26 58 N	117 04 W	3765	25
	H 1790	T	rd cl	26 12 N	116 37 W	3855	6
	H 1791	T	rd cl	25 29 N	116 09 W	3950	1
	H 1798	T	rd cl	23 46 N	115 34 W	3855	0
	H 1799	T	rd cl	22 57 N	115 25 W	3950	0
	H 1826	T	rd cl	20 09 N	110 33 W	3000	3
	H 1828	T	rd cl	21 41 N	110 05 W	3100	8
	near Guam	T	rd cl	20 55 N	142 54 E	3900	4
Carnegie[1]	53	....	volc glob mud	26 20 N	144 24 E	3036	48

Table 36. Distribution of calcium carbonate in the area investigated by the Carnegie, according to latitude and depth--Continued

Station[1]		Reference[2]	Type of sample[3]	Latitude	Longitude	Depth in meters	$CaCO_3$ in per cent
20° - 30° N--Concluded							
3000-4000 meters--Concluded							
Surveyor	59	....	rd cl	20°04′N	107°59′W	3305	4
	61	....	gn mud	21 16 N	109 36 W	3072	6
	62	....	gn mud	21 55 N	110 40 W	3374	6
4000-5000 meters							
Albatross	H 2834	T	rd cl	29°11′N	143°20′W	4150	6
	H 2917	T	rd cl	21 39 N	156 49 W	4760	10
	2	M and L	rd cl	28 23 N	126 57 W	4331	1
	4	M and L	rd cl	24 45 N	130 16 W	4807	2
Challenger	229	M and R	rd cl	22 01 N	140 27 E	4573	tr
	230	M and R	rd cl	26 29 N	137 57 E	4435	0
	259	M and R	rd cl	23 03 N	156 06 W	4070	tr
Carnegie[1]	66	....	rd cl	29 21 N	132 20 W	4426	1
	67	....	rd cl	27 45 N	135 22 W	4528	<1
	68	....	rd cl	26 39 N	139 07 W	4695	<1
	69	....	rd cl	26 13 N	142 02 W	4713	1
	75	....	rd cl	27 27 N	138 14 W	4840	<1
	76	....	rd cl	24 57 N	137 44 W	4835	<1
>5000 meters							
Albatross	H 2844	T	rd cl	28°34′N	144°37′W	5110	0
	H 2854	T	rd cl	27 36 N	146 19 W	5300	0
	H 2864	T	rd cl	26 36 N	148 10 W	5285	0
	H 2869	T	rd cl	26 05 N	149 07 W	5480	0
	H 2883	T	rd cl	24 37 N	151 48 W	5540	0
	5	M and L	rd cl	22 42 N	131 54 W	5011	1
	6	M and L	rd cl	20 26 N	133 28 W	5139	1
Challenger	258	M and R	rd cl	26 11 N	155 12 W	5075	tr
Carnegie[1]	52	....	rd cl	23 22 N	144 08 E	5252	<5
	70	....	rd cl	24 02 N	145 33 W	5208	1
	71	....	rd cl	22 53 N	151 15 W	5382	<1
	77	....	rd cl	21 18 N	138 36 W	5320	1
30° - 40° N							
0-1000 meters							
Brit. Mus.	8172	T	gy st	32°34′N	123°25′E	37	1
Albatross	3018	T	gy f g s	30 16 N	113 05 W	64.	0
	3019	T	gy m g s	30 28 N	113 07 W	25	10
	3035	T	lt gy cl	30 21 N	114 25 W	55	8
	2840	T	gn cl	34 11 N	120 15 W	500?	10
	2891	T	gn cl	34 25 N	120 42 W	424	4
	2892	T	gn cl	34 15 N	120 36 W	518	6
	4447	T	gy st cl	36 42 N	121 54 W	86	0
	H 4878	T	gy s	37 27 N	137 29 E	150	20
	H 4879	T	gy cl	37 26 N	137 43 E	745	0
	H 2766	T	gy s	36 47 N	122 05 W	357	2
	H 2768	T	gn st	36 47 N	122 08 W	686	0
	4813	T	gy cl	38 35 N	138 41 E	366	4
	4819	T	gy cl	38 09 N	138 32 E	448	0
	4820	T	gy cl	37 37 N	138 19 E	870	1
	4822	T	gy cl	37 08 N	137 08 E	238	2
	4825	T	gy cl	37 28 N	137 33 E	214	15
	4828	T	gy cl	37 23 N	137 36 E	297	8
	4834	T	gy cl	36 04 N	135 54 E	238	7
	4835	T	gy cl	36 04 N	135 52 E	245	4
	4838	T	gn cl	35 57 N	135 39 E	265	4
Challenger	232	M and R	gn mud	35 11 N	139 28 E	631	3
	233	M and R	bu mud	34 39 N	135 14 E	14.6	11
	233a	M and R	s	34 38 N	135 01 E	91.5	0
	233b	M and R	bu mud	34 18 N	133 35 E	27.4	4
	233c	M and R	bu mud	34 18 N	133 21 E	21.9	4
	236a	M and R	gn mud	34 59 N	139 31 E	768	tr

Table 36. Distribution of calcium carbonate in the area investigated by the *Carnegie*, according to latitude and depth--Continued

Station[1]		Reference[2]	Type of sample[3]	Latitude	Longitude	Depth in meters	CaCO$_3$ in per cent
30° - 40° N--Continued							
1000-2000 meters							
Albatross	H 1775	T	gn cl	31°50′N	117°28′W	1463	15
	H 1776	T	gy cl	31 30 N	117 33 W	1467	25
	H 1777	T	gy cl st	31 04 N	117 40 W	1560	30
	4517	T	gy st cl	36 44 N	122 04 W	1400	1
	4831	T	gy cl	37 23 N	137 47 E	1125	1
Challenger	235	M and R	gn mud	34 07 N	138 00 E	1033	(5)
	236	M and R	gn mud	34 58 N	139 29 E	1417	tr
Albatross	2980	T	st s gr	33 50 N	119 25 W	1100	18
	H 1773	T	gy cl	32 18 N	117 20 W	1345	20
2000-3000 meters							
Albatross	H 1778	T	rd cl	30°21′N	117°52′W	2780	22
Carnegie[1]	56	....	gy sil volc mud	34 44 N	141 04 E	2911	4
3000-4000 meters							
Albatross	H 2690	T	gy cl	36°28′N	123°44′W	3770	1
	H 2691	T	gy cl	36 26 N	124 03 W	3850	1
	H 4013	T	gy cl	36 61 N	142 23 E	3200	2
Challenger	237	M and R	bu mud	34 37 N	140 32 E	3429	4
	246	M and R	glob oz	36 10 N	178 00 E	3749	56
Carnegie[1]	55	....	gy volc mud	33 51 N	141 15 E	3931	<10
	63	....	gn mud	37 05 N	123 43 W	3188	< 5
4000-5000 meters							
Brit. Mus.	4463	T	rd cl	38°31′N	136°38′W	4800	0
Albatross	E. Pacific	T	rd cl	32 01 N	129 47 W	4700	1
	E. Pacific	T	rd cl	32 56 N	124 23 W	4690	0
	E. Pacific	T	rd cl	32 56 N	131 00 W	4550	0
	H 2695	T	gy cl	36 03 N	125 13 W	4415	0
	H 2696	T	gy cl	35 58 N	125 31 W	4650	4
	H 2697	T	gy cl	35 53 N	125 48 W	4710	1
	H 2698	T	(rd cl ?)	35 48 N	126 05 W	4690	1
	H 2704	T	(rd cl ?)	35 20 N	127 54 W	4760	1
	H 2724	T	rd cl	33 20 N	133 12 W	4860	0
	H 2744	T	rd cl	32 18 N	136 04 W	4160	1
	H 2752	T	rd cl	31 43 N	137 31 W	4870	2
	H 2778	T	dk br cl	33 07 N	133 46 W	4070	0
	H 2799	T	rd cl	33 33 N	133 57 W	4600	0
	H 2784	T	rd cl	32 44 N	134 43 W	4450	0
	H 2794	T	rd cl	32 13 N	136 01 W	4860	1
	H 2814	T	rd cl	30 48 N	139 23 W	4700	0
Challenger	231	M and R	bu mud	31 08 N	137 08 E	4115	tr
	234	M and R	bu mud	32 31 N	135 39 E	4893	tr
	241	M and R	rd cl	35 41 N	157 42 E	4207	17
	242	M and R	rd cl	35 29 N	161 52 E	4710	tr
	247	M and R	rd cl	35 49 N	179 57 W	4627	10
Carnegie[1]	64	....	rd cl	33 49 N	126 20 W	4418	1
	65	....	rd cl	31 38 N	128 48 W	4251	tr
	74	....	rd cl	31 50 N	141 50 W	4756	1
>5000 meters							
Albatross	E. Pacific	T	rd cl	37°51′N	132°50′W	5060	0
	E. Pacific	T	rd cl	35 46 N	137 26 W	5270	0
	H 2714	T	rd cl	34 21 N	130 40 W	5070	0
	H 2824	T	rd cl	30 03 N	141 15 W	5000	0
	H 4014	T	(rd cl ?)	36 13 N	142 46 E	6900	1
Challenger	238	M and R	rd cl	35 18 N	144 08 E	7225	0
	239	M and R	rd cl	35 18 N	147 09 E	6630	0
	240	M and R	rd cl	35 20 N	153 39 E	5304	0
	243	M and R	rd cl	35 24 N	166 35 E	5121	1
	244	M and R	rd cl	35 22 N	169 53 E	5304	tr
	245	M and R	rd cl	36 23 N	174 31 E	5075	tr
	248	M and R	rd cl	37 41 N	177 04 W	5304	tr
	249	M and R	rd cl	37 59 N	171 48 W	5487	tr
	250	M and R	rd cl	37 49 N	166 47 W	5578	tr

Table 36. Distribution of calcium carbonate in the area investigated by the Carnegie, according to latitude and depth--Continued

Station[1]		Reference[2]	Type of sample[3]	Latitude	Longitude	Depth in meters	$CaCO_3$ in per cent
			30° - 40° N--Concluded				
			>5000 meters--Concluded				
Carnegie[1]	54	....	br volc mud	31°00′N	144°16′E	6008	5
	57	....	radiol oz	37 40 N	145 26 E	5396	1
	58	....	radiol or diat oz	38 41 N	147 41 E	5545	1
	72	....	rd cl	32 42 N	160 44 W	5787	1
	73	....	rd cl	33 27 N	145 30 W	5584	1
Challenger	252	M and R	rd cl	37 52 N	160 17 W	5011	tr
	253	M and R	rd cl	38 09 N	156 25 W	5716	tr
	254	M and R	rd cl	35 13 N	154 43 W	5533	1 (T)
	255	M and R	rd cl	32 28 N	154 33 W	5213	2
	256	M and R	rd cl	30 22 N	154 56 W	5396	tr
			40° - 50° N				
			0-1000 meters				
Brit. Mus.	4325	T	gn s	48°18′N	124°58′W	312	1
	4326	T	gn st	48 18 N	124 59 W	314	3
Albatross	H 1506	T	gn cl	48 04 N	125 55 W	925	1
	H 1519	T	gy f g s	47 56 N	125 42 W	690	0
	H 1598	T	gn cl	46 15 N	124 36 W	770	0
	H 5492	T	gy cl	44 39 N	124 25 W	113	0
	2866	T	gy s	48 09 N	125 03 W	318	6
			1000-2000 meters				
Brit. Mus.	4333	T	gn st cl	47°45′N	125°44′W	1060	2
Albatross	H 1505	T	gn cl	48 06 N	125 48 W	1065	1
	H 1507	T	gn cl	48 03 N	126 02 W	1265	1
	H 1508	T	gn cl	48 01 N	126 09 W	1400	1
	H 1509	T	gn cl	47 59 N	126 15 W	1560	1
	H 1593	T	gy cl	46 07 N	124 48 W	1100	1
	2871	T	gy s	46 55 N	125 11 W	1020	2
			2000-3000 meters				
Brit. Mus.	4337	T	gn cl	46°22′N	127°44′W	2750	4
	4340	T	gy cl	45 08 N	129 08 W	2760	4
			3000-4000 meters				
Carnegie[1]	62	....	rd cl	40°37′N	132°23′W	3806	7
			4000-5000 meters				
Carnegie[1]	61	....	gy cl mud	44°16′N	137°37′W	4026	1
			>5000 meters				
Carnegie[1]	59	....	diat oz	40°20′N	150°58′E	5296	tr
	60	....	diat oz	45 24 N	159 36 E	5198	1
			50° - 60° N				
			0-1000 meters				
Albatross	H 3224	T	gy cl	59°14′N	141°35′W	213	0
	H 3568	T	gn st	57 35 N	170 24 E	975	0
	4779	T	s	52 11 N	179 57 W	100	0
	4781	T	s	52 15 N	174 13 E	880	10
	H 4875	T	gn s	52 38 N	173 22 E	127	10
	2848	T	gy st	55 10 N	160 18 W	200	1
	2856	T	gy s	58 07 N	151 36 W	125	30
	2858	T	gy cl	58 17 N	148 36 W	420	6
	2861	T	gy s st	51 14 N	129 50 W	377	8
	2862	T	gy st	50 49 N	127 37 W	435	15
	3484	T	gy cl	57 18 N	171 54 W	109	0
	3487	T	gn s	57 10 N	173 45 W	150	4
	3489	T	gn s	57 00 N	173 14 W	335	4
	3492	T	gn s	56 32 N	171 50 W	128	0
	H 4024	T	(gy st ?)	54 24 N	179 24 E	828	22
	H 4025	T	(gy st ?)	54 18 N	179 14 E	975	18

Table 36. Distribution of calcium carbonate in the area investigated by the Carnegie, according to latitude and depth--Continued

Station[1]	Reference[2]	Type of sample[3]	Latitude	Longitude	Depth in meters	$CaCO_3$ in per cent
50° - 60° N--Continued						
0-1000 meters--Concluded						
Albatross H 4028	T	f g s forams	54°40′N	179°08′E	567	12
3497	T	gy s	56 18 N	169 38 W	156	0
3521	T	gy cl	59 09 N	170 05 W	73	6
3525	T	s gr	57 21 N	170 05 W	54	20
3526	T	gy cl	57 21 N	170 57 W	90	2
3539	T	gy cl	56 34 N	167 19 W	102	1
3540	T	gy cl	56 27 N	166 08 W	93	1
3554	T	gy st	56 34 N	170 19 W	113	1
H 1421	T	gn cl	57 57 N	151 08 W	66	0
H 1428	T	gn cl	57 47 N	150 00 W	208	0
H 1435	T	gy st	58 17 N	150 17 W	68	0
H 2287	T	gy st	54 24 N	166 39 W	584	0
1000-2000 meters						
Albatross H 3569	T	gy cl	57°41′N	170°39′E	1115	0
H 3571	T	gn cl	57 53 N	171 09 E	1270	0
H 3620	T	gn s	54 17 N	168 54 W	1850	1
4767	T	gy cl	54 12 N	179 07 E	1415	5
4768	T	gy cl	54 21 N	179 09 E	1390	8
H 1493	T	gn cl	51 34 N	131 25 W	2000	4
H 4877	T	gy cl	52 41 N	158 55 E	1470	2
3490	T	gn s	56 47 N	173 14 W	1144?	1
3501	T	gn s st	55 51 N	169 18 W	1260	3
H 1453	T	gy cl	58 10 N	148 20 W	1395	1
H 4023	T	(terrigenous?)	54 31 N	179 30 E	1160	30
H 4027	T	volc ash?	54 22 N	179 08 E	1290	15
H 4856	T	volc mud	52 35 N	179 33 E	1640	6
H 4869	T	volc mud	52 08 N	174 25 E	1490	2
H 2474	T	gy s	58 14 N	174 35 W	1789	1
2000-3000 meters						
Albatross H 3572	T	gy cl	58°13′N	171°51′E	2780	0
H 3604	T	lt gy cl	54 46 N	169 29 W	2465	0
4764	T	gy cl	53 20 N	171 00 W	2065	1
H 1492	T	gy cl	52 32 N	133 05 W	2930	0
2859	T	br gy cl	55 20 N	136 30 W	2860	5
3308	T	gy cl	56 12 N	172 07 W	2980	0
3604	T	br st cl	54 54 N	168 59 W	2560	0
H 4030	T	(gy cl ?)	54 47 N	179 25 E	2330	0
H 4868	T	diat oz	51 51 N	174 39 E	2680	0
H 1482	T	gy cl	59 12 N	143 00 W	2840	7
H 1486	T	gy cl	58 58 N	141 59 W	2740	0
H 1487	T	gy cl	58 51 N	141 46 W	2830	2
3000-4000 meters						
Albatross H 2468	T	gy cl	54°43′N	171°16′W	3200	0
H 2469	T	gy cl	55 31 N	171 42 W	3305	0
H 2477	T	gy cl	56 02 N	175 35 W	3650	1
H 2478	T	gy cl	55 17 N	175 32 W	3700	0
H 2479	T	gy cl	54 31 N	175 32 W	3900	0
H 3545	T	gy cl	55 45 N	179 57 W	3800	0
H 3548	T	br cl	55 52 N	177 25 E	3870	0
H 3549	T	br cl	55 53 N	173 53 E	3860	0
H 3551	T	gy cl	56 00 N	169 46 E	3950	0
H 3554	T	gy cl	55 43 N	166 15 E	3800	0
H 3564	T	gy cl	56 25 N	167 52 E	3890	0
H 3565	T	gy cl	56 56 N	169 06 E	3410	0
H 3574	T	gy cl	58 23 N	174 17 E	3600	0
H 3580	T	lt gy cl	57 30 N	178 50 W	3755	0
H 3581	T	lt gy cl	57 23 N	178 17 W	3755	0
H 3582	T	lt gy cl	57 13 N	177 07 W	3640	0
H 3583	T	lt gy cl	57 03 N	176 00 W	3300	0
4761	T	gy cl	53 58 N	159 31 W	3595	1
H 4019	T	gy cl volc ash	54 41 N	163 04 E	3800	1
H 4849	T	gy cl	53 05 N	176 11 E	3750	0
H 1481	T	gy cl	59 08 N	143 30 W	3880	1
H 1483	T	gy cl	59 00 N	142 37 W	3230	0
H 1484	T	gy cl	58 54 N	142 33 W	3200	1
H 1485	T	gy cl	58 56 N	142 18 W	3050	1

Table 36. Distribution of calcium carbonate in the area investigated by the *Carnegie*, according to latitude and depth--Continued

Station[1]		Reference[2]	Type of sample[3]	Latitude	Longitude	Depth in meters	$CaCO_3$ in per cent
50° - 60° N--Concluded							
3000-4000 meters--Concluded							
Albatross	H 1488	T	gy cl	58°17′N	140°35′W	3300	0
	H 1489	T	gy cl	57 45 N	139 25 W	3250	0
4000-5000 meters							
Albatross	H 2563	T	gy cl	56°01′N	152°26′W	4770	0
	H 3262	T	gy cl	51 11 N	176 25 W	4290	0
	H 1134	T	gy cl	52 17 N	162 48 W	4900	0
	H 1137	T	gy cl	52 20 N	166 05 W	4870	0
	H 1138	T	gy cl	52 40 N	166 35 W	4150	0
	H 1480	T	gy cl	59 01 N	144 22 W	4050	0
>5000 meters							
Albatross	H 3265	T	gy cl	50°28′N	175°10′W	7300	0
	H 3267	T	gy cl	50 03 N	174 30 W	5120	0
	H 1136	T	gy cl	52 20 N	165 00 W	6970	1
0° - 10° S							
0-1000 meters							
Albatross	2792	T	gn cl	0°37′S	81°00′W	732	12
1000-2000 meters							
Albatross	2808	T	bn gy cl	0°37′S	89°19′W	1150	20
	3407	T	lt gy cl	0 04 S	90 25 W	1608	10
	4641	M and L	glob oz	1 34 S	89 30 W	1158	75
	4654	M and L	gn mud	5 46 S	81 32 W	1895	tr
Carnegie[1]	11	....	volc gr	1 32 S	82 16 W	1344	5
2000-3000 meters							
Albatross	4639	M and L	glob oz	0°04′S	87°40′W	2594	56
Carnegie[1]	15	M and L	glob oz	9 06 S	108 20 W	2905	80
3000-4000 meters							
Brit. Mus.	5250	T	gn cl	3°39′S	127°34′E	3240	8
	5254	T	gy cl	1 19 S	126 51 E	3200	13
Albatross	H 1114	T	gy cl	5 16 S	83 09 W	3150	5
	H 1115	T	rd gy cl	4 18 S	85 14 W	3445	12
	H 1117	T	rd gy cl	4 02 S	85 26 W	3195	30
	4715	M and L	glob oz	2 40 S	90 19 W	3188	50
	4520	M and L	glob oz	1 47 S	91 36 W	3320	46
	4521	M and L	glob oz	2 14 S	92 30 W	3422	45
	4522	M and L	glob oz	2 42 S	93 30 W	3519	56
	4523	M and L	glob oz	3 34 S	95 35 W	3715	56
	4717	M and L	glob oz	5 10 S	98 56 W	3938	60
	4721	M and L	glob oz	8 07 S	104 10 W	3812	75
	21	M and L	glob oz	8 28 S	139 12 W	3993	66
	22	M and L	glob oz	8 31 S	139 26 W	3546	71
	23	M and L	glob oz	8 33 S	139 36 W	3296	70
Carnegie[1]	12	....	glob oz	1 32 S	93 10 W	3539	30
	13	....	glob oz	2 30 S	95 43 W	3352	67
	14	....	glob oz	3 15 S	99 48 W	3423	76
4000-5000 meters							
Brit. Mus.	4969	T	gn cl	5°16′S	129°12′E	4200	1
Albatross	4649	M and L	rd cl	5 17 S	85 20 W	4088	20
	4658	M and L	rd cl	8 30 S	85 36 W	4335	0
	4711	M and L	glob oz	7 48 S	94 06 W	4097	55
	4713	M and L	glob oz	5 35 S	92 22 W	4007	55
	4719	M and L	rd cl	6 30 S	101 17 W	4179	0
	4740	M and L	glob oz	9 02 S	123 20 W	4430	65
	4537	M and L	glob oz	4 30 S	120 46 W	4298	79
	4538	M and L	glob oz	2 14 S	118 55 W	4190	66
	18	M and L	glob oz	6 25 S	138 59 W	4527	72

Table 36. Distribution of calcium carbonate in the area investigated by the *Carnegie*, according to latitude and depth--Continued

Station[1]		Reference[2]	Type of sample[3]	Latitude	Longitude	Depth in meters	$CaCO_3$ in per cent
0° - 10° S--Concluded							
4000-5000 meters--Concluded							
Albatross	19	M and L	glob oz	7°58′S	139°09′W	4183	71
	20	M and L	glob oz	8 13 S	139 10 W	4146	69
Challenger	271	M and R	glob oz	0 33 S	151 34 W	4435	81
	272	M and R	radiol oz	3 48 S	152 56 W	4755	10
	273	M and R	radiol oz	5 11 S	152 56 W	4298	2
Carnegie[1]	34	....	gn cl mud	9 58 S	82 10 W	4480	0
	82	....	glob oz	1 48 S	152 22 W	4693	85
	83	....	glob oz	6 33 S	154 58 W	4065	90
>5000 meters							
Challenger	274	M and R	radiol oz	7°25′S	152°15′W	5030	4
Britannia	581	M	radiol oz	3 52 S	166 08 W	5386	2
Tuscarora	12/25/75	M	glob oz	3 21 S	171 23 W	5185	42
Carnegie[1]	49	....	rd cl	6 47 S	172 23 W	5269	1
	50	....	rd cl	3 47 S	172 39 W	5253	10
	84	....	rd cl	9 24 S	159 01 W	5545	<5
10° - 20° S							
1000-2000 meters							
Brit. Mus.	1011	T	glob oz	18°30′S	178°30′E	1170	50
Albatross	74	M and L	volc mud	17 28 S	149 34 W	1476?	30
	109	M and L	glob oz	16 13 S	143 48 W	1805	79
	191	M and L	pter oz	18 56 S	178 43 W	1097	83
	193	M and L	glob oz	18 56 S	179 16 W	1811	78
Challenger	279a	M and R	volc mud	17 30 S	149 34 W	1079	25
	279b	M and R	volc mud	17 30 S	149 34 W	1134	23
	279c	M and R	volc mud	17 29 S	149 35 W	1244	20
Britannia	487	M	volc mud	15 11 S	176 45 W	1646	21
Penguin	258	M	glob oz	17 09 S	179 50 W	1915	75
Waterwitch	147	M	glob oz	17 13 S	179 57 W	1948	70
Penguin	260	M	glob oz	16 54 S	179 32 W	1425	75
	329	M	pter oz	14 04 S	171 50 W	1878	70
	236	M	pter oz	16 46 S	179 14 W	1410	90
2000-3000 meters							
Albatross	4671	M and L	bu mud	12°07′S	78°28′W	2725	0
	35	M and L	glob oz	14 42 S	147 08 W	2674	74
	70	M and L	volc mud	17 21 S	149 15 W	2899	20
	75	M and L	glob oz	16 57 S	147 29 W	2912	41
	94	M and L	glob oz	16 57 S	145 49 W	2800	81
	113	M and L	glob oz	15 55 S	142 39 W	2749	80
	188	M and L	rd cl or volc mud	18 43 S	175 28 W	2526	17
	194	M and L	glob oz	12 43 S	179 50 W	2643	84
Challenger	278	M and R	volc mud	17 12 S	149 43 W	2789	21
Britannia	495	M	glob oz	14 33 S	175 55 W	2343	41
Penguin	263	M	glob oz	16 23 S	178 03 W	2738	80
	256	M	glob oz	17 32 S	179 55 W	2513	80
	228	M	glob oz	18 26 S	177 08 W	2215	60
	230	M	glob oz	17 26 S	177 57 W	2643	63
	336	M	volc mud	16 29 S	173 01 W	2947	10
	226	M	glob oz	19 24 S	176 19 W	2332	34
	225	M	volc mud	19 52 S	175 55 W	2555	5
	266	M	glob oz	15 55 S	177 36 W	2619	52
	325	M	volc mud	15 06 S	174 20 W	2491	20
	342	M	volc mud	18 23 S	173 50 W	2087	20
Carnegie[1]	42	....	glob oz	13 03 S	121 12 W	2953	93
	46	....	glob oz (?)	17 36 S	141 55 W	2132	90
	85	....	glob oz	10 54 S	161 53 W	2614	94

Table 36. Distribution of calcium carbonate in the area investigated by the Carnegie, according to latitude and depth--Continued

Station[1]		Reference[2]	Type of sample[3]	Latitude	Longitude	Depth in meters	$CaCO_3$ in per cent
10° - 20° S--Continued							
3000-4000 meters							
Brit. Mus.	1004	T	glob oz	19°13′S	109°12′W	3380	30
Albatross	4509	M and L	bu mud	12 27 S	78 34 W	3565	5
	4726	M and L	glob oz	12 30 S	111 42 W	3109	68
	102	M and L	glob oz	17 10 S	145 19 W	3071	84
	136	M and L	glob oz	18 08 S	141 49 W	4000	74
	140	M and L	glob oz	18 27 S	140 21 W	3735	73
	142	M and L	glob oz	18 30 S	139 30 W	3846	78
	146	M and L	rd cl	18 36 S	139 14 W	3155	30
	151	M and L	glob oz	19 27 S	138 47 W	3488	85
Challenger	280	M and R	glob oz	18 40 S	149 52 W	3548	53
Carnegie[1]	16	....	glob oz	14 07 S	111 50 W	3080	87
	36	....	glob oz	14 15 S	92 05 W	3480	91
	37	....	glob oz	15 18 S	97 28 W	3197	93
Albatross	4705	M and L	glob oz	15 05 S	99 19 W	3715	79
	4707	M and L	glob oz	12 33 S	97 42 W	3877	71
	4709	M and L	glob oz	10 15 S	95 41 W	3722	78
	4534	M and L	glob oz	13 51 S	126 54 W	3996	73
Penguin	328	M	volc mud	14 12 S	172 11 W	3892	30
Carnegie[1]	31	....	rd cl	16 49 S	78 39 W	3657	20
	33	....	gn st mud	11 57 S	78 37 W	3357	<1
	40	....	glob oz	12 36 S	112 14 W	3090	78
	41	....	glob oz	12 39 S	117 22 W	3515	90
	43	....	glob oz	14 52 S	126 07 W	3631	89
	44	....	glob oz	17 00 S	129 45 W	3966	75
	45	....	glob oz	17 12 S	136 37 W	3791	94
4000-5000 meters							
Albatross	4666	M and L	rd cl	11°56′S	84°20′W	4755	tr
	4674	M and L	diat oz	12 14 S	78 43 W	4276	0
	4676	M and L	rd cl	14 29 S	81 24 W	4964	0
	4679	M and L	rd cl	17 26 S	86 46 W	4545	0
	4681	M and L	rd cl	18 47 S	89 26 W	4380	4
	31	M and L	rd cl	12 20 S	144 15 W	4938	8
	33	M and L	rd cl	14 10 S	146 10 W	4622	4
	62	M and L	glob oz	15 33 S	148 45 W	4146	67
	63	M and L	glob oz	15 42 S	148 44 W	4110	57
	67	M and L	glob oz	16 32 S	148 40 W	4322	40
	68	M and L	rd cl	16 57 S	148 58 W	4068	28
	152	M and L	rd cl or glob oz	19 35 S	139 13 W	4271	34
Challenger	275	M and R	rd cl	11 20 S	150 30 W	4774	tr
	276	M and R	rd cl	13 28 S	149 30 W	4298	28
	277	M and R	rd cl	15 51 S	149 41 W	4252	9
Britannia	510	M	rd cl or radiol oz	13 35 S	174 14 W	4627	28
Penguin	335	M	volc mud	15 52 S	172 37 W	4439	15
Carnegie[1]	35	....	rd cl	11 00 S	87 24 W	4141	1
	38	....	rd cl	14 20 S	103 12 W	4094	<10
Albatross	4701	M and L	rd cl	19 12 S	102 24 W	4143	12
	4703	M and L	glob oz	17 19 S	100 52 W	4075	41
	4532	M and L	rd cl	18 29 S	130 51 W	4241	18
	4535	M and L	glob oz	11 20 S	125 01 W	4051	77
	172	M and L	glob oz	19 22 S	145 47 W	4247	41
	173	M and L	rd cl	18 55 S	146 23 W	4463	1
Penguin	331	M	rd cl	14 49 S	171 52 W	4631	5
	326	M	volc mud	14 45 S	173 37 W	4818	0
Carnegie[1]	32	....	gn diat mud	13 53 S	77 54 W	4742	< 1
	47	....	rd cl	18 05 S	145 33 W	4315	15
	48	....	rd cl	12 47 S	171 35 W	4760	<10
>5000 meters							
Albatross	4672	M and L	rd cl	13°12′S	78°18′W	5204	0
	4675	M and L	rd cl	12 54 S	78 33 W	5706	0
Challenger	279	M and R	volc mud	17 30 S	149 33 W	7682	22

Table 36. Distribution of calcium carbonate in the area investigated by the *Carnegie*, according to latitude and depth--Continued

Station[1]		Reference[2]	Type of sample[3]	Latitude	Longitude	Depth in meters	$CaCO_3$ in per cent
10° - 20° S--Concluded							
>5000 meters--Concluded							
Penguin	239	M	pter oz	17°18′S	179°56′W	8980	80
Albatross	182	M and L	rd cl	18 59 S	164 47 W	5271	0
Penguin	333	M	rd cl	14 32 S	172 04 W	6460	0
20° - 30° S							
1000-2000 meters							
Carnegie[1]	29	....	glob oz	24°57′S	82°15′W	1089	94
2000-3000 meters							
Albatross	4514	M and L	volc s	27°16′S	108°56′W	2839	12
	4516	M and L	glob oz	26 55 S	109 16 W	2976	33
Carnegie[1]	18	....	glob oz	29 06 S	114 48 W	2898	94
3000-4000 meters							
Albatross	4687	M and L	rd cl	22°50′S	97°31′W	3995	8
	4689	M and L	rd cl	24 05 S	100 20 W	3966	14
	4691	M and L	glob oz	25 27 S	103 29 W	3546	70
	4517	M and L	glob oz	26 51 S	109 12 W	3151	64
	4518	M and L	glob oz	26 47 S	109 09 W	3237	53
	4695	M and L	glob oz	25 22 S	107 45 W	3695	62
	4699	M and L	glob oz	21 40 S	104 30 W	3965	33
	4525	M and L	glob oz	21 36 S	131 35 W	3883	66
	4739	M and L	glob oz	22 11 S	133 21 W	3735	59
Challenger	283	M and R	glob oz	26 09 S	145 17 W	3795	47
	284	M and R	glob oz	28 22 S	141 22 W	3631	66
Carnegie[1]	17	....	glob oz	23 16 S	114 45 W	3098	74
	20	....	glob oz	29 17 S	108 54 W	3061	top 76 btm 80} 78
4000-5000 meters							
Brit. Mus.	1002	T	rd cl	23°13′S	79°01′W	4390	1
Albatross	4683	M and L	rd cl	20 02 S	91 52 W	4362	3
	4685	M and L	glob oz	21 36 S	94 56 W	4033	34
	4697	M and L	rd cl	23 24 S	106 02 W	4002	11
	4531	M and L	ca mud[4]	21 04 S	133 01 W	4070	73
	156	M and L	rd cl	20 31 S	142 00 W	4514	26
	157	M and L	glob oz	20 46 S	142 51 W	4234	42
	167	M and L	rd cl	20 02 S	144 28 W	4616	4
Challenger	281	M and R	rd cl	22 21 S	150 17 W	4362	tr
	282	M and R	rd cl	23 46 S	149 59 W	4481	tr
Carnegie[1]	30	....	rd cl	21 28 S	80 26 W	4156	3
>5000 meters							
Albatross	186	M and L	rd cl	21°18′S	173°51′W	8304	0
30° - 40° S							
2000-3000 meters							
Albatross	2790	M and L	gn cl	39°21′S	74°42′W	2350	7
Challenger	292	M and R	glob oz	38 43 S	112 31 W	2926	84
	300	M and R	glob oz	33 42 S	78 18 W	2515	54
Carnegie[1]	19	....	glob oz	31 28 S	112 51 W	2851	86
3000-4000 meters							
Brit. Mus.	1009	T	rd cl	31°44′S	79°33′W	3700	12
Challenger	293	M and R	glob oz	39 04 S	105 05 W	3704	45
	296	M and R	glob oz	38 06 S	88 02 W	3338	64
	297	M and R	glob oz	37 29 S	83 07 W	3246	71

Table 36. Distribution of calcium carbonate in the area investigated by the *Carnegie*, according to latitude and depth--Concluded

Station[1]		Reference[2]	Type of sample[3]	Latitude	Longitude	Depth in meters	$CaCO_3$ in per cent
			30° - 40° S--Concluded				
			3000-4000 meters--Concluded				
Challenger	299	M and R	bu mud	33°31'S	74°43'W	3951	15
Carnegie[1]	21	....	glob oz	33 59 S	106 43 W	3139	84
	24	....	glob oz	38 29 S	94 14 W	3299	86
	25	....	glob oz	34 35 S	91 52 W	3610	74
	26	....	glob oz	32 10 S	89 04 W	3393	91
	27	....	glob oz	31 54 S	88 17 W	3879	43
	28	....	glob oz	31 07 S	86 39 W	3626	66
			4000-5000 meters				
Challenger	285	M and R	rd cl	32°36'S	137°43'W	4344	26
	286	M and R	rd cl	33 29 S	133 22 W	4271	25
	287	M and R	rd cl	36 32 S	132 52 W	4390	(1)
	294	M and R	rd cl	39 22 S	98 46 W	4152	tr
	298	M and R	bu mud	34 07 S	73 56 W	4070	6
Carnegie[1]	22	....	glob oz	39 51 S	101 04 W	4116	42
			40° - 50° S				
			2000-3000 meters				
Challenger	302	M and R	glob oz	42°43'S	82°11'W	2652	82
	303	M and R	bu mud	45 31 S	78 09 W	2423	26
			4000-5000 meters				
Challenger	288	M and R	rd cl	40°03'S	132°58'W	4755	tr
Carnegie[1]	23	....	glob oz	40 24 S	97 33 W	4007	75

[1] *Carnegie* numbers are sample, not station numbers. [2] M = Murray (1902, 1906); M and L = Murray and Lee (1909); M and R = Murray and Rénard (1891); T = Trask (1932). [3] The designations for deposit types are those of the authors referred to. The following abbreviations are used: br = brown, bu = blue, ca = calcareous, cl = clay, diat = diatom, dk = dark, f g = fine-grained, glob = globigerina, gn = green, gr = gravel, gy = gray, lt = light, m g = medium-grained, oz = ooze, pter = pteropod, radiol = radiolarian, rd = red, s = sand or sandy, sil = siliceous, st = silt or silty, volc = volcanic. [4] Probably a pelagic sample.

Table 37. Index of methods employed

Sample no.	Chemical analyses								
	Entire sample	Volcanic fragments, etc.	Foraminifera	Fine fractions	Total CO_2	Carbonate in various size grades	Organic matter	Base exchange	Spectrographic
1	x	..	..	..	..	..	x	..	x
2	x	..	..	..	..	..	..	..	x
3	..	..	..	..	..	..	..	..	x
4	..	..	..	..	..	..	..	..	x
5	..	..	..	..	..	..	..	..	..
6	..	..	..	..	..	..	..	..	x
7	..	..	..	..	..	..	..	..	..
8	..	..	..	..	..	..	..	..	x
9	x	..	..	..	..	..	x	..	x
10	x	..	..	..	..	..	x	..	x
11	..	x	..	..	..	..	..	..	x
12	..	..	..	..	..	..	..	..	..
13	x	..	..	..	x	..	x	..	x
14	x	..	..	..	..	..	x	..	x
15	..	..	..	..	..	..	..	..	..
16	x	..	..	..	..	..	x	..	x
17	x	..	x	x	..	x	x	x	x
18	x	..	..	..	..	..	x	..	x
19	x	..	x	x	..	..	x	x	x
20	..	..	..	..	x[1]	x[1]	..	..	x
21	x	..	x	x	..	..	x	..	x
22	x	..	..	..	..	..	x	..	x
23	x	..	x	x	..	..	x	..	x
24	..	..	..	..	x	x	..	..	x
25	x	..	..	..	..	..	x	..	x
26	x	..	..	..	..	..	x	..	x
27	x	..	..	..	..	..	x	..	x
28	..	..	..	..	x	..	..	..	x
29	x	..	..	..	..	..	x	..	x
30	..	..	..	..	x	..	..	..	x
31	x	..	..	x	x	..	x	..	x
32	..	..	..	..	x	..	..	..	x
33	..	..	..	..	..	..	..	..	..
34	x	..	..	x	..	..	..	x	x
35	x	..	..	..	..	..	x	..	x
36	x	..	..	..	..	..	x	..	x
37	..	..	..	..	x	..	..	..	..
38	..	..	..	..	..	..	..	..	x
39	..	..	..	..	..	..	..	..	..
40	..	..	..	..	x	x	..	..	x
41	x	..	..	..	..	..	x	..	x
42	..	..	..	..	x	..	..	..	x
43	..	..	..	..	x	..	..	..	x
44	x	..	x	..	x	..	x	..	x
45	x	..	..	..	..	..	x	..	x
46	..	..	..	..	..	..	..	..	x
47	..	..	..	..	x	..	..	..	x
48	..	..	..	..	..	..	..	..	..
49	..	..	..	..	x	..	..	..	x
50	..	..	..	..	..	..	..	..	..
51	..	..	..	..	x	..	..	..	x
52	..	..	..	..	..	..	..	..	..
53	..	..	..	..	x	x	..	..	x
54	..	..	..	..	x	..	..	..	x
55	..	..	..	..	..	..	..	..	..
56	x	..	..	..	..	..	x	..	x
57	x	..	..	..	..	..	x	..	x
58	x	..	..	..	..	..	x	..	x
59	x	..	..	..	..	..	x	..	x
60	x	..	..	..	..	..	x	..	x
61	x	..	..	..	..	..	x	..	x
62	x	..	..	..	x	..	x	..	x
63	..	..	..	..	..	..	..	..	..
64	x	..	..	..	..	..	x	..	x
65	x	..	..	..	..	..	x	..	x
66	x	..	..	..	..	..	x	..	x
67	..	..	..	..	..	..	..	..	..
68	..	..	..	..	..	..	..	..	..
69	x	..	..	..	..	..	x	..	x
70	x	..	..	..	..	..	x	..	x

in study of *Carnegie* bottom samples

	Mechanical analyses		Physical analyses		Identification of organic remains			
Radium content	Pipette method	U.S.B.S. method	Density and temperature-humidity relations	X-ray powder diagrams	Foraminifera	Sponges	Echinoids	Ostracods
x	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..
..	..	x	..	x	..	..	..	..
..	..	x	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..
x	..	x	..	..	x	..	..	..
x	..	x	..	x	x	x	x	..
..	..	x	..	..	..	..	..	..
x	..	x	..	x	..	..	..	..
..	..	x	x	x	x	..	x	x
x	..	x	..	..	x	..	x	x
..	x	..	x	x	x	..	..	..
..	..	x[1]	..	x	..	..	..	..
..	x	..	..	x	x	..	..	..
..	..	x	..	x	x	..	..	..
x	x	..	..	x	x	..	..	x
..	..	..	..	..	..	..	..	..
x	..	x	..	x	x	x	x	x
x	..	x	..	..	x	..	..	x
x	..	x	..	x	x	x	x	x
..	..	..	..	..	..	..	..	..
x	..	x	..	..	x	x	x	x
..	..	..	..	x	..	..	..	..
..	x	..	x	x	x	x	x	x
..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..
..	x	..	x	x	x	x	..	..
..	..	x	..	x	x	x	..	..
..	..	x	..	..	x	..	x	x
..	..	x	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..
..	x	..	..	x	..	..	..	..
..	..	x	..	..	x	..	x	x
..	..	x	..	..	..	..	..	..
..	x	..	..	x	..	..	..	..
..	..	x	..	..	x	..	..	..
..	..	x	..	..	x	..	..	..
..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..
..	x	..	..	x	..	x	..	..
..	..	..	..	..	..	..	..	..
..	..	x	..	x	..	..	..	..
..	..	..	..	..	..	..	..	..
..	..	x	..	x	..	..	..	..
..	..	x	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..
x	..	x	..	x	..	..	..	..
x	..	x	..	..	..	..	..	..
x	..	x	..	..	..	..	..	..
x	..	x	..	..	x	x	..	..
x	..	x	..	x	..	..	..	..
x	..	x	..	..	..	..	..	..
x	..	x	..	x	x	..	x	..
..	..	..	..	..	..	..	..	..
x	..	x	..	..	..	..	..	..
x	..	x	..	..	..	..	..	..
x	..	x	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..
x	x	..	x	x	..	..	..	..
x	x	..	..	x	..	..	..	..

Table 37. Index of methods employed in study

Sample no.	Chemical analyses								
	Entire sample	Volcanic fragments, etc.	Foraminifera	Fine fractions	Total CO_2	Carbonate in various size grades	Organic matter	Base exchange	Spectrographic
71	..	..	..	..	..	..	..	..	..
72	x	..	..	x	x	..	x	x	x
73	x	..	..	x	..	..	..	x	x
74	..	..	..	..	x	..	..	..	x
75	..	..	..	..	..	..	..	..	..
76	..	..	..	..	..	..	..	..	x
77	x	..	..	x	..	..	x	x	x
78	..	..	..	..	..	..	..	..	..
79	x	..	..	..	..	..	x	..	x
80	x	..	..	..	x	..	x	..	x
81	x	..	..	x	x	..	x	..	x
82	x	..	..	..	..	x	x	..	x
83	..	..	..	..	..	..	..	..	..
84	..	..	..	..	..	..	..	..	..
85	x	..	..	..	x	..	x	..	x
88	x	..	..	..	..	..	..	..	..
89	x	..	..	..	..	..	..	..	x
Total	46	1	5	10	23	6	41	6	67
Total, deep-sea Pacific	41	1	5	10	23	6	39	6	59

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[1] Top and bottom of 24-inch core analyzed separately.

of *Carnegie* bottom samples--Concluded

	Mechanical analyses		Physical analyses		Identification of organic remains			
Radium content	Pipette method	U.S.B.S. method	Density and tempera-ture-humid-ity relations	X-ray powder diagrams	Foramin-ifera	Sponges	Echinoids	Ostracods
..	..	..	..	..	..	..	..	..
..	x	..	x	x	..	x	..	..
..	x	..	x	x	..	..	..	..
..	x	..	..	x	..	..	..	..
..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..
x	x	..	x	x	..	..	..	..
..	..	..	..	..	..	..	..	..
x	..	x	..	x	..	x	..	..
x	..	x	..	..	..	..	..	..
x	x	..	..	x	x	x	x	..
x	..	x	..	x	x	x	..	x
..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..
x	..	x	..	..	x	..	x	..
..	..	x	..	..	..	..	..	..
..	..	x	..	..	..	..	..	..
28	15	41	8	32	24	13	12	11
27	15	39	8	32	24	13	12	11

5000 meters. The curve for pelagic samples in these latitudes is somewhat similar in form to that for all samples but shows a higher percentage of calcium carbonate at any given depth.

Between 10° and 20° south the average amounts of calcium carbonate for depths of 1000 to 4000 meters are approximately 50 to 65 per cent for all samples combined, and 66 to 74 per cent for pelagic samples alone. Below 4000 meters there is a marked diminution in $CaCO_3$ content to less than 20 per cent. From 10° to 20° north the curves, though much more irregular than in the corresponding southern latitudes, tend to show a decrease with depth from 47 per cent $CaCO_3$ in the upper thousand meters to 1 per cent at depths greater than 5000 meters.

There is a good correlation between depth and carbonate content for the pelagic samples collected between 20° and 30° south, the amount of carbonate decreasing in a regular manner from over 90 per cent for one sample less than 2000 meters in depth to an average of 18 per cent for eleven samples between 4000 and 5000 meters, and 0 per cent for one sample collected below 5000 meters. In the north Pacific at the same latitudes no samples have been analyzed containing more than 48 per cent calcium carbonate and the average for even the shallowest depths is less than 20 per cent, the percentage of carbonate then decreasing in a more or less regular manner to average values of 1.9 per cent between 4000 and 5000 meters and 0.8 per cent for depths greater than 5000 meters.

Between 30° and 40° south there is a decrease with depth for the eighteen pelagic samples analyzed from 75 per cent $CaCO_3$ between 2000 and 3000 meters to 19 per cent between 4000 and 5000 meters. South of 40° south only four samples have been analyzed from the area investigated by the Carnegie, so that the average curve, though given for the sake of completeness, has little significance.

Between 30° and 50° north the average values of $CaCO_3$, although low throughout, tend to have a maximum at intermediate depths. North of 50° north ninety samples were collected by the Albatross and have been analyzed by Trask (1932). These are all terrigenous samples and contain, on the average, very little calcium carbonate, but nevertheless they exhibit a good correlation between $CaCO_3$ and depth, the average values ranging from 5.8 per cent for twenty-eight samples collected between 0 and 1000 meters to considerably less than 1 per cent for thirty-five samples collected at depths greater than 3000 meters.

In figure 41 the distribution of calcium carbonate content with latitude for each depth division is shown. As before, two curves are usually plotted, one for the averages of all available samples and the other for pelagic samples. The number of samples entering into each average value is also given. The average carbonate values for each latitude interval are plotted at the mid-point, halfway between the two limiting latitudes; for example, the average latitude of samples collected between the equator and 10° north has been assumed to be 5° north.

For depths between 0 and 1000 meters the maximum average carbonate content of all samples lies between 10° and 20° north latitude, and the average values decrease sharply both to the north and to the south. All but two of these samples are terrigenous.

Between 1000 and 2000 meters the maximum average carbonate content of all samples analyzed lies between 20° and 30° south and the curve for all samples taken together first shows a sharp drop and then an irregular decrease in $CaCO_3$ content to the northward.

Between 2000 and 3000 meters the curve for pelagic samples shows a more or less regular decrease in $CaCO_3$ content from latitudes 40° to 50° south to 20° to 30° north, with a slight secondary maximum being evident between 0° and 10° south. The curve for all samples combined is more irregular but shows a pronounced decrease of calcium carbonate north of the equator, and relatively constant values to the southward.

For depths between 3000 and 4000 meters the maximum average carbonate content lies between 10° and 20° south, the average carbonate values being almost constant to 40° south, but decreasing markedly to 20° north. North of 30° very little carbonate is present except in one pelagic sample.

The curves for depths between 4000 and 5000 meters show a pronounced maximum in $CaCO_3$ between 0° and 10° north, with a regular decrease of average carbonate contents in both directions toward the higher latitudes, and an increase south of 30° to a secondary maximum of 37.5 per cent between 40° and 50° south.

The curve for samples obtained at depths greater than 5000 meters is somewhat similar in general shape to the last curve, but the average values of carbonate content are all much smaller. There is a maximum between 0° and 10° north of 24.2 per cent $CaCO_3$, and a secondary maximum between 10° and 20° south of 17 per cent. North of 10° north the average carbonate content of all samples never rises above 1 per cent.

Comparison of Atlantic and Pacific. That there is a correlation between decreasing calcium carbonate content and increasing depths was pointed out by Murray and Rénard (1891), and this relation has since been confirmed by the results of other oceanographic expeditions. Andrée (1920), however, was able to find very little correlation between depth and carbonate content when considering Globigerina oozes of the Atlantic alone, and Pratje (1932) has suggested that there is no significant influence of depth, as such, on the carbonate content of sediments. Pia (1933), using the data collected by Andrée, found a Bravais correlation coefficient between $CaCO_3$ content and depth of -0.3179±0.0762 for the Globigerina oozes collected by the Challenger, Valdivia, and other expeditions in the Atlantic. Using Gebbing's data (1909) from the Challenger, Gazelle, and Gauss he calculated a correlation coefficient of -0.3047±0.0821. From these calculations he concluded that "die Korrelation ist also negativ, nicht sehr vollkommen, aber sehr sicher." From a compilation given by Murray and Chumley (1924), however, of the data for all samples collected from the Atlantic previous to 1922, Pia was able to calculate somewhat higher correlation coefficients as follows:

For all samples at depths greater than 1500 fathoms	-0.3884±0.0283
For Globigerina oozes, pteropod oozes, and red clay at depths greater than 1500 fathoms	-0.6312±0.0221
For Globigerina oozes alone (thus reducing the influence of terrigenous materials) at depths less than 1500 fathoms	-0.3316±0.0360

Pia has plotted his average data for calcium carbonate content against depth for all the 1426 samples given by Murray and Chumley and for Globigerina oozes, pteropod oozes, and red clays alone. The latter curve is reproduced in figure 44, together with the average data for all pelagic samples collected in the Pacific. The general similarity in the shapes of the two curves at depths greater than 1000 meters is very striking. The discrepancy at depths less than 1000 meters is probably owing to the fact that only two pelagic samples from these depths are available for the Pacific. There is a marked quantitative difference, however, between the two curves below 1500 meters; that is, the curve for the Pacific samples at every depth shows a smaller calcium carbonate content than at the corresponding depth in the Atlantic. This is particularly marked below 3500 meters, where the decrease shown by the curve for the Pacific samples is rapid and almost linear from 49 per cent at 3500 meters to 5 per cent at depths greater than 5000 meters. The curve for the Atlantic samples starts to show a decrease from an average value of 71 per cent at 4000 meters to 6 per cent at 6400 meters.

Irregularity of Depth Relation. The relation between $CaCO_3$ and depth is a very irregular one and, as will be shown later, it is complicated by many factors. The irregularity of the relation was pointed out by Murray and Chumley who showed that the maximum and minimum carbonate values for Globigerina oozes of various depths at any given latitudes in the Atlantic are very variable. Pia, using Andrée's data for depths between 4000 and 5000 meters, gives a short table showing the frequency distribution of samples having different percentages of carbonate and points out that the variations at any given depth cannot be described in terms of the normal frequency curve. This may also be seen from the writer's table 35, in which the samples listed in table 36 for each latitude and depth division are arranged in order of increasing $CaCO_3$ content in ten groups of 0 to 10 per cent, 10 to 20 per cent, etc. The samples have been divided into pelagic and terrigenous types. When maximum frequencies are present, they may be seen to be very wide in extent, and in many cases secondary maxima are shown. A rather extreme case, that for pelagic samples collected at depths between 4000 and 5000 meters in latitudes 0° to 10° north, is shown in figure 43. Of twenty-eight pelagic samples, five have carbonate contents of less than 10 per cent, two samples have between 20 and 50 per cent $CaCO_3$, and twenty-one samples, or seventy-five per cent of the total number, have carbonate contents between 50 and 90 per cent.

Relation Between Carbonate Content and Bottom Fauna. Mention has already been made of the fact that samples which contain many individuals and many species of benthonic foraminifera are usually, other things being equal, those of relatively low content of pelagic foraminifera (hence, low $CaCO_3$ content), higher organic matter, and greater proportions of broken pelagic shells. In the south and central Pacific, far from land, samples 13, 14, 31, 35, 79, 80, 81, and 82 are relatively high in organic matter, in proportions of benthonic foraminifera, and broken to whole pelagic tests. They are correspondingly low in carbonate content when compared with other samples of the same depth and general location. Samples 31 and 35 are red clays; samples 79 and 80 are radiolarian oozes; samples 13, 14, 81, and 82 are siliceous Globigerina oozes. The latter, containing 67, 76, 40, and 85 per cent calcium carbonate, respectively, lie either under the paths of the Peruvian Current or of the Equatorial Current. Agassiz long ago pointed out that the sea bottom underlying these currents is high in living organisms of many kinds, and the surface waters above them are rich in living forms, in contrast with the pelagic and benthonic faunas of the waters south and west of the currents which are poor both in numbers of individuals and of species. He also noticed that the bottom deposits from the area south and west of the currents are relatively rich in manganese iron nodules. Agassiz did not develop a correlation, however, between high carbonate content and a small bottom fauna.

The Globigerina oozes which contain the highest percentage of calcareous benthonic foraminifera are samples 22 and 27 and these, although they are not notably high in organic matter, contain only slightly more than 42 per cent $CaCO_3$. The inverse relation between whole tests of pelagic foraminifera and benthonic foraminifera, and between benthonic foraminifera and carbonate content, may also be observed from a study of the average composition of red clays and Globigerina oozes collected by the Challenger. In the former, the proportion of calcareous benthonic to pelagic foraminifera is as 1 to 8, namely, 0.59 to 4.77 per cent, whereas in Globigerina oozes it is approximately 1 to 25, namely, 2.13 to 53.10 per cent.

Two inferences are possible from these relations. One, that living benthonic animals are more or less evenly distributed over the floor of the deep sea, but that their remains are masked in some cases by the rapid accumulation of calcareous shells of pelagic organisms, so that they appear to be relatively few in number. This possibility has been suggested by Cushman (1928) among others, but since the quantity of animals living on the bottom must be largely dependent, in the last analysis, on the rate of accumulation of edible organic materials, such a hypothesis would imply that the rate of accumulation of organic material in the deep sea is everywhere much the same. Furthermore, since the tests of benthonic foraminifera must be about as soluble as those of pelagic foraminifera, it would also imply that little solution takes place on the ocean floor; otherwise, there would be a direct relation between the $CaCO_3$ content and the percentage of benthonic foraminifera.

On the other hand, Agassiz's researches(1892,1906) showed that areas in which the surface water is rich in plankton also have rich bottom faunas. Therefore a second inference seems more probable, namely, that the apparently varying quantities in the samples of the tests of benthonic foraminifera, as of the remains of other bottom-living organisms, represent real variations in the bottom faunas and are chiefly dependent on varying rates of accumulation of available organic materials. The high percentages of broken pelagic shells and low carbonate contents of deposits which support large communities of bottom-living organisms might then be explained in part by assuming that the shells had passed more frequently through the alimentary tracts of mud eaters, and in part by the fact that more carbon dioxide would be produced by the metabolism of the animals and the decomposition of the organic matter; hence conditons would be more favorable for solution of carbonates. Also the presence of such communities may mean that the bottom deposits are more or less continually churned over, thus allowing more rapid interchange between the presumably saturated interstitial water of the sediments and the overlying presumably unsaturated water.

Summary of Facts of $CaCO_3$ Distribution

We may now summarize the chief facts as to the distribution of $CaCO_3$ in the north and southeast Pacific which have been brought out in the above discussion.

1. Sediments of high lime content cover most of the bottom of the south Pacific in the area investigated (that is, east of 150° west longitude, and north of 50° south latitude), but there is an irregular band of sediments poor in carbonate along the South American coast, and, also, the sediments at depths greater than 4000 to 4500 meters, depending on the latitude, are usually poor in lime.
2. Except for the areas surrounding oceanic islands and for certain others at depths less than approximately 3500 meters, almost the entire bottom of the Pacific north of latitude 10° north is covered by sediments of low carbonate content.
3. Sediments of intermediate carbonate content, between 15 and 50 per cent, cover a much smaller total area than do those either higher or lower in lime, and generally form narrow borders of varying width around areas of sediments rich in carbonate.
4. The rather sharp boundary between sediments of high and low carbonate content in the central eastern Pacific does not follow the depth contours but lies closely parallel to the average southern limits of the Counter Equatorial Current and the Peruvian Current, approximately along the 34.5 per cent surface isohaline.
5. Within any given latitude limits the average calcium carbonate content of all sediments taken together tends to be at a maximum value between 1500 and 3000 meters, and then decreases irregularly with increasing depth, reaching a minimum between 4500 and 5000 meters, depending on the latitude. Pelagic sediments, in general, exhibit a continuous but irregular decrease of average calcium carbonate with increasing depth. For most depth and latitude intervals, however, the carbonate contents of individual samples are widely and unevenly distributed.
6. For depths less than 1000 meters and greater than 4000 meters the average carbonate content of all sediments is at a maximum near the equator and tends to decrease with increasing latitude toward both the south and the north; for depths between 1000 and 4000 meters there is a more or less continuous decrease in the amount of $CaCO_3$ from south of latitude 40° south to latitude 60° north. On the whole, sediments of any depth in the south Pacific are higher in $CaCO_3$ than sediments of the same depth in the north Pacific.
7. The average carbonate content of pelagic sediments is higher than that of terrigenous sediments of the same depth and latitude.
8. The average carbonate content of Atlantic pelagic sediments is higher than the average of Pacific pelagic sediments of the same depth. The difference between the two oceans is particularly marked for pelagic deposits of depths between 4000 and 5000 meters. Pacific sediments of these depths contain, on the average, only one-half to one-third the amount of carbonate present in similar Atlantic sediments.
9. There is an inverse relation between the contents of organic matter in sediments and of $CaCO_3$, and between the latter and the ratio of benthonic to pelagic foraminifera. These relations are interpreted to mean that regions in which there is a relatively rapid rate of accumulation of available organic material, and hence a rich bottom fauna, tend to be, other things being equal, somewhat poor in $CaCO_3$.

Although several facts about the distribution of $CaCO_3$ in the area of the Pacific investigated have been summarized above, doubtless many other and more detailed relations would be discovered on further exploration of the physical, chemical, and biological conditions of the water and of the bottom sediments, such as those which have been determined for the Atlantic and which are mentioned in the following discussion.

Theoretical Considerations

The Cycle of $CaCO_3$. Before attempting to explain the causes of the relations summarized above, let us first briefly discuss the general conditions which determine the amounts of $CaCO_3$ in marine sediments. In the last analysis, the rate of accumulation of $CaCO_3$ on the sea bottom depends on the rate of increment from rivers of dissolved calcium to the ocean as a whole. The dissolved salts of rivers are usually relatively very high in dissolved calcium (Clarke, 1920, p. 125), whereas in sea water itself the amount of calcium is relatively small and bears a more or less constant ratio to the total salt content. It is probable that the excess of lime carried in by rivers, as indicated by the difference in the calcium salinity ratios of river and ocean waters, is largely removed by deposition of solid calcium carbonate on the sea bottom and that, as suggested by Murray and Irvine (1890), the sea as a whole is about in equilibrium with respect to $CaCO_3$. Both accumulation from river waters and withdrawal by precipitation are exceedingly slow, however, and little is known of the absolute rates of these processes, so that it is impossible to say whether a balance is actually preserved. For example, Murray and Irvine estimate that the discharge of rivers would require 680,000 years to make up an amount of lime equal to that already present in the sea.

There is also a cycle of $CaCO_3$ in the sea itself. Carbonates are precipitated from solution in certain regions and redissolved in others. Although most known fossil limestones were probably deposited in shallow warm waters, at the present time by far the greatest surfaces where lime sediments are being deposited are covered by deep water (Vaughan, 1924). The general process of lime deposition in deep water is usually as follows: (1) the sinking of lime shells and skeletons formed near the surface toward the bottom, perhaps accompanied, as Heim (1924) suggests, by $CaCO_3$ particles chemically precipitated from supersaturated water; (2) the solution of some or all of these at depths where the water is not saturated with $CaCO_3$, and (3) further solution, together with some reprecipitation, on the sea bottom. The physical and chemical factors which accompany and control these processes are chiefly the carbon dioxide and calcium contents, which control the hydrogen-ion concentration, and the temperature, salinity, and hydrostatic pressure of the water.

In another paper (1934) the writer has discussed the significance of these physical and chemical factors and has shown that their order of importance is, first, carbon dioxide content and, then, temperature and salinity, whereas the known effects of hydrostatic pressure and the calcium content are of relatively minor significance. In general, precipitation and absence of solution are favored by the low carbon dioxide content and high temperature, salinity, and calcium content which characterize surface waters, whereas high carbon dioxide and low temperature, salinity, and calcium, together with large hydrostatic pressure, tend to bring about solution, and to inhibit precipitation. The latter are the properties of deep water.

The percentage of calcium carbonate in a bottom sediment depends, first, on its relative rate of deposition with respect to that of other materials, and second, on the relative rates of removal, by solution or otherwise, of calcareous and noncalcareous materials after deposition. In a terrigenous deposit the increment of detrital noncalcareous material may be so great as to mask the calcium carbonate even though the rate of deposition of the latter may be quite rapid. Large amounts of detrital material, however, are not favorable for the extensive growth of lime-secreting organisms, hence the rate of precipitation of carbonates from sea water in many near-shore regions is not rapid. On the other hand, the detrital material of terrigenous deposits is often calcareous and therefore adds to (rather than reducing) the total amount of lime in the sediment.

The rate of deposition of noncalcareous materials in pelagic deposits is presumably more or less constant, so that only the absolute rate of deposition of $CaCO_3$ is of importance in these sediments. The rate of deposition is dependent on the rate of precipitation in the surface waters and the rate of solution at depth.

Precipitation of $CaCO_3$ in Surface Waters. Although the biological precipitation of $CaCO_3$ undoubtedly plays a far greater role than does purely inorganic precipitation, which may occur only in certain shallow regions, the amounts of both are doubtless partly controlled by the physicochemical conditions. The fact that removal of lime takes place from waters near the surface is shown by the curve for the titratable base-chloride ratios[1] of Atlantic and Pacific waters, given in figure 46. In the Atlantic a marked decrease in the amount of base takes place at about 100 meters below the surface. In the Pacific the minimum zone is somewhat lower, but an even greater amount of removal has apparently occurred. This diminution in the base must be almost entirely owing to the removal of lime. It is generally believed (Vaughan [1924], Wattenberg [1933]) that there are two types of biogenetic lime precipitation; the building up of calcium carbonate in the cells of benthonic and planktonic plants and animals, and precipitation outside the cells. In plants this is brought about by reduction of CO_2 tension through assimilation and also, in bacteria, through NH_3 production, etc. The possible effects of one physical factor, namely, temperature, on lime-secreting organisms are indicated by Murray and Hjort (1912) who state, with reference to the horizontal distribution of calcium carbonate organisms, "that they are most abundant both at the surface and at the bottom in warm tropical regions where the annual range of surface temperature is least." Furthermore, "Of the pelagic deposits, the Globigerina and pteropod oozes of tropical regions probably accumulate the most rapidly, from the greater variety of tropical pelagic species of foraminifera and molluscs, and the larger and more massive shells secreted in tropical as compared with extra-tropical regions."

Wattenberg (1931), on the basis of Hentschel's data (1931) from the Meteor expedition, has pointed out that the proportion of calcium carbonate-forming organisms in the nannoplankton of the Atlantic, that is, the Coccolithophoridae, decreases markedly as the physicochemical conditions for precipitation of calcium carbonate become less favorable.

Trask (1932) has adduced statistical evidence that $CaCO_3$ content, other things being equal, is a function of the salinity of the surface waters. This holds especially for the two sides of the Central American isthmus. On the east side there is much more calcium carbonate at any given depth than on the west side, yet the water temperatures of both regions are about the same. The salinity, on the contrary, as may be seen from Schott's (1928) map, is much lower on the western side. Similarly, in the southeastern Pacific, the area of high carbonate is an area of salinity over 36.0 per mille; as already stated, the boundary of high $CaCO_3$ content north of the equator closely parallels the 34.5 per mille isohaline. On the other hand, the salinity off the east coast of South America is very high (37.0 per mille) in comparison with that of the eastern south Atlantic, and yet the bottom deposits of the eastern south Atlantic are much higher in calcium carbonate than are those of the western south Atlantic. As will be shown, however, this is probably to be explained by greater solution at depth in the western Atlantic. That there is little noticeable correlation between calcium carbonate content and salinity in the north Pacific is probably related to the great average depth of that ocean.

A rise in salinity effects an increase in the degree of saturation of surface water, especially when it is in equilibrium with the atmosphere, but the effect of increasing salinity is much less than that of a comparable rise in temperature or loss of carbon dioxide. The large apparent effect of salinity found by Trask probably is owing to some other factor whose variations may be correlated with varying salinity.

An important consideration affecting the rate of precipitation of calcium carbonate is the length of time during which surface water remains at the surface. After chemical precipitation has occurred from supersaturated surface water, obviously no more precipitation will occur until the conditions in the water are changed, that is, usually until deep water of high titratable base content has risen to the surface. Similarly, after the quantity of nutrient salts in surface water has been depleted by organisms, lime-secreting organisms, especially plants, will no longer be present in appreciable amounts.

Solution at Depth. The degree of solution of solid particles of calcium carbonate settling from the surface which will take place in deep water is dependent on the degree of undersaturation of that water and on the amount of water which is brought into contact with the solid particles of calcium carbonate. Over great depths these particles will thus be more likely to dissolve than in shallow water simply because they are brought in contact with more water during the period of settling and, similarly, particles which are kept in suspension by turbulent currents will tend to be dissolved more completely. Murray and Irvine (1891) have set up the following mechanism for the correlation between calcium carbonate content

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[1] The titratable base, defined as the equivalent concentration in milli-equivalents per liter of strong bases balanced against weak acid radicals (principally carbonate, bicarbonate, and borate) bears a more or less constant ratio to the total lime content, and varies with the amount of precipitation and solution of calcium carbonate (see Moberg, Greenberg, Revelle, and Allen [1934]).

and depth previously referred to. The deeper the water column the more water must be passed through by calcareous skeletons settling from the surface, and therefore more solution of these skeletons will occur. The rate of deposition of calcareous skeletons on the bottom will consequently be slower and the calcareous material lying on the bottom surface will be exposed longer to the dissolving action of the sea water above the bottom. The relative amounts of solution taking place both during the settling of $CaCO_3$ particles and on the bottom surface will thus be greater than in shallower waters where the sediments have a shorter period of settling and are buried more quickly.

This explanation of the correlation between carbonate content and depth is not accepted by some workers, notably Wattenberg (1933), and Buch and Gripenberg (1932), who state that the increasing hydrostatic pressure at greater depths increases the ability of the water to dissolve calcium carbonate. A similar suggestion was also made by Murray and Rénard (1891) and by Reid (1888). The effect of hydrostatic pressure is still somewhat problematical since no data are available as to the effect of pressure on the solubility product of calcium carbonate. The known effects of hydrostatic pressure on the factors involved in the carbonate equilibrium of sea water are, however, quite small (Revelle, 1934).

With regard to the influence of currents, it is obvious, as pointed out by Pia (1933), that horizontal currents alone cannot affect the time of settling of calcium carbonate particles, but that only the vertical components of these currents and the turbulence induced by them can be effective. Defant (1932) has shown that the deep currents of the Atlantic exhibit considerable turbulence.

The degree of undersaturation of deep waters, with respect to calcium carbonate, is probably of greatest importance for the distribution of calcium carbonate in marine bottom sediments. For example, it is known that the Antarctic deep waters are very high in CO_2 and, as Wüst (1934) has shown, the boundaries of deep water of Antarctic origin in the Atlantic, indicated by potential temperature differences, are also the boundaries of low $CaCO_3$ content in the bottom sediments. In the western basin of the south Atlantic, where the Antarctic deep current penetrates far to the north, the percentages of $CaCO_3$ in the sediments are much less than in the eastern Atlantic where the current is cut off by the Walfish Ridge. Likewise, according to Pratje (1932), the sediments even in the two halves of the eastern south Atlantic basin are very different as far as their contents of $CaCO_3$ are concerned, the sediments in the western half being much higher in $CaCO_3$ for any given depth than those in the eastern part of the basin. This is to be correlated, Pratje claims, with the fact that in the west the bottom topography is very uneven, and tends to retard the Antarctic Current, whereas in the east the comparatively flat nature of the bottom allows it to pass over the sediments. The relation between the presence of Antarctic deep water and low $CaCO_3$ content also holds for the Indian Ocean, according to Wüst, who postulates a ridge in the western half of this ocean which cuts off the Antarctic water and, therefore, prevents the solution of $CaCO_3$, whereas in the eastern half the Antarctic Current moves farther north so that the $CaCO_3$ is dissolved. Wüst, basing his statement on data given by Schott and Schu (1910), claims that Antarctic bottom water covers most of the floor of the Pacific, but Sverdrup (1931), employing the later data of the Carnegie, believes that Pacific deep water also contains a considerable mixture of the subtropical deep water of the Indian Ocean, a suggestion first made by Möller (1929). It will be shown below that this deep water of the Pacific is of low pH and high CO_2 content, and is probably markedly undersaturated with respect to $CaCO_3$. Murray and Philippi (1908) were the first to point out the relation between deep waters of Antarctic origin and the low $CaCO_3$ content in the sediments underlying them.

Solution after Deposition. Besides the solution of $CaCO_3$ particles which takes place as they settle through the water, there is probably also considerable removal of $CaCO_3$ from the bottom sediments themselves, for which suggestive evidence was first obtained by Dittmar (1884) and Brennecke (1921). These authors found that the amounts of dissolved calcium in waters immediately above the bottom seem to be somewhat higher than the normal values for the ocean as a whole. The evidence was not conclusive, however, since the variations were of about the same magnitude as the analytical errors involved. Wattenberg's careful determinations of the relation between titratable base, which he claims is a very sensitive measure of variations in the calcium content, and the chlorinity, definitely showed an increase in the ratio of titratable base to chlorinity directly above the bottom, at depths greater than 2000 meters. The fact of interchange between the interstitial waters of the sediments and the superjacent bottom water was also shown by a decrease in the oxygen content of the latter. Another type of evidence of solution within the sediments is given by Andrée, who claims that normally there is a decrease in $CaCO_3$ content with increasing depth within a sediment. Many of the bottom cores collected by the Michael Sars (see Chumley, 1930), however, showed an increase with depth in the sediment, but these are believed to be "abnormal"[1] by Andrée, and to indicate changes of the conditions of sedimentation. A third type of evidence of carbonate solution on the sea floor has been mentioned previously, namely, the inverse relation between contents of organic matter and of benthonic foraminifera, on the one hand, and the percentage of $CaCO_3$ on the other.

The Meteor workers also believe that in some cases there may be a relative increase in $CaCO_3$ on the sea bottom owing to the removal by bottom currents of the clay fractions, which are presumably low in $CaCO_3$. Correns (1927) claims that coarser sediments tend to be higher in $CaCO_3$ than those of finer particle size and he believes that this is owing to the removal by currents of some of the finer-grained noncalcareous material. An alternative explanation may be that coarser particles, since they have less surface in proportion to volume than fine-grained particles, tend to dissolve more slowly. Wüst (1934) thinks that a partial explanation of the relation between $CaCO_3$ and depth is that in deep waters the bottom currents move more slowly than in shallower waters, therefore not removing as much of the fine fractions. On the other hand, it should be pointed out that the more slowly a current moves the less solution of $CaCO_3$ can take place, since the water becomes more nearly saturated; furthermore, the stirring up of sediments by relatively rapid currents allows fresh water to come in

[1] W. Schott (1935) has shown that the relatively low carbonate contents of the lower parts of core samples of Atlantic deep-sea sediments may be owing to deposition during the glacial period.

contact with them, and thereby aids the process of solution.

That some recrystallization and reprecipitation of $CaCO_3$ takes place on the sea bottom is indicated by the presence in many of the Globigerina oozes collected by the Carnegie, as also in certain of the Valdivia samples (see Murray and Philippi, 1905) of recrystallized tests of several species of pelagic foraminifera, notably Globorotalia tumida, and also by the distribution of $CaCO_3$ in the various size grades of some of the sediments. It is shown in the section on mechanical analyses that both the sand and clay fractions of certain Globigerina oozes contain more $CaCO_3$ than the intermediate silt grades. X-ray analyses show the fine-grained calcium carbonate to be calcite, and not aragonite, as would be expected if it were formed under conditions comparable with those of the Bahama Banks (see Vaughan, 1924). It seems reasonable, therefore, that if these fine-grained materials are the result of chemical precipitation, their formation might have taken place under cold water conditions, probably at the bottom.

Summary of Theoretical Considerations

In summarizing the above discussion, we may repeat the statement that the percentage of calcium carbonate in a bottom sediment depends on its relative rate of deposition with respect to that of other materials, and on the relative rates of removal by solution or otherwise of calcareous and noncalcareous materials after deposition. Besides being affected by the rates of deposition of noncalcareous materials, the relative rate of deposition of $CaCO_3$ is also dependent on the rate of precipitation in waters near the surface, and the rate of solution at depth. Precipitation at the surface, though largely organic, is probably favored by certain physical and chemical conditions in the water, such as high salinity and temperature, and low carbon dioxide content, and it is also affected by the length of time during which surface water remains at the surface. The amount of solution of solid particles of calcium carbonate which will take place in deep water is dependent on the degree of undersaturation of the water due to high CO_2 content, low temperature and salinity, and possibly also to hydrostatic pressure; and on the amount of water which is brought into contact with the solid particles of calcium carbonate. The depth of the water and the intensity of turbulence are thus factors of importance. The amount of solution of calcium carbonate on the bottom itself is dependent on the rate of interchange between the interstitial waters of the sediments and the supernatant bottom water and on the degree of undersaturation of the bottom water. The velocity of the bottom currents and the quantity of the bottom fauna affect these factors. Enrichment in $CaCO_3$ also perhaps takes place at the bottom, due to removal by currents of the finer noncalcareous parts of the sediments and, in certain cases, perhaps to reprecipitation.

Theoretical Explanation of Observed Facts of Distribution

Many of the facts summarized on pages 4 and 5 with respect to the distribution of $CaCO_3$ in the sediments of the Pacific may be explained in terms of the general factors affecting the percentage of $CaCO_3$ which have been outlined above. The large amount of lime in the sediments of the southeast Pacific, thus, is probably to be correlated in part with the moderate depths of this region. The irregular band of sediments poor in carbonate along the South American coast is probably owing to at least three factors: (1) the masking effect of terrigenous materials; (2) the relatively low temperature of the surface waters of the Peruvian Current; (3) the large amount of organic matter in the water and on the bottom, which allows the development of a large bottom fauna, and the decomposition of which produces carbon dioxide. The small lime content of the sediments of the north Pacific probably is owing to the great average depth of this region. The abrupt decrease in calcium carbonate in the region of the Counter Equatorial Current may be related to (1) the decrease in the salinity, temperature, and pH of the waters near the surface which occurs here, (2) the turbulence of the water, (3) the rich bottom faunas underlying the current. The decrease of average calcium carbonate content with increasing depth is probably to be explained by a mechanism similar to that proposed by Murray and Irvine (1891), although the enormous hydrostatic pressure of deep water may play some part. The irregularity of the relation of bottom depth and $CaCO_3$ content may be owing to the varying intensities of turbulence and the varying degrees of undersaturation of the deep waters of different regions, as well as to the varying rates of precipitation of calcium carbonate in the subsurface waters. The decrease of average calcium carbonate content with increasing latitude, which is observed for certain depth intervals, may be explained by the low temperatures and high CO_2 contents of the waters of high latitudes. The excess of calcium carbonate in pelagic sediments with reference to terrigenous sediments of the same depth and latitude may be owing to the rapid rate of accumulation of noncalcareous materials in terrigenous deposits and also to the relatively rapid rate of accumulation of organic matter in terrigenous deposits.

The differences between the average carbonate content of Atlantic and Pacific pelagic sediments of the same depth and between those of the south and north Pacific may also be shown in terms of the above-mentioned factors. The marked excess of calcium carbonate in Atlantic sediments of any depth when compared with Pacific sediments of the same depth, thus, might be explained by the fact that the deep water of the Pacific is more undersaturated with calcium carbonate than is the deep water of the Atlantic. For example, according to the Carnegie results, the pH of the Pacific deep water averages about a tenth less than that of the Atlantic. Similarly, the data of Thompson, Thomas, and Barnes (1934) on the vertical distribution of CO_2 for a deep station off the coast of Washington, gave values for carbon dioxide in deep water far in excess of any of those obtained by Wattenberg (1933) in the Atlantic. Furthermore, the total amount of dissolved oxygen in the deep water of the north and east Pacific, according to the results of the Carnegie (Graham and Moberg [1935], see also Moberg [1930]) and of the Bushnell (Revelle, unpublished data) is much lower than the amounts of oxygen at corresponding depths and latitudes in the Atlantic. Since the sum of the dissolved oxygen and carbon dioxide for any given water mass is usually more or less constant, the low oxygen content in the Pacific must be balanced by a correspondingly high CO_2 content, and hence by a greater degree of undersaturation of calcium carbonate.

An interesting light on the fate of calcium carbonate in the deep waters of the Pacific is given by figure 45, in which the available base chloride ratios for two stations in the north Pacific are plotted against depth and compared with the average base chloride ratios for waters of the same depth in the Atlantic, given by Wattenberg. For the Atlantic curve Wattenberg's average data for the base chloride ratios of water samples collected by the Meteor expedition between 19° south and 2.5° south down to depths of 3000 meters have been used. The curve has been extended below 3000 meters by the use of one of the curves given in Wattenberg's figure 13 which shows the average vertical distribution of the base chloride ratio between 3000 and 4000 meters for stations in which the average depth of the bottom is 4000 meters. One of the two Pacific curves shown represents determinations of the titratable base made by Dr. P. H. Mitchell on samples which the writer collected in 1933 aboard the U.S.C. and G.S.S. Pioneer in latitude 34° 33′ north and longitude 122° 31′ west, about 150 miles off the California coast. The bottom depth was 3975 meters. The other curve represents the base chloride ratio of samples the writer collected in 1934 aboard the U.S.S. Bushnell in latitude 31° 49′ west, longitude 163° 24′ west in the mid-Pacific about 600 miles north of the Hawaiian Islands. The bottom depth here was approximately 3270 meters. The determinations[1] were carried out at the Scripps Institution by Miss Katherine Gehring. In the first 500 meters below the surface the curves for both the Atlantic and the Pacific are similar, although the base chloride ratios of the Pacific surface water are somewhat higher than the average given by Wattenberg, and a much more marked diminution of the base content takes place below the surface. Below 500 meters, however, the curves rapidly diverge. The average base chloride ratio of the Atlantic water reaches a constant value of 0.1225 at about 1000 meters; this is maintained to a depth of 3000 meters. After this a marked increase takes place to the bottom where a value of 0.1258 was obtained. The Pacific samples show a much more marked increase to a depth of about 1000 meters at which values of 0.1258 and 0.1281 were obtained, and then a slow increase to bottom values of 0.1278 and 0.1304. The high base chloride ratios of the Pacific deep waters shown by these curves almost certainly mean a correspondingly high calcium content. If the sum of the titratable base contents of the entire water column, including both the surface and the deep water, were the same in the two oceans, the excess of base in the deep water would be counterbalanced by a depletion at or near the surface. The excess base at depth might then be explained on the basis of a slower cycle of interchange of deep and surface water in the Pacific, that is, the deep water would have been at depth for a longer period of time and hence would have had more time to dissolve calcium carbonate whereas, correspondingly, the waters nearer the surface would have had more time in which to lose calcium by the precipitation and settling of solid particles. Pacific subsurface waters, in fact, do show a more pronounced decrease in the base chloride ratios, relative to Pacific surface waters, than do Atlantic subsurface waters in comparison with Atlantic surface water. In other words, more $CaCO_3$ has been removed from any given volume of subsurface water in the Pacific than in the Atlantic. Furthermore, it has been suggested on other grounds by Sverdrup (1931) and Moberg (1930) that there is less interchange of surface and deep water in the Pacific than in the Atlantic.

The base chloride ratios, however, at all depths in the Pacific from the surface to the bottom, are higher than at the corresponding depths in the Atlantic, and the total base in the entire water column is much greater. There is an especially marked divergence in the deep water. The excess of base in the deep water of the Pacific is probably owing to two causes. (1) As suggested by the authors referred to, it seems probable that the deep water of the Pacific has originated in the southern Atlantic and Indian oceans from the mixing of Antarctic and subtropical deep waters, hence has not been at or near the surface for a long time, and owes part of its high calcium content to its having passed under large amounts of subsurface waters from which $CaCO_3$ particles have settled and been dissolved. (2) Owing to the greater amounts of CO_2 in the water and the lower pH, any given volume of Pacific deep water has been capable of dissolving more carbonates than a corresponding volume of Atlantic deep water.

The fact that, in spite of the calcium brought into the Pacific from the Atlantic and Indian oceans by the deep water, there is a greater degree of undersaturation in the Pacific than in the Atlantic, can only mean that the rate of precipitation of $CaCO_3$ in waters near the surface is slower in the Pacific. This must be owing primarily to the much smaller amount of calcium-bearing river water which is emptied into the Pacific.

An examination of the pH data obtained by the Carnegie shows no pronounced differences between the deep waters of the north and the south Pacific, but on the contrary a rather symmetrical distribution of pH values with respect to the equator. No carbon dioxide or titratable base determinations are available for the south Pacific. The results of the Carnegie (Moberg and Graham [1935]) and of the Dana (Thomsen [1931]), however, show **that there is much more oxygen in the deep waters of the central south Pacific than in the north. Presumably, therefore, there is less carbon dioxide since, as already stated, the sum of the dissolved oxygen and carbon dioxide in any given water mass is usually constant.** Now the pH of the water is a function of the relative contents of carbon dioxide and titratable base. Since there probably is less carbon dixoide in the south Pacific than in the north, though the pH values in the two regions are the same, probably there is also less titratable base (less dissolved calcium) in the south Pacific. We may consequently infer that the deep waters of the south Pacific have dissolved less calcium carbonate than the deep waters of the north Pacific, and that, consequently, more calcium carbonate has settled to the bottom. It is obvious that this explanation for the difference between the sediments of the north and the south Pacific is far from satisfactory. There is an urgent need for further investigation of the physical and chemical conditions of the waters of the central eastern and southeastern Pacific if the problems of distribution of calcium carbonate are to be satisfactorily solved.

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[1] The results of the titratable base analyses of the Bushnell and the Pioneer samples have been confirmed by determinations of the vertical distribution of titratable base in certain recent deep Scripps stations in southern California waters, and by calcium analyses of the samples collected by the Bushnell.

ON THE NATURE OF THE FINE-GRAINED NONCALCAREOUS MATERIAL IN PACIFIC DEEP-SEA CLAYS

The results obtained from this study are of two main sorts: first, those which throw light on the distribution of calcium carbonate in Pacific deep-sea deposits, and which have been discussed in the preceding section; second, information obtained from chemical, mechanical, and X-ray analyses, and from a study of temperature-dehydration relations, on the nature and origin of the fine-grained noncalcareous material which is the principal constituent of Pacific deep-sea clays. We may now summarize and coordinate the results of the second kind, especially with regard to the red clays of the northeast Pacific.

(1) The chemical composition of deep-sea clays from the northeast Pacific is very constant, the extreme values of the silica sesquioxide ratios in the ten samples analyzed deviating by only 3 per cent from the average value of 4.0. The molecular amount of alumina is nearly four times that of ferric oxide. There are more equivalents of divalent than of monovalent bases; the order of importance being magnesium, potassium, sodium, and calcium; the ratio between silica and total bases is close to 7. Owing to the presence of siliceous remains of organisms, the ratios between silica and sesquioxides in the remainder of the noncalcareous samples analyzed are wider than in northeast Pacific clays, but the proportions between the other constituents are of about the same order of magnitude.

(2) Colloidal fractions separated from these clays contain relatively less silica and more alumina and iron than do the whole samples. The following empirical formula roughly agrees with the observed chemical composition of the colloidal fractions (the amount of water not being taken into account):

$$(Mg, K_2, Na_2, Ca)O \cdot 2(Al,Fe)_2O_3 \cdot 6\ SiO_2$$

This is close to the formula of the clay mineral beidellite, which often is found in bentonites and is similar to the principal clay mineral or minerals of many soil colloids. The fact that the average silica sesquioxide ratio in the colloidal fractions is somewhat less than 3 indicates that more or less kaolinite, halloysite, or muscovite may be present.

(3) The colloidal fractions from two northeast Pacific red clays were found by Professor W. P. Kelley to have base exchange capacities of about 55 milliequivalents per 100 grams, close to those of two California soil colloids which are believed to consist largely of a beidellite-like clay mineral, together with quartz. Magnesium apparently is the chief replaceable base.

(4) Northeast Pacific red clays and a terrigenous clayey mud from off the South American coast were found by Dr. P. G. Nutting to dehydrate on heating in a manner similar to soil colloids containing a beidellite-like mineral. Water is gradually driven off between room temperature and approximately 450°, after which there is a relatively sharp decrease of about 3 per cent in water content between 450° and 600°, followed by a further slight loss at higher temperatures. The curves of these clays differ from curves obtained on bentonites in that the latter lose more water below 100°.

(5) The X-ray powder diagrams given by colloidal fractions separated from northeast Pacific red clays are closely comparable both in position and intensity of diffraction lines with those of California soil colloids containing a beidellite-like clay mineral and quartz. The principal lines of quartz are present in every noncalcareous sample examined. The greater intensity of quartz lines in the patterns of separates containing coarser particles explains the relatively higher silica sesquioxide ratios of the whole samples, as compared with their colloidal fractions. Kaolinite, halloysite, or muscovite are perhaps also present.

(6) As in chemical composition, most red clays from the northeast Pacific are strikingly alike also in the distribution of particle sizes, having median diameters of about 1.1 microns, coefficients of sorting slightly less than 3, and small negative skewnesses. Particles of sand size, mostly organic skeletal remains, are usually present in amounts less than 1 per cent, whereas the average proportions of silt and clay are about 13 and 87 per cent, respectively.

Several converging lines of evidence thus lead to two conclusions. (1) The red clays of the northeast Pacific, and probably also terrigenous and pelagic noncalcareous clays of certain other areas, contain about 50 per cent of particles less than one micron in diameter. (2) These colloidal particles are almost exactly similar in many ways to those soil colloids which are formed under conditions of moderate leaching by neutral or slightly alkaline waters, and consist of beidellite-like clay minerals together with small amounts of quartz. Quartz is a major constituent also of the fractions of larger particle size in these sediments.

Two explanations are possible for the ultimate origin of the fine-grained materials in red clays from the northeast Pacific. They may have been formed in situ, as Murray believed, from the decomposition of volcanic debris, or they may represent finely divided soil material which has been carried from the continents in suspension in the sea, or by the wind.

Most bentonites, which probably were formed by the decomposition of acid volcanic ash, contain quartz together with clay minerals of the montmorillonite beidellite group. Many residual soils formed in situ are as fine-grained as these red clays. It is possible, therefore, that the red clays may have been formed by decomposition on the surface of the sea floor under conditions which over long periods effectively reproduced those of certain types of subaerial weathering; namely, oxidizing conditions and slow leaching by slightly alkaline waters which contain large amounts of metallic cations.

On the other hand, the striking similarity between the red clays and soil colloids strongly suggests that at least considerable amounts of these materials may be soils transported from land.

It is interesting to speculate on the means of transportation whereby that part of the fine material which is of continental origin has been carried to its present position. Many analyses, by various workers, of atmospheric dust and of fine-grained wind deposits, such as loess, show that these are coarser in texture than deep-sea clays and contain small amounts of clay minerals. It seems reasonable to believe, therefore, that the colloidal materials have been transported chiefly in suspension in the sea itself. Colloidal particles carried in suspension in rivers, however, quickly coagulate into larger grains and settle on coming into contact with sea water. On the other hand, the rate of coagulation must become slower as the process of flocculation continues, since the distance between the particles becomes greater and greater, and a few particles will be carried far from shore before settling. A similar conclusion was reached by Murray and Irvine (1891).

In so far as these pelagic deep-sea sediments consist of materials of continental origin, they represent a largely permanent loss of relatively heavy substances from the continent and a corresponding gain by the sea floor.

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FIGURES 1 - 45, CHARTS 1 - 10,

PLATES I - XIII

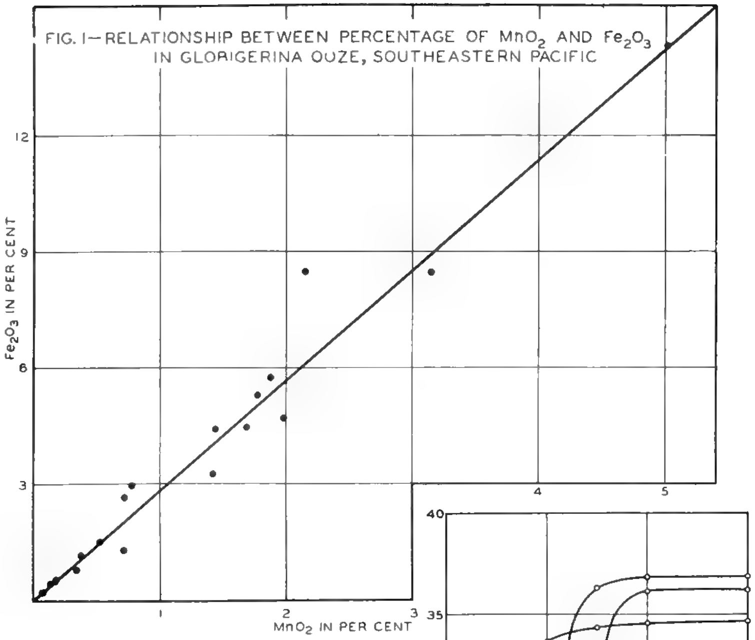


FIG. 1—RELATIONSHIP BETWEEN PERCENTAGE OF MnO_2 AND Fe_2O_3 IN GLOBIGERINA OOZE, SOUTHEASTERN PACIFIC

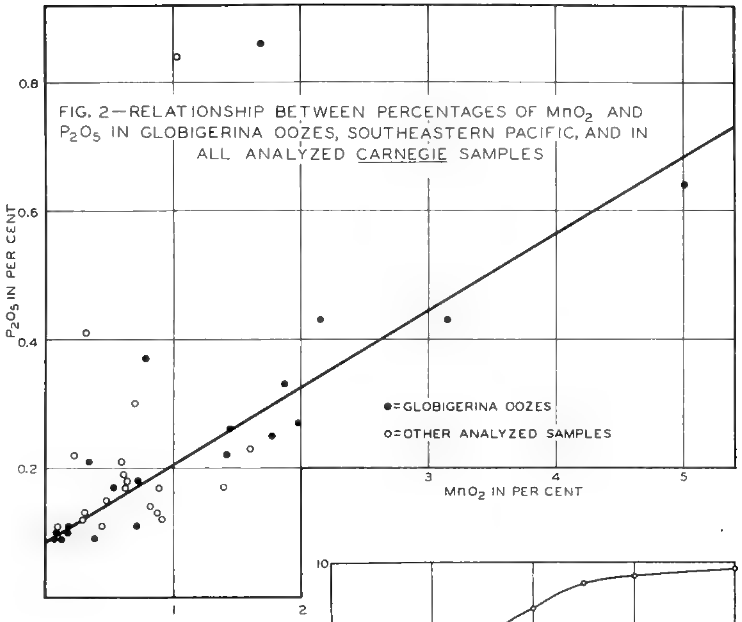


FIG. 2—RELATIONSHIP BETWEEN PERCENTAGES OF MnO_2 AND P_2O_5 IN GLOBIGERINA OOZES, SOUTHEASTERN PACIFIC, AND IN ALL ANALYZED CARNEGIE SAMPLES

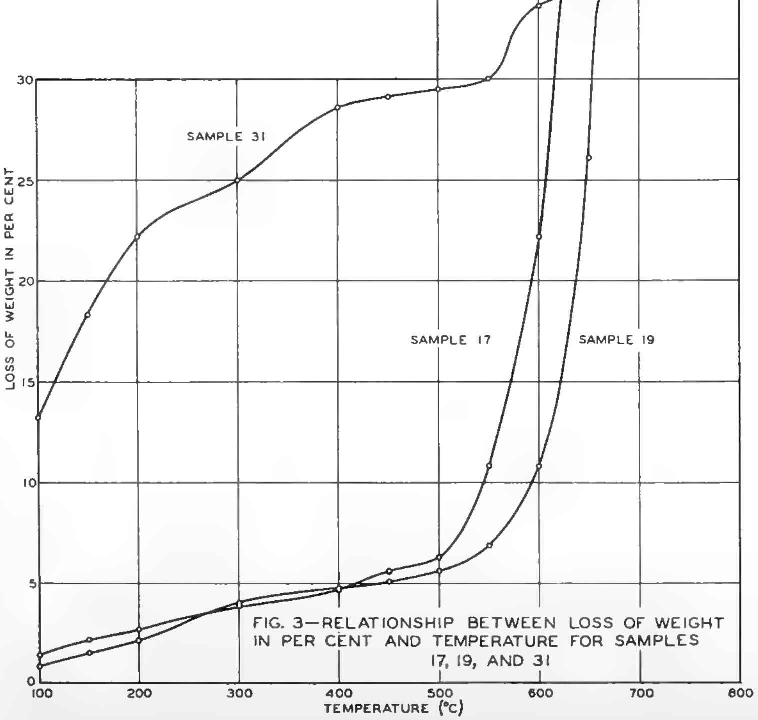


FIG. 3—RELATIONSHIP BETWEEN LOSS OF WEIGHT IN PER CENT AND TEMPERATURE FOR SAMPLES 17, 19, AND 31

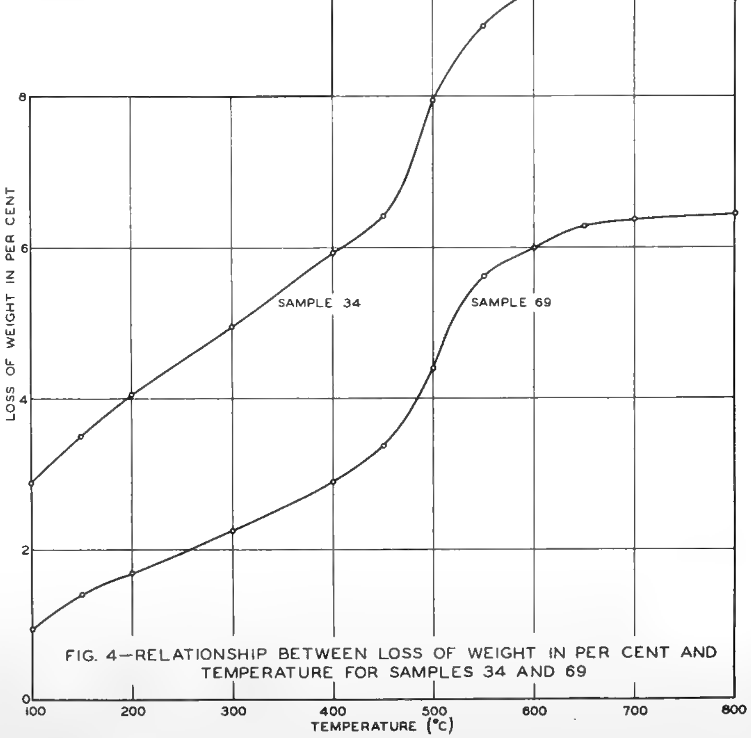


FIG. 4—RELATIONSHIP BETWEEN LOSS OF WEIGHT IN PER CENT AND TEMPERATURE FOR SAMPLES 34 AND 69

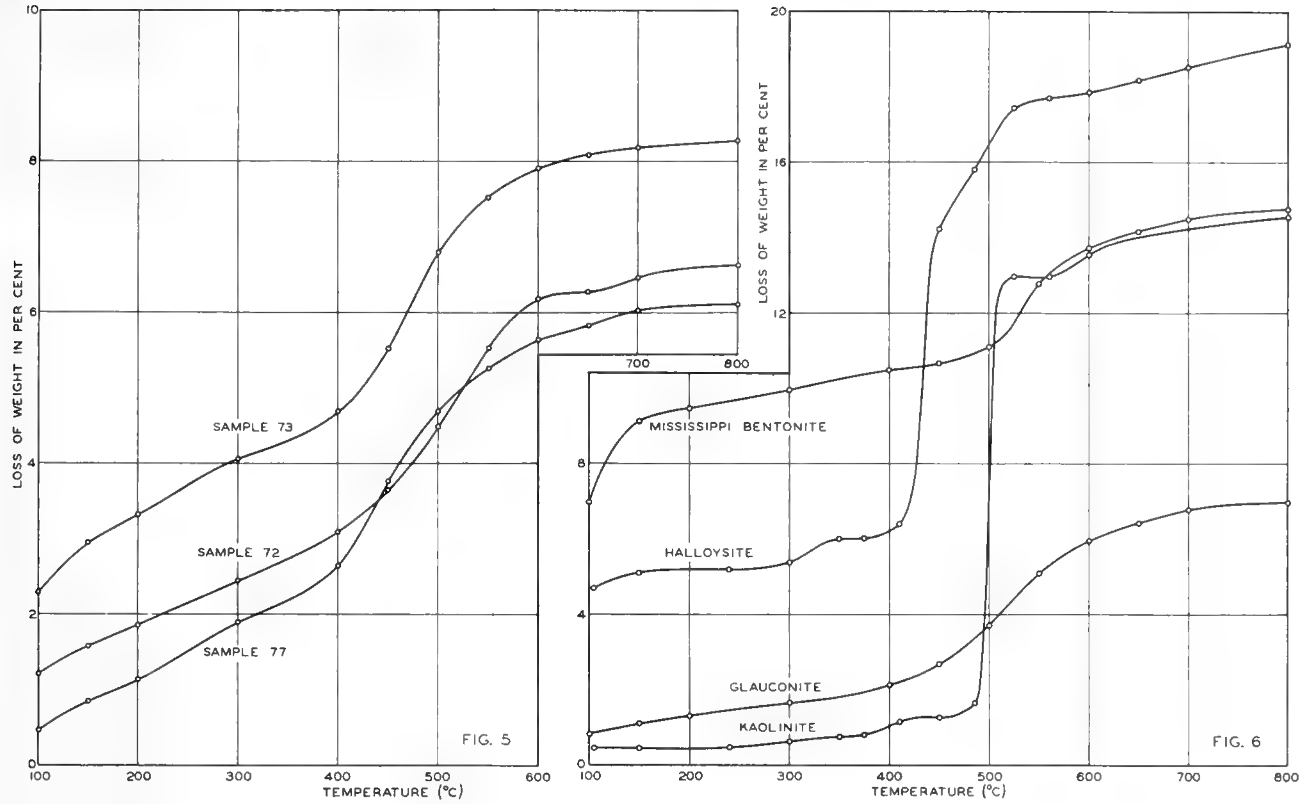


FIG. 5—RELATIONSHIP BETWEEN LOSS OF WEIGHT IN PER CENT AND TEMPERATURE FOR SAMPLES 72, 73, AND 77

FIG. 6—RELATIONSHIP BETWEEN LOSS OF WEIGHT IN PER CENT AND TEMPERATURE IN MISSISSIPPI BENTONITE, HALLOYSITE, GLAUCONITE, AND KAOLINITE

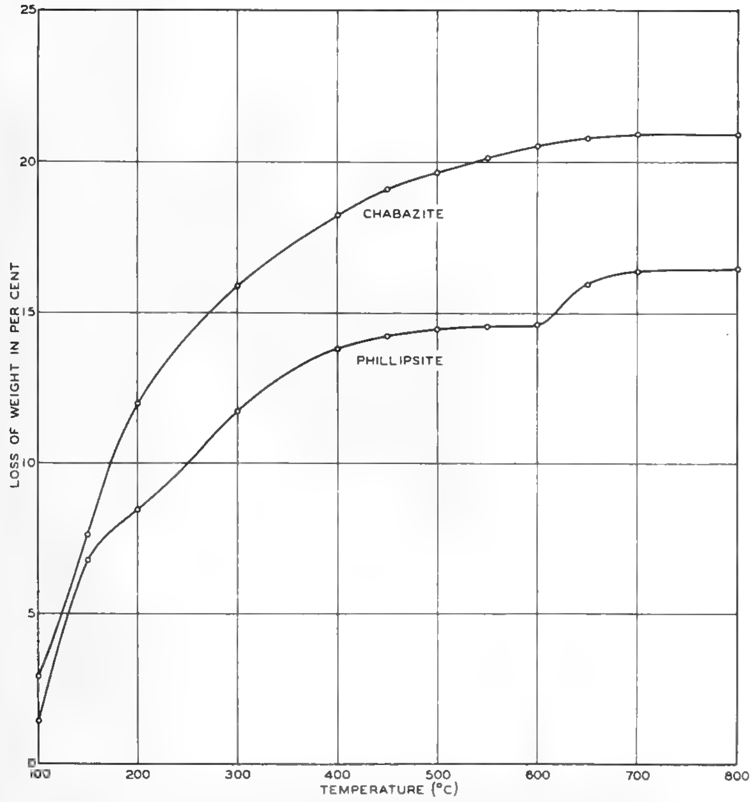


FIG. 7—RELATIONSHIP BETWEEN LOSS OF WEIGHT IN PER CENT AND TEMPERATURE IN CHABAZITE AND PHILLIPSITE

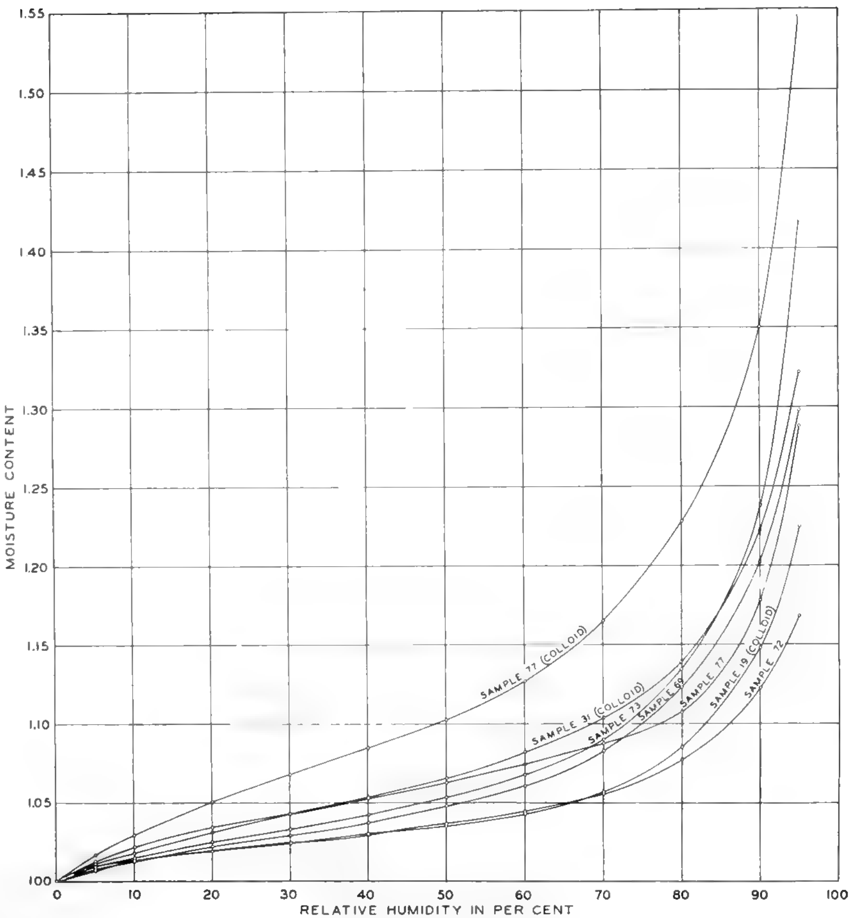


FIG. 8—RELATIONSHIP BETWEEN MOISTURE CONTENT AND RELATIVE HUMIDITY FOR SAMPLES 19, 31, 69, 72, 73, AND 77

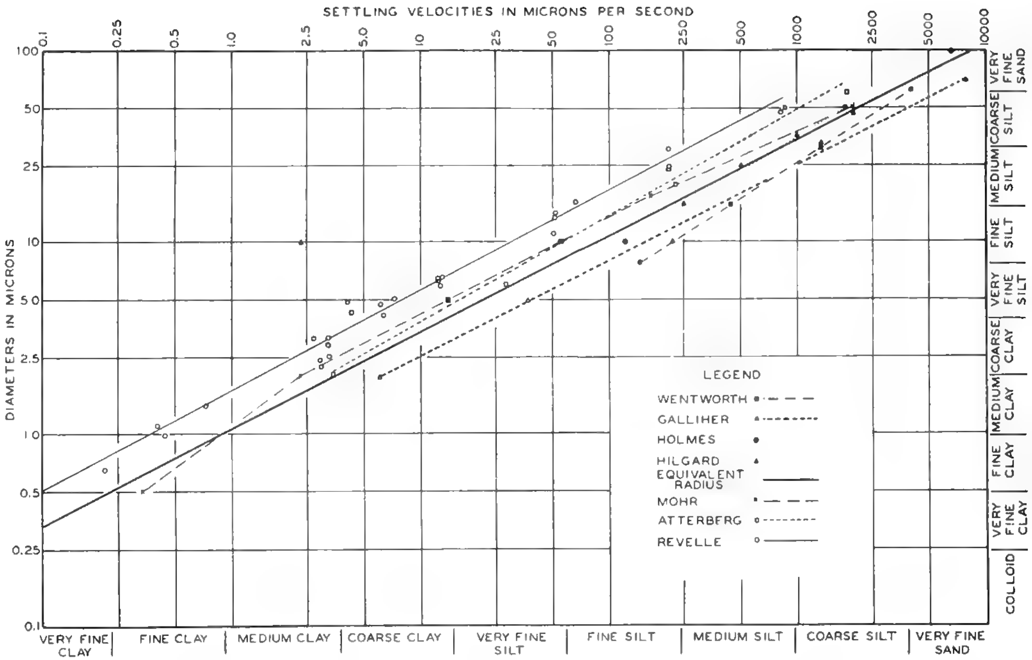


FIG. 9—RELATIONSHIPS BETWEEN SETTLING VELOCITY AND PARTICLE SIZE USED BY VARIOUS INVESTIGATORS, COMPARED WITH CARNEGIE OBSERVED VALUES OF TWO DIMENSIONS OF PARTICLES, MARINE CLAYS—THE DESCRIPTIVE TERMS USED ARE MODIFIED FROM RUBEY (1930)

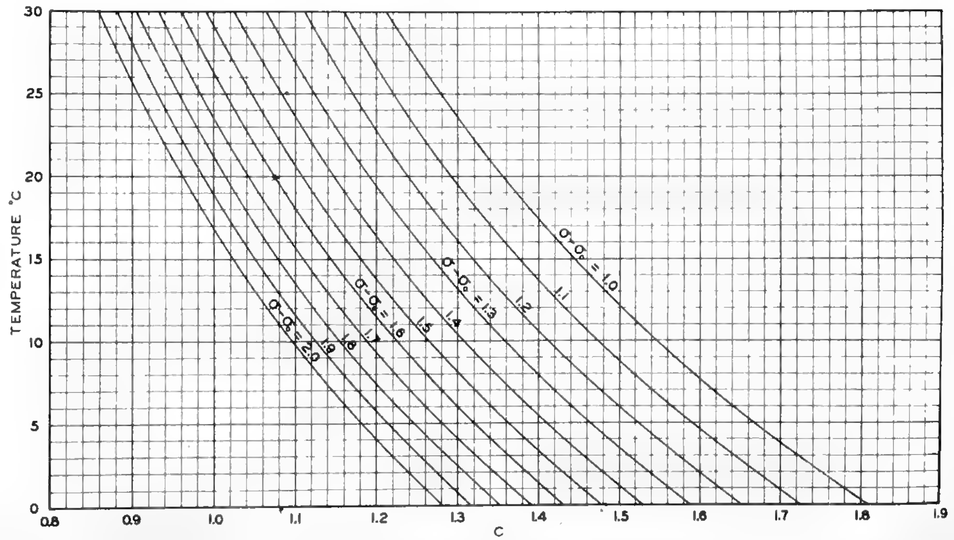


FIG. 10—VALUES OF CONSTANT C IN EQUATION $D=C\sqrt{V}$, GRAIN DENSITIES 2.0 TO 3.0 AND TEMPERATURES 0° TO 30°

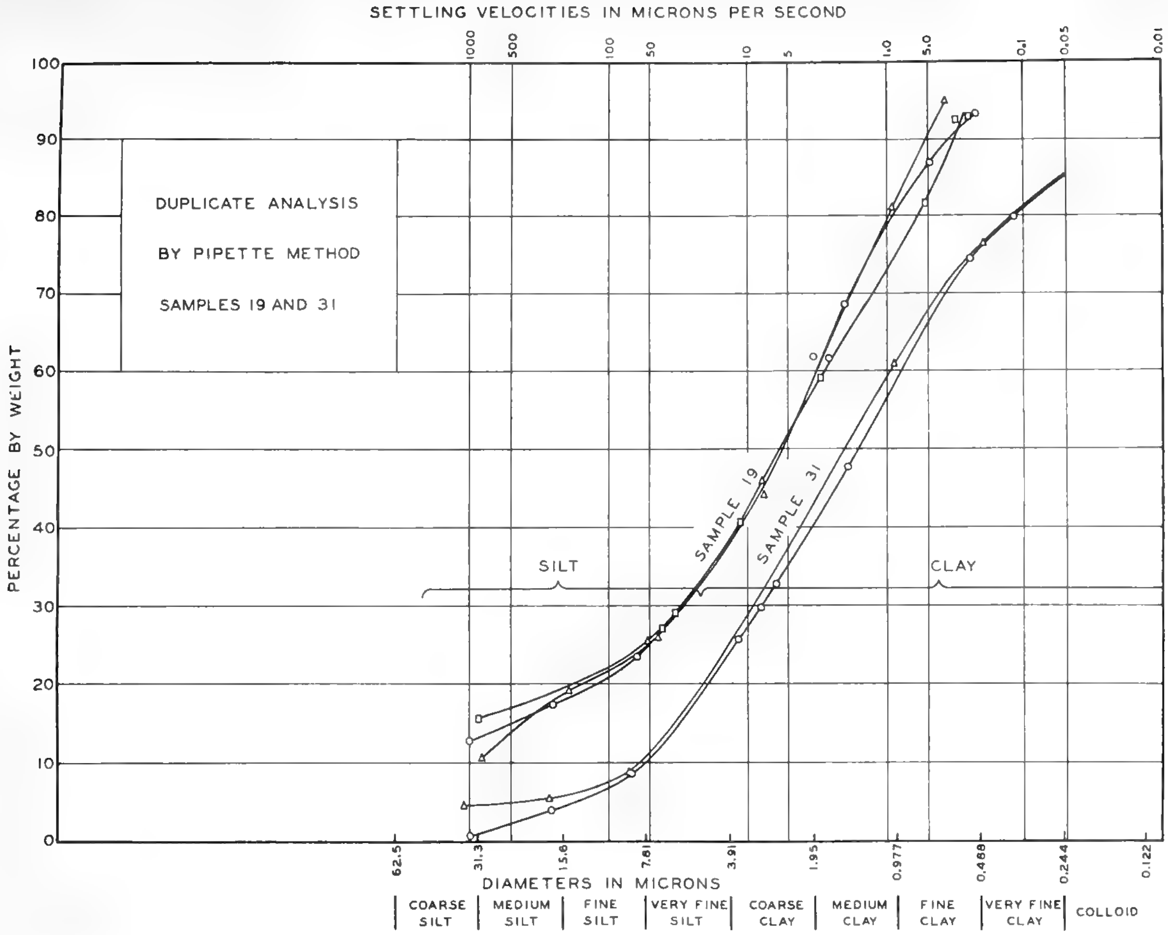


FIG. 11—MULTIPLE ANALYSES BY PIPETTE METHOD OF FRACTIONS LESS THAN 70 MICRONS IN SIZE, SAMPLES 19 AND 31

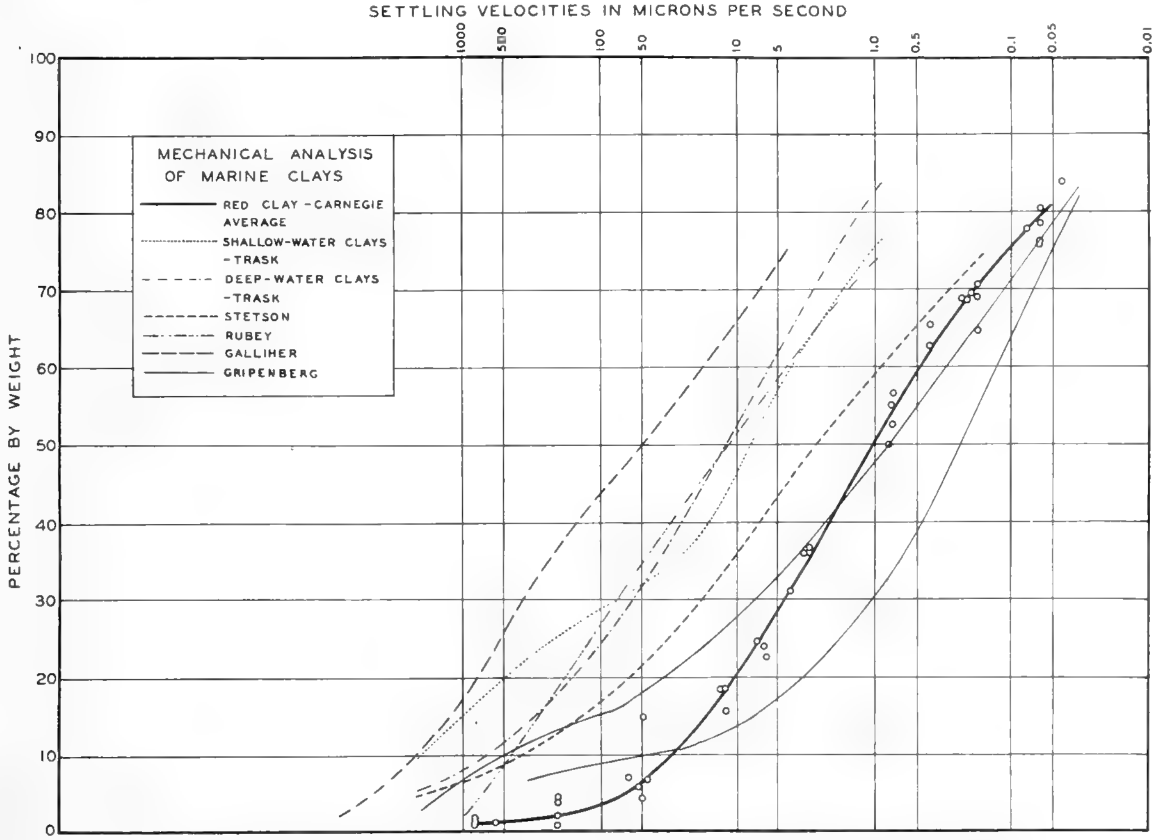


FIG. 12—AVERAGE SETTLING VELOCITIES, MICRONS PER SECOND, FOR MARINE CLAYS, AFTER VARIOUS INVESTIGATORS, COMPARED WITH AVERAGE FOR CERTAIN CARNEGIE RED CLAYS FROM NORTH PACIFIC

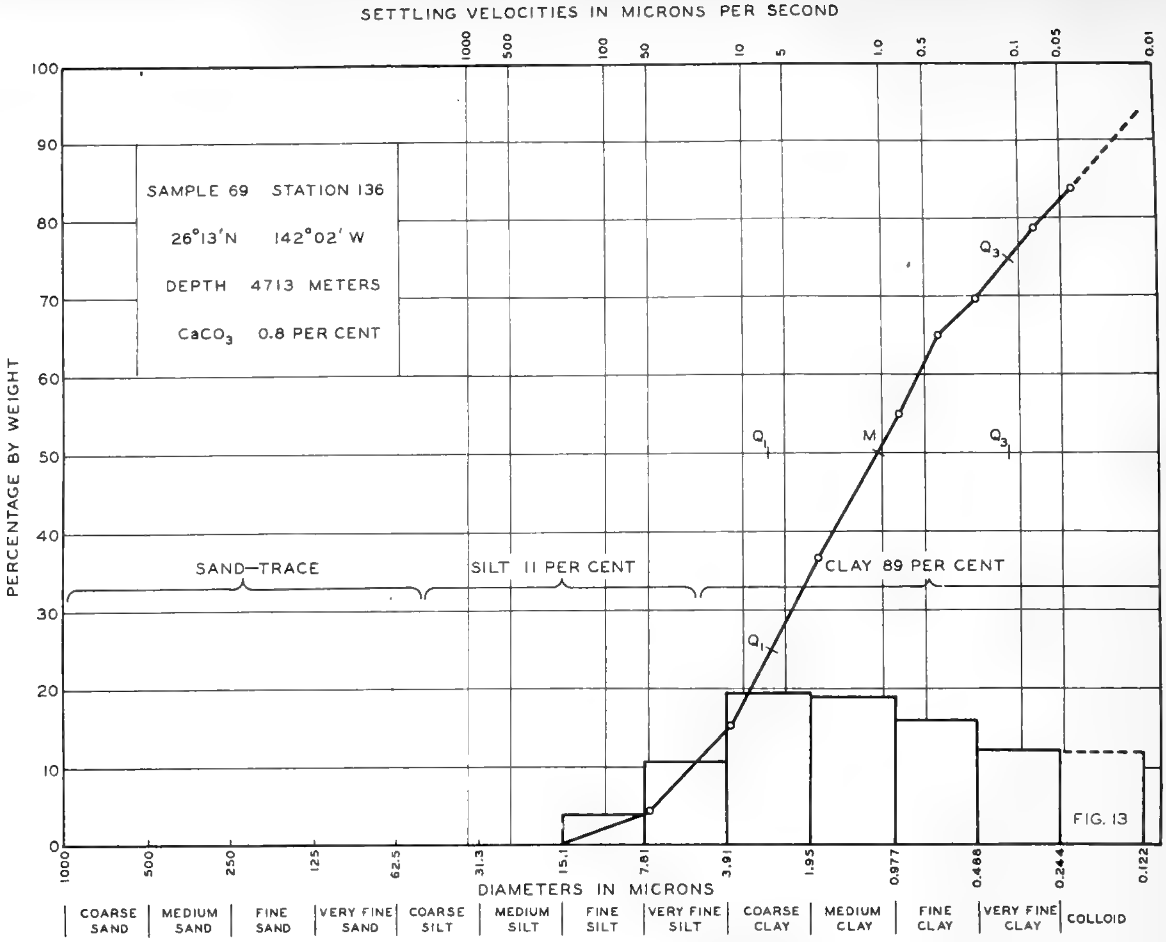


FIG. 13

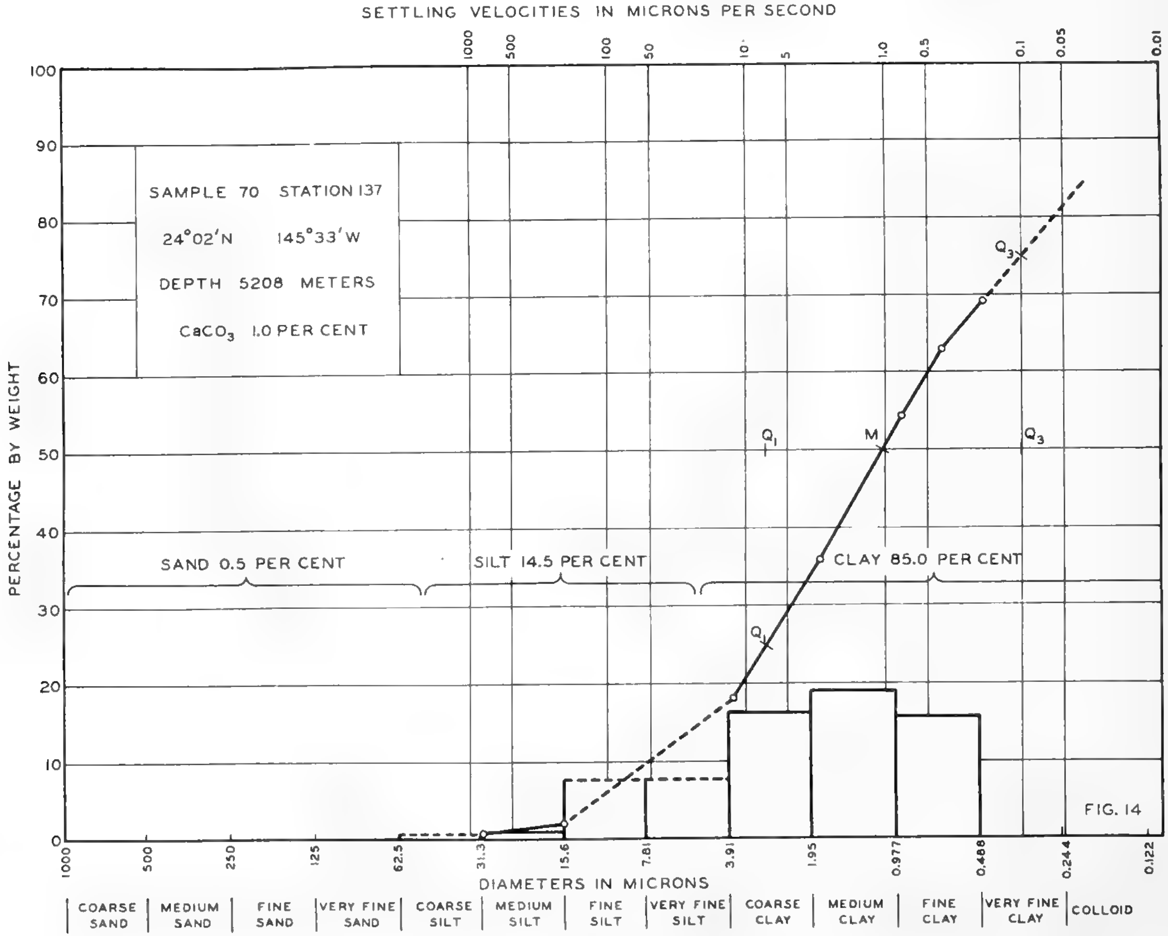


FIG. 14

FIGS. 13-14—SETTLING VELOCITIES IN MICRONS PER SECOND AT 20°C, SAMPLES 69 AND 70

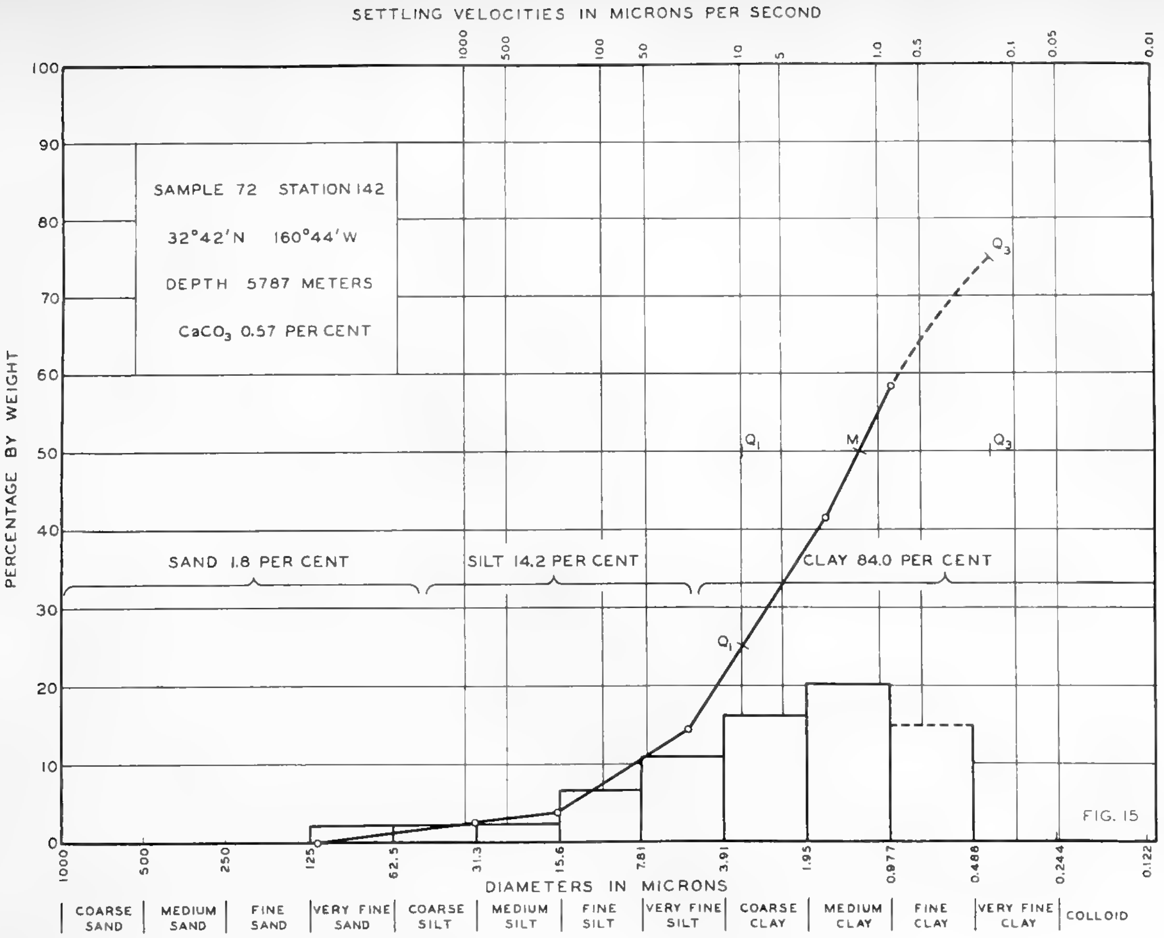


FIG. 15

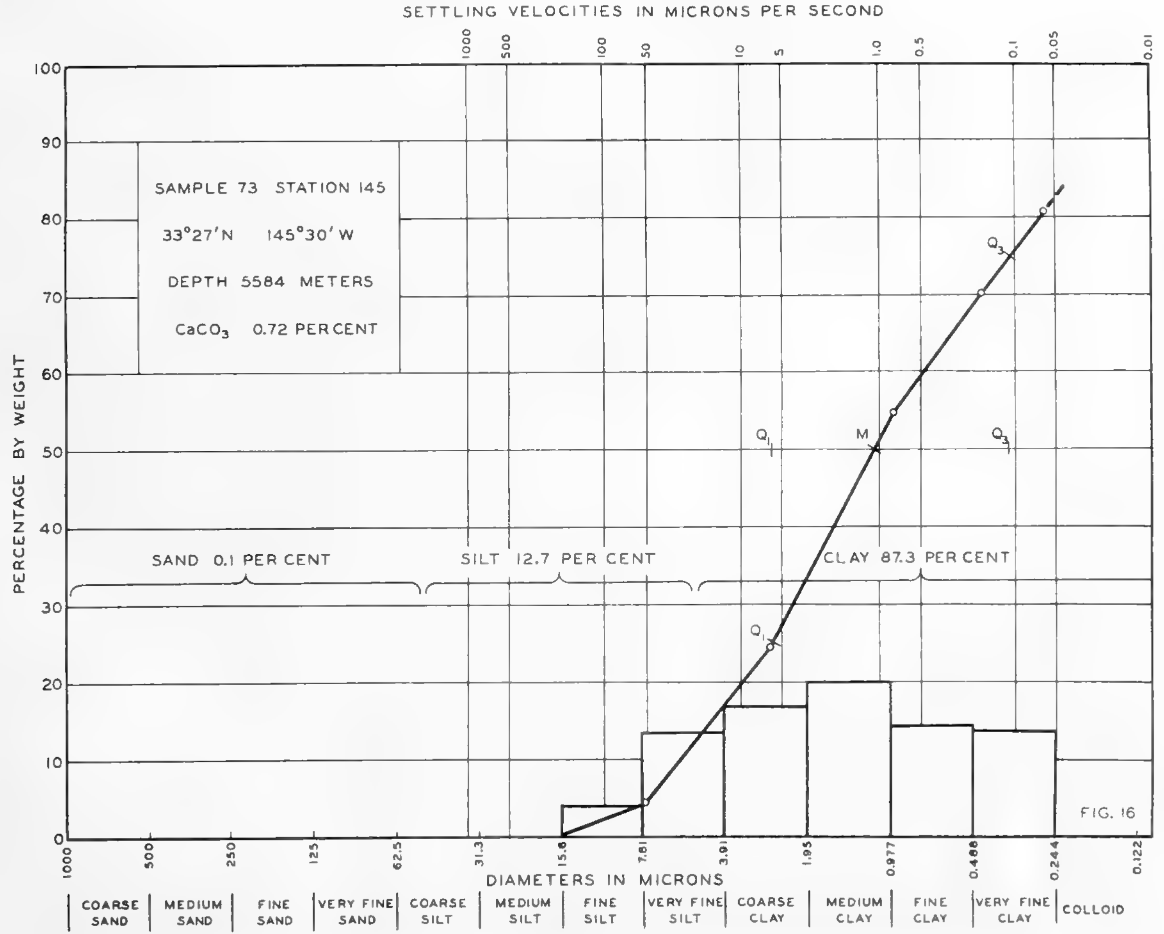


FIG. 16

FIGS. 15–16—SETTLING VELOCITIES IN MICRONS PER SECOND AT 20°C, SAMPLES 72 AND 73

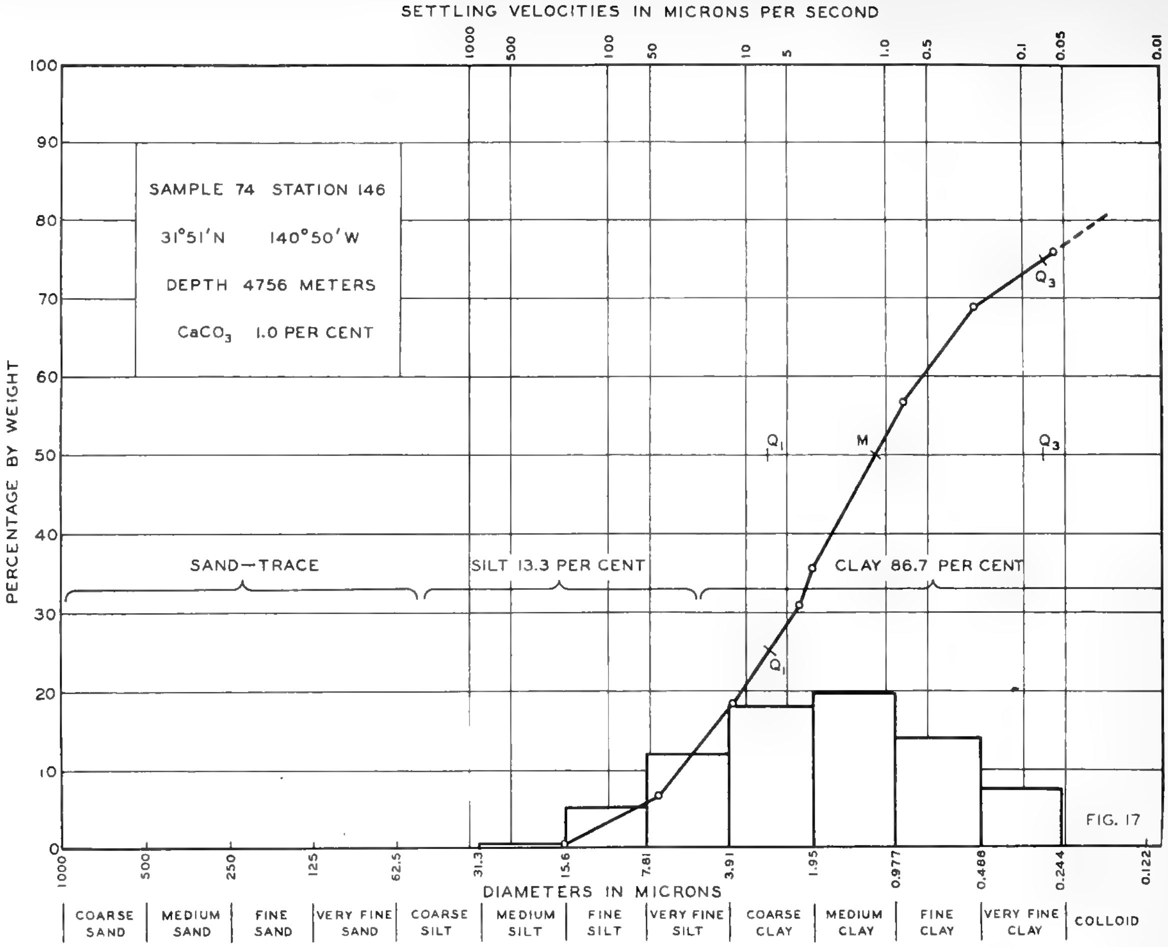


FIG. 17

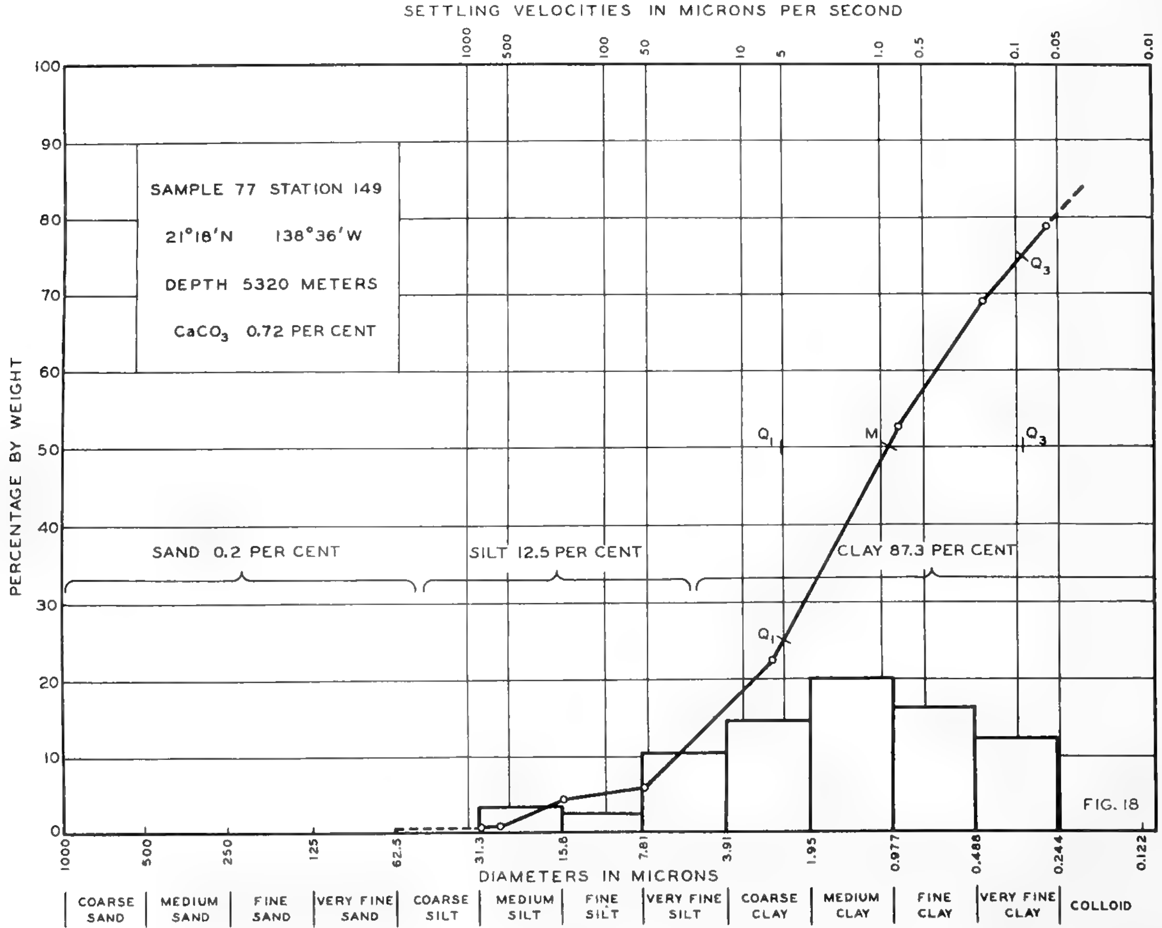


FIG. 18

FIGS. 17-18—SETTLING VELOCITIES IN MICRONS PER SECOND AT 20 °C, SAMPLES 74 AND 77

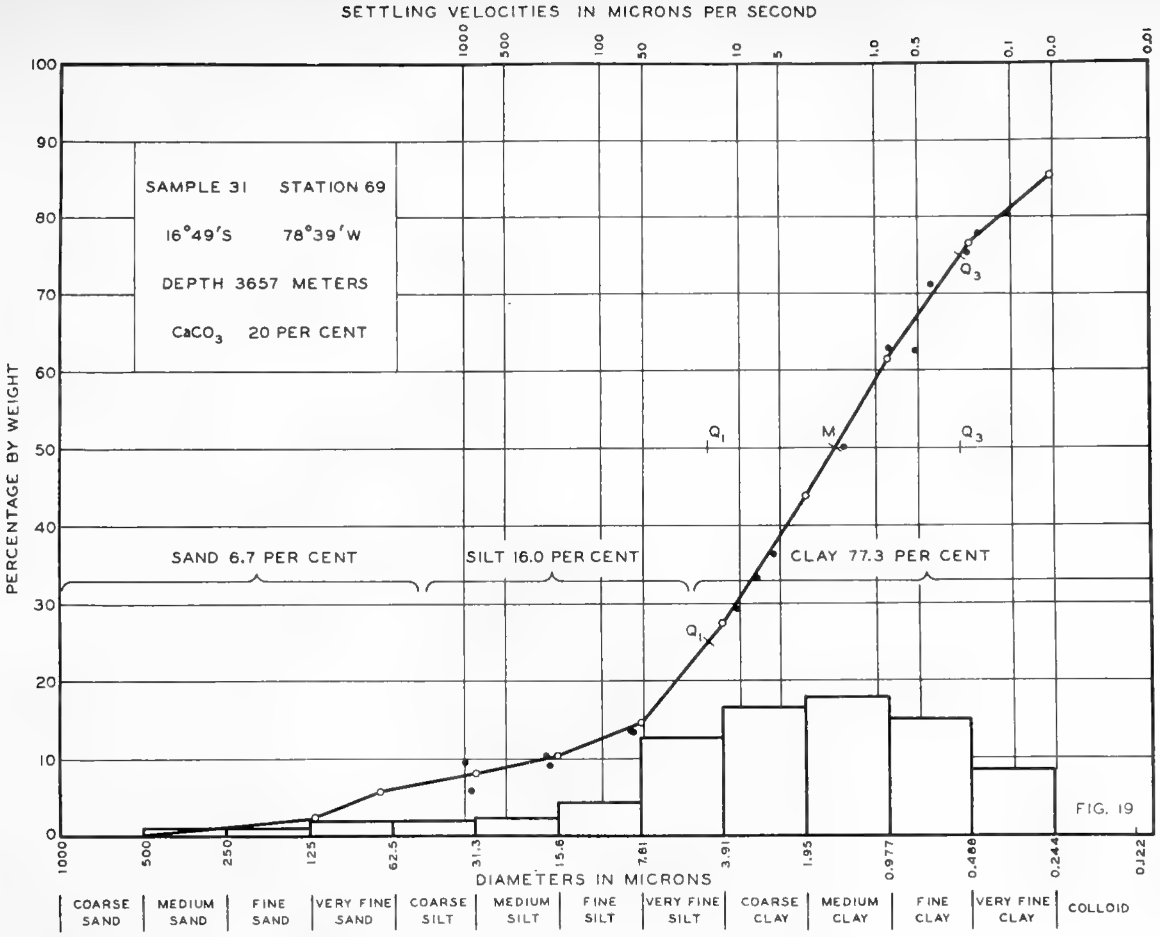


FIG. 19

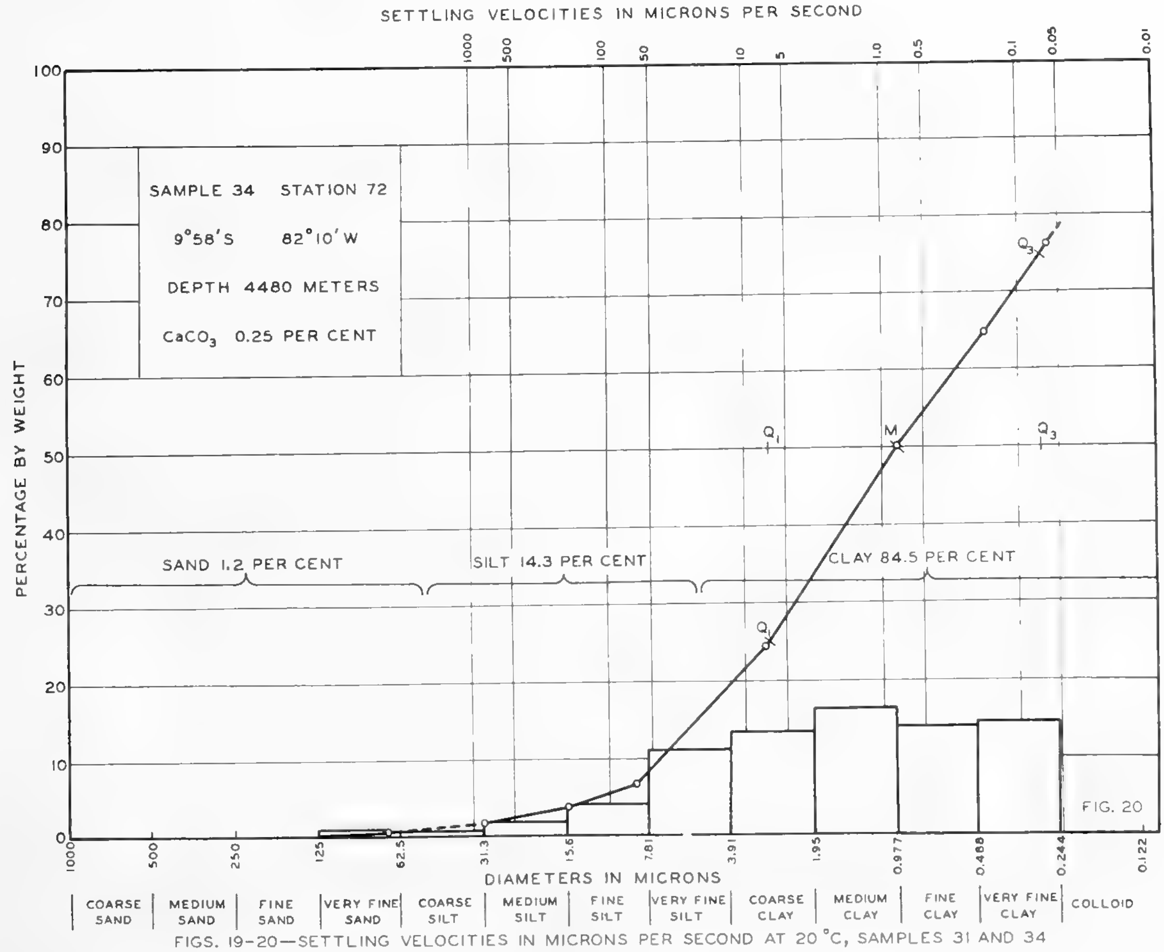


FIG. 20

FIGS. 19-20—SETTLING VELOCITIES IN MICRONS PER SECOND AT 20 °C, SAMPLES 31 AND 34

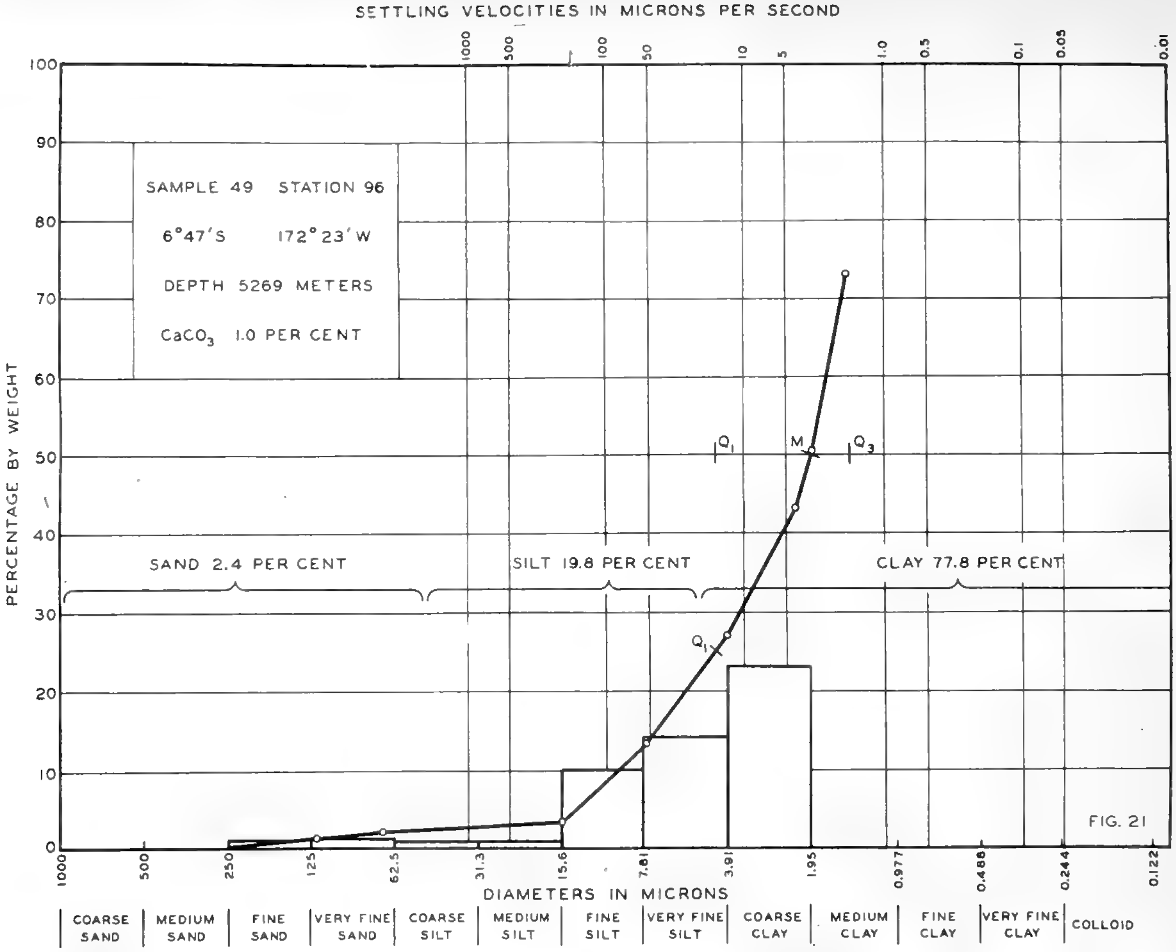


FIG. 21

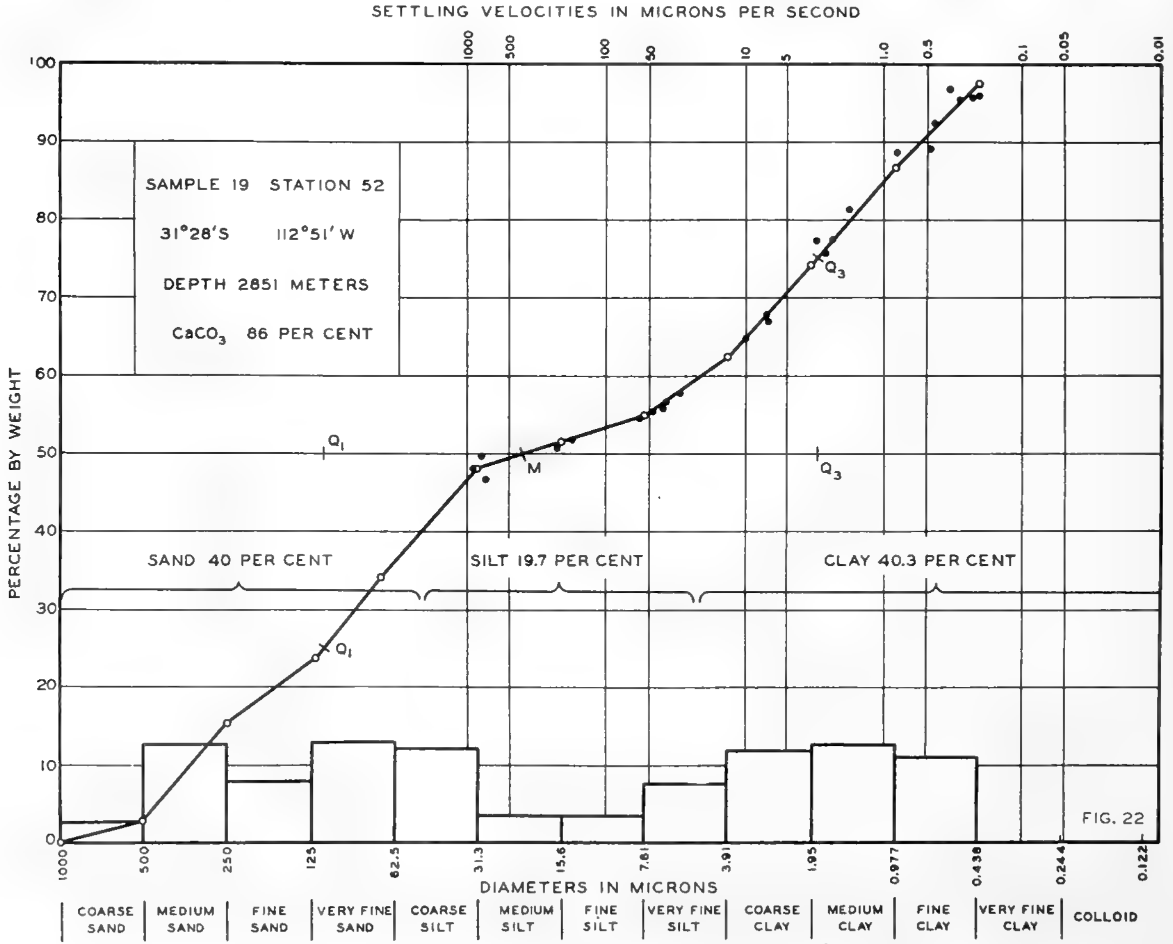


FIG. 22

FIGS. 21-22—SETTLING VELOCITIES IN MICRONS PER SECOND AT 20°C, SAMPLES 49 AND 19

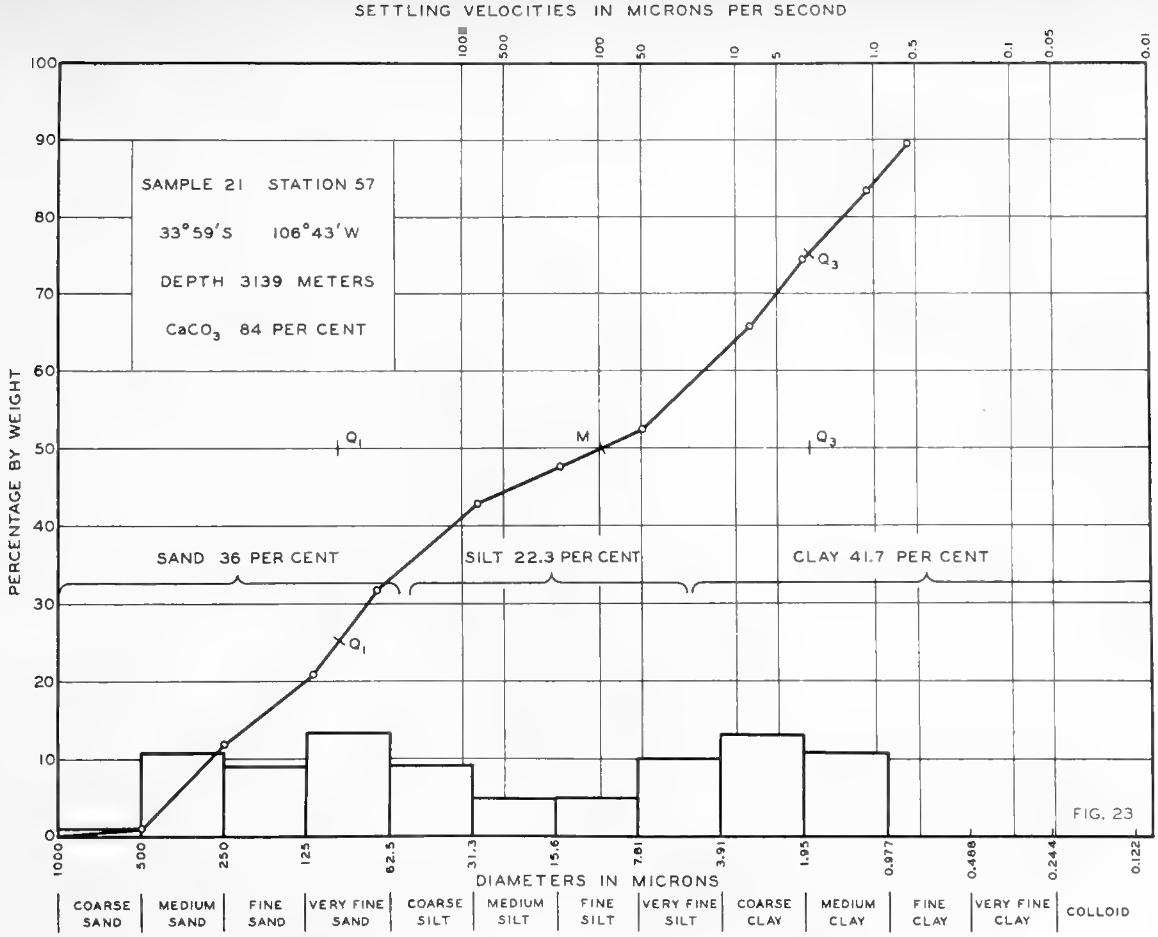


FIG. 23

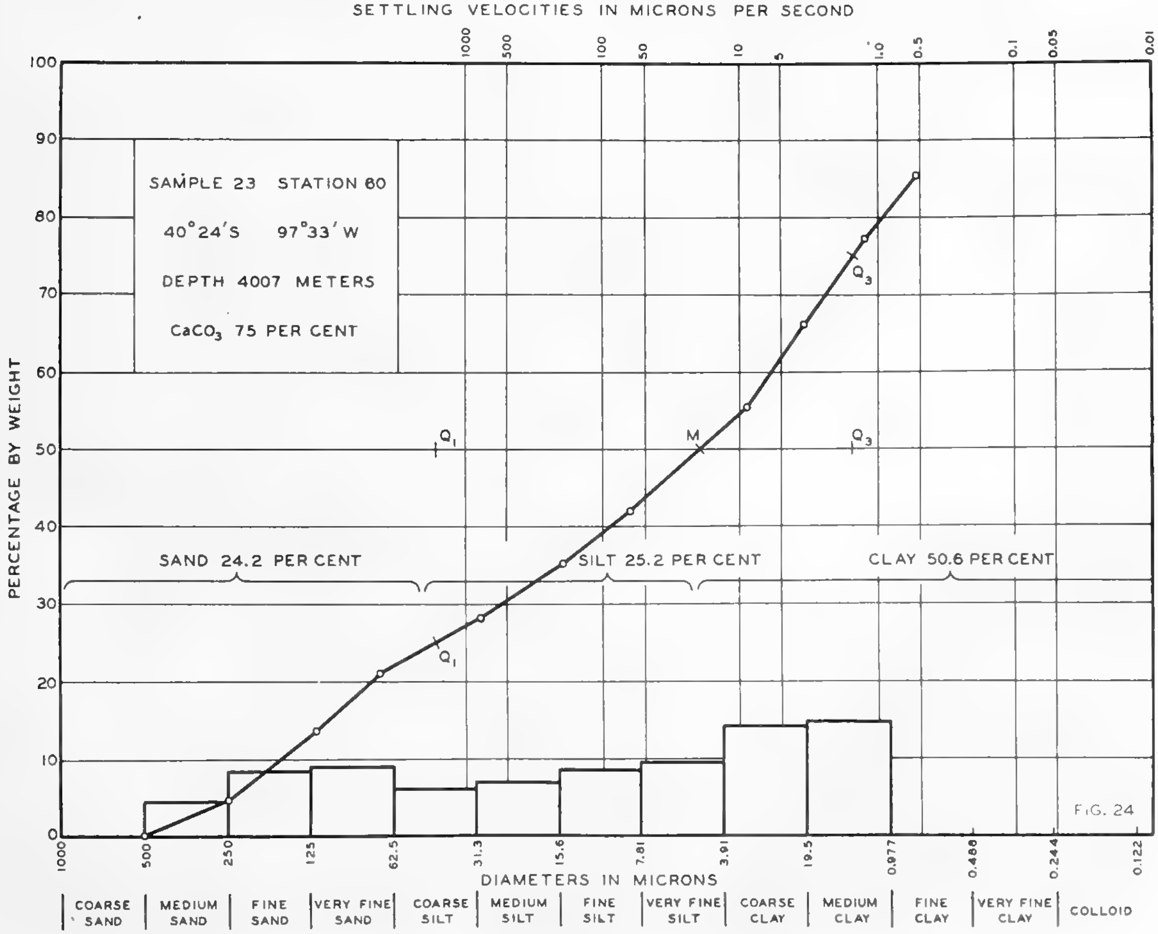


FIG. 24

FIGS. 23-24—SETTLING VELOCITIES IN MICRONS PER SECOND AT 20 °C, SAMPLES 21 AND 23

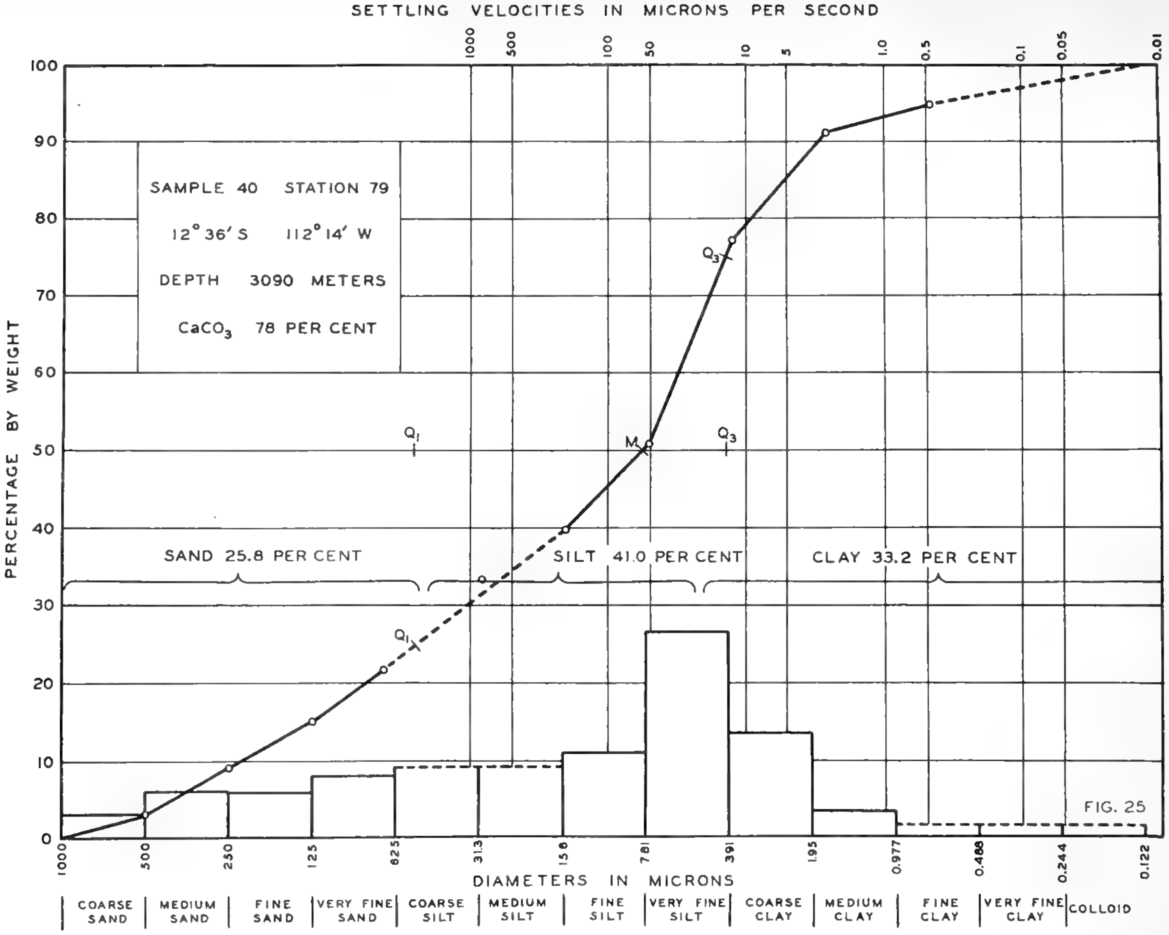


FIG. 25

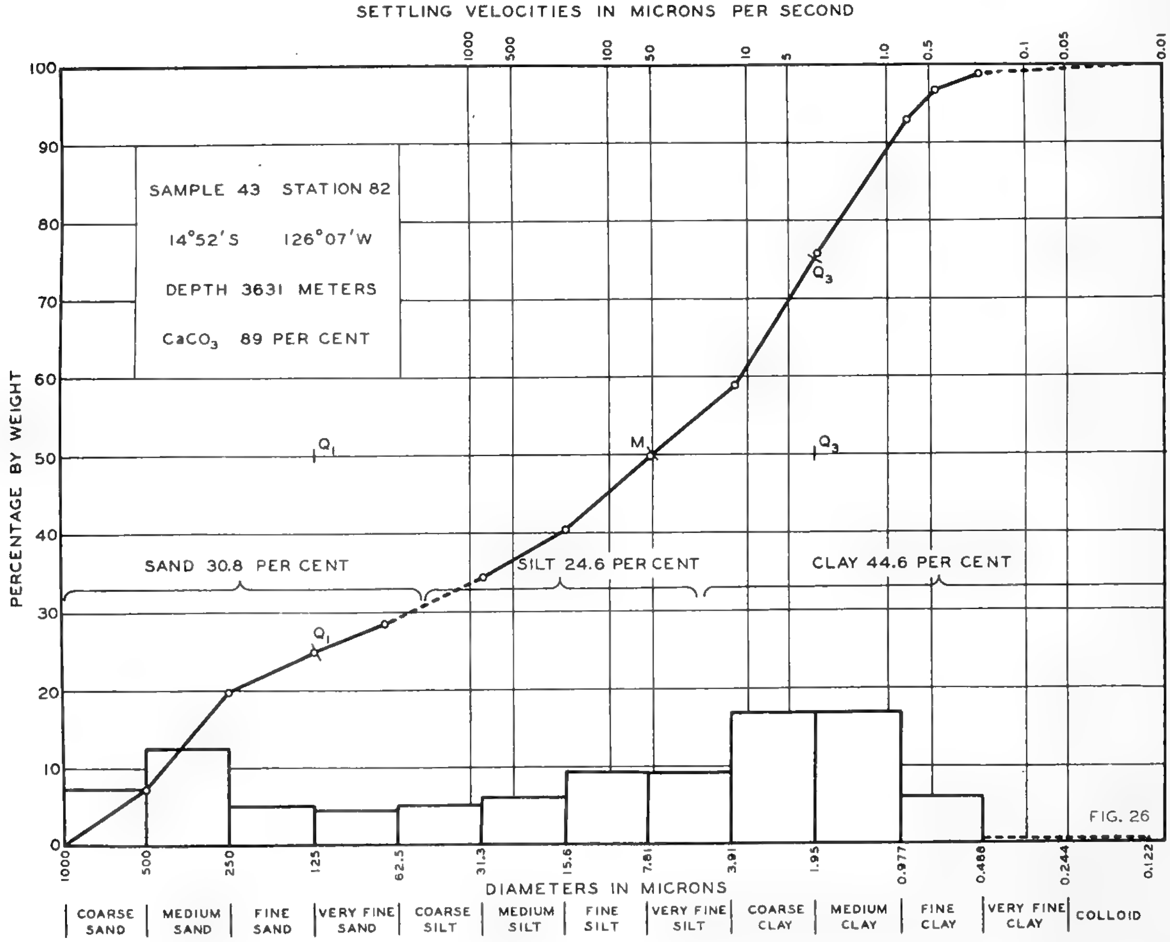


FIG. 26

FIGS. 25-26—SETTLING VELOCITIES IN MICRONS PER SECOND AT 20°C, SAMPLES 40 AND 43

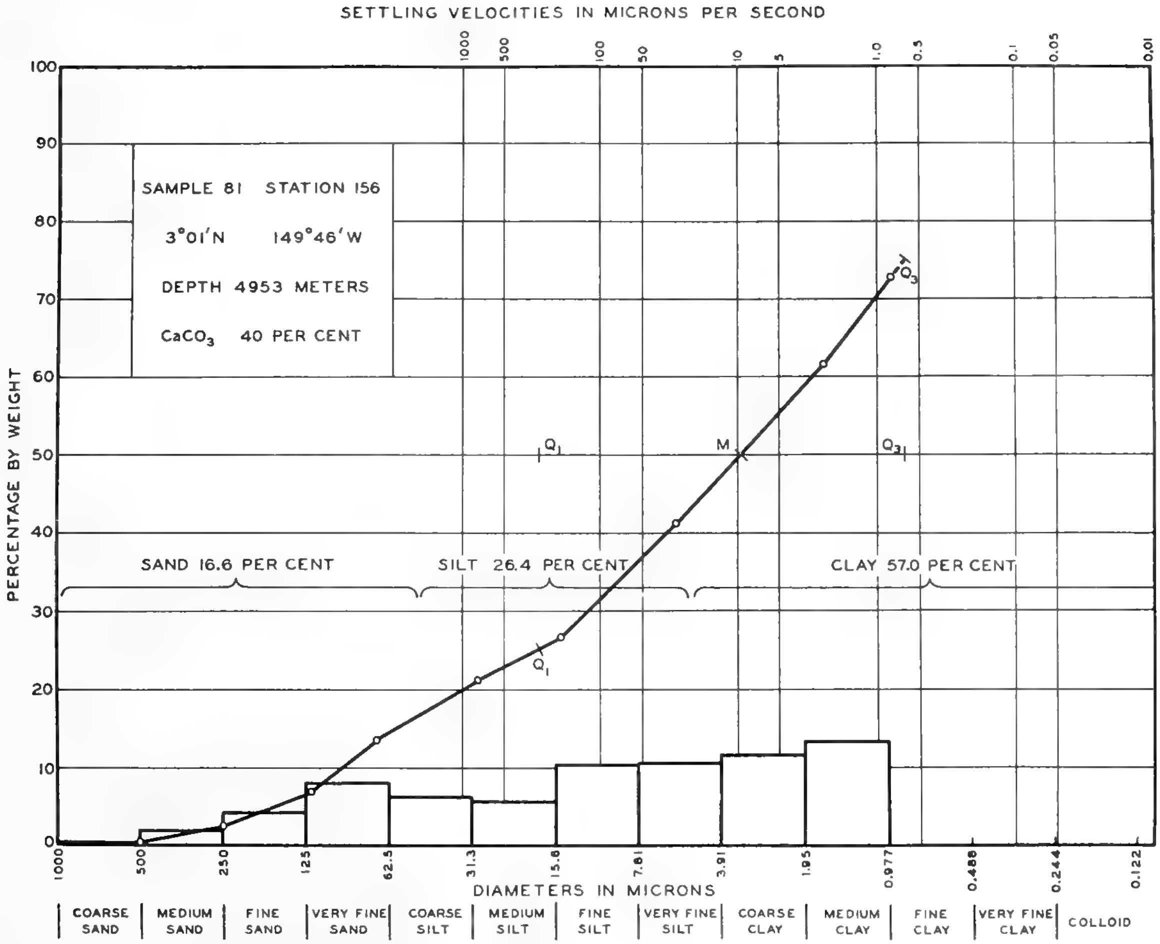


FIG. 27—SETTLING VELOCITIES IN MICRONS PER SECOND AT 20°C, SAMPLE 81

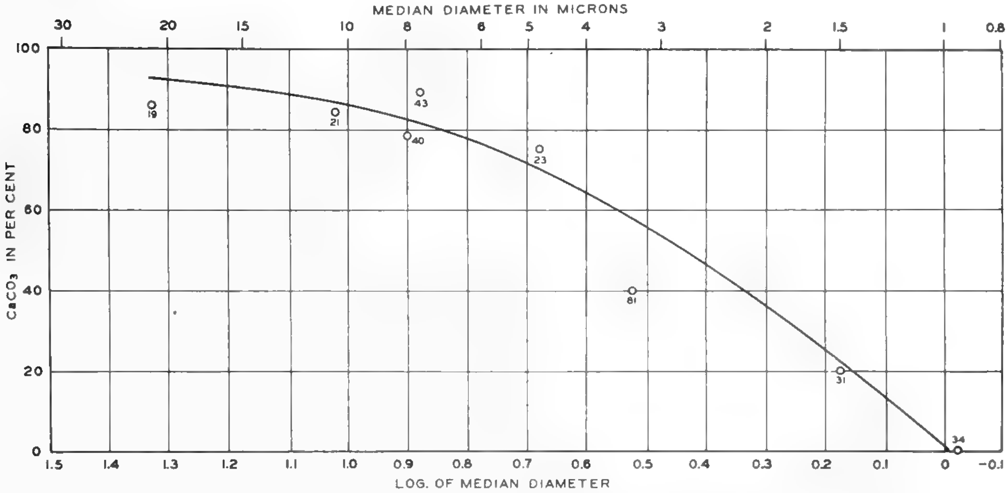


FIG. 28—RELATIONSHIP BETWEEN MEDIAN PARTICLE DIAMETER AND CALCIUM CARBONATE CONTENT OF SAMPLES FROM SOUTH PACIFIC

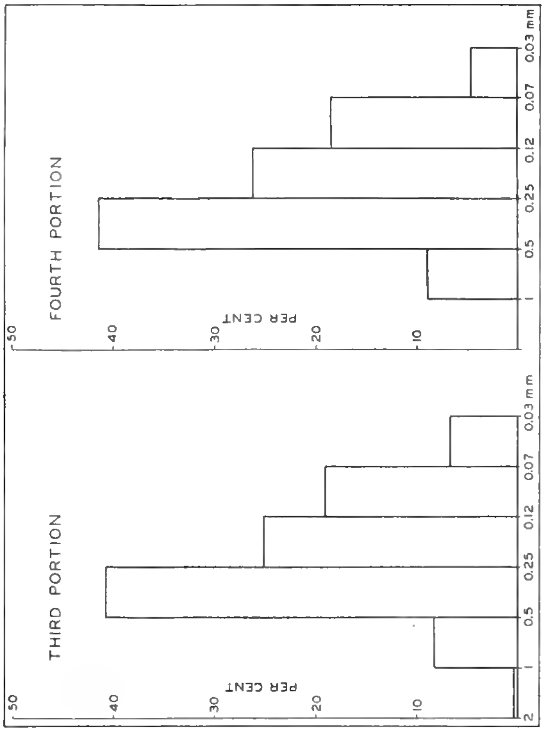


FIG. 29—DUPLICATE ANALYSES OF SAND GRADES, SAMPLE 19
(SHOWING MAXIMUM ERROR OWING TO QUARTERING)

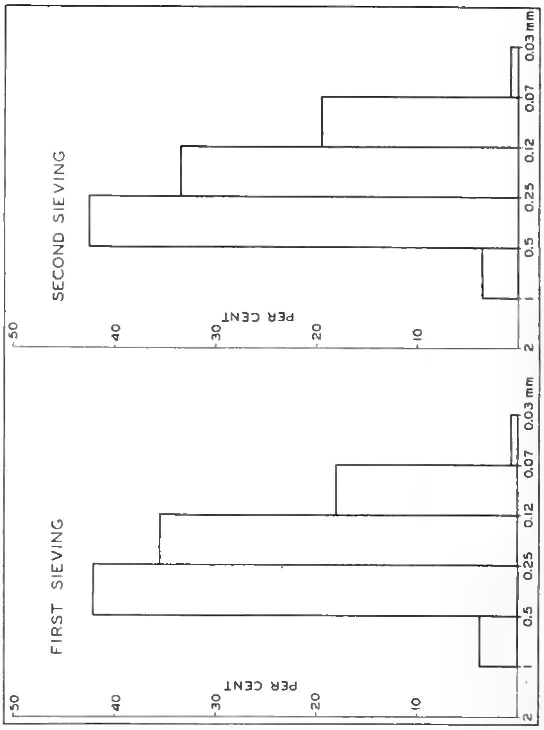


FIG. 30—DUPLICATE ANALYSES OF SAND GRADES, SAMPLE 21, FIRST PORTION
(SHOWING MAXIMUM ERROR OWING TO SIEVING)

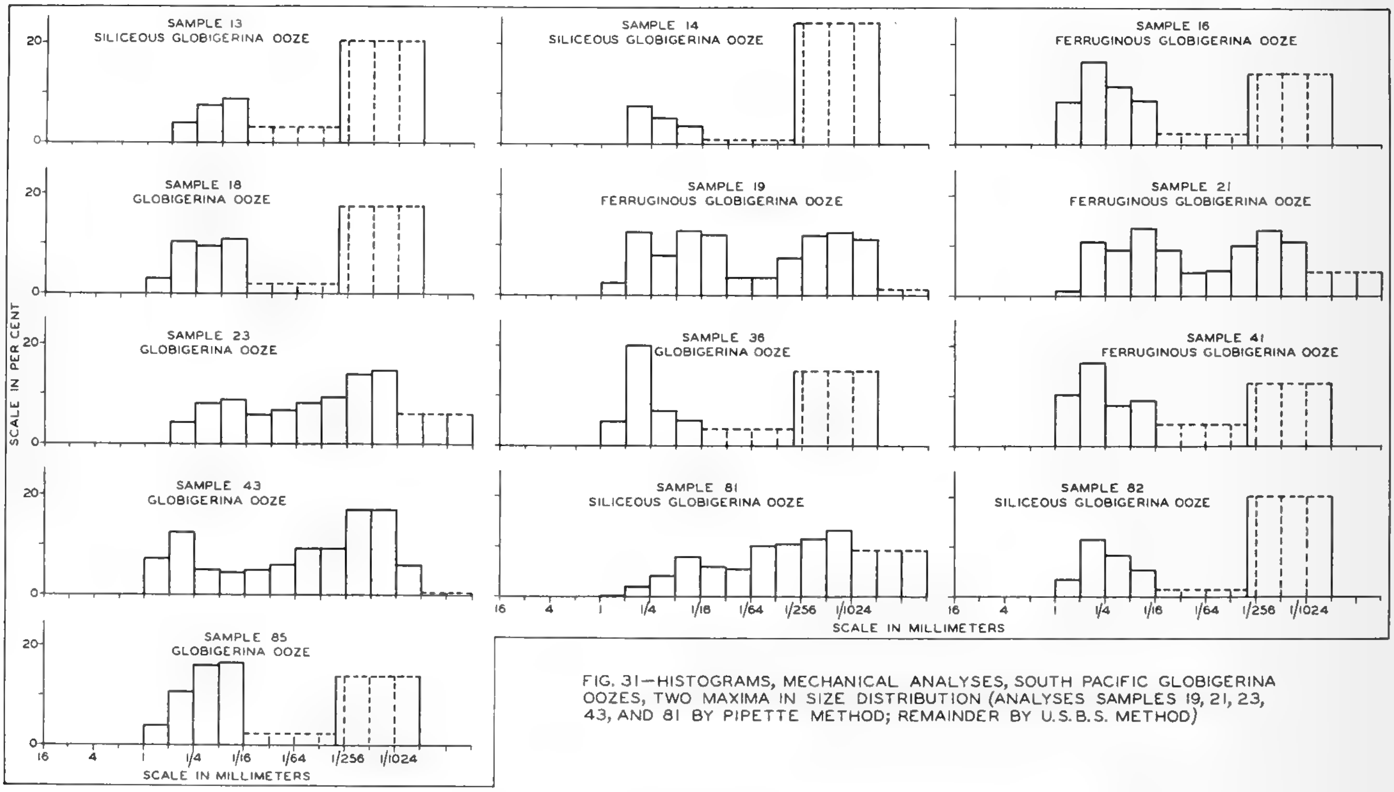


FIG. 31—HISTOGRAMS, MECHANICAL ANALYSES, SOUTH PACIFIC GLOBIGERINA OOZES, TWO MAXIMA IN SIZE DISTRIBUTION (ANALYSES SAMPLES 19, 21, 23, 43, AND 81 BY PIPETTE METHOD; REMAINDER BY U.S.B.S. METHOD)

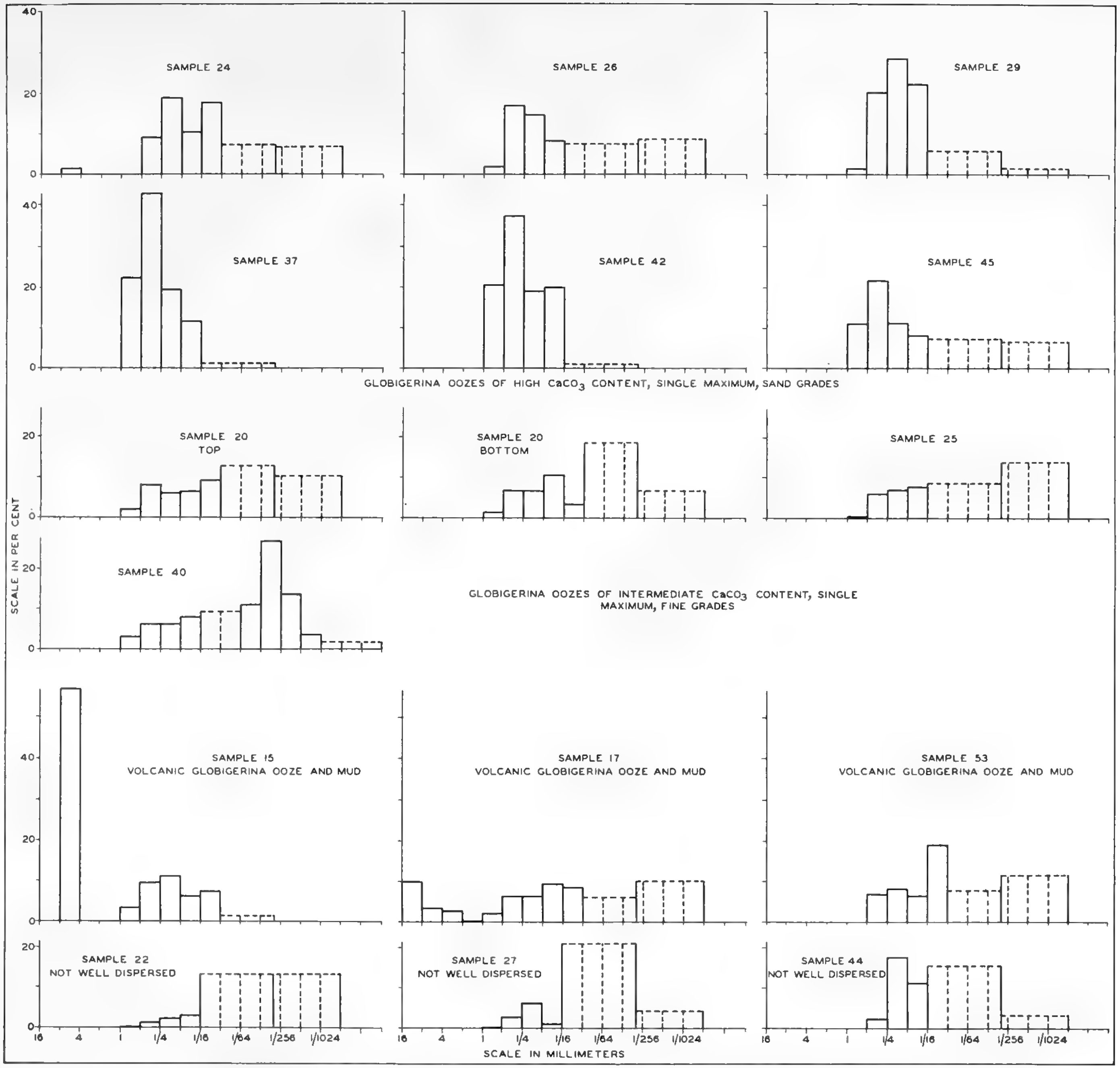


FIG. 32—HISTOGRAMS, MECHANICAL ANALYSES, GLOBIGERINA OOZES (ALL BUT SAMPLE 40 BY U.S.B.S. METHOD)

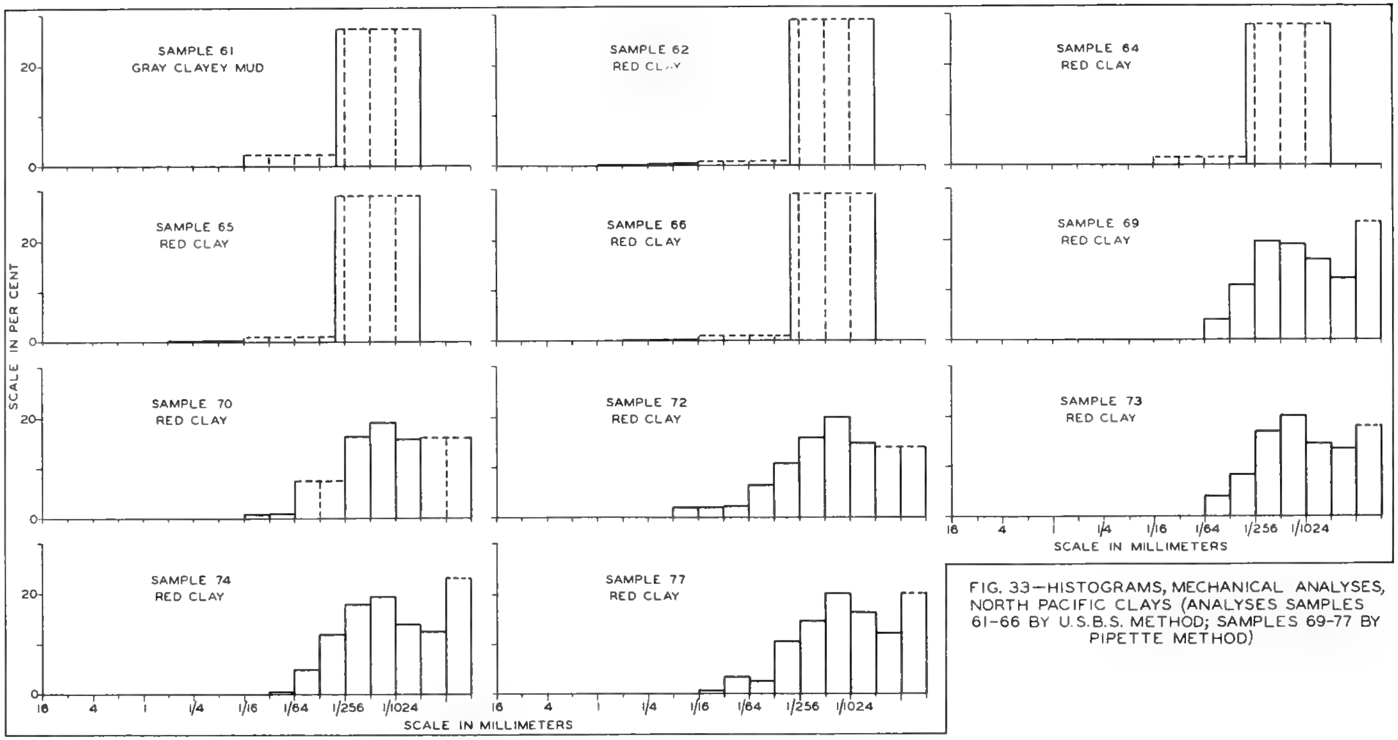


FIG. 33—HISTOGRAMS, MECHANICAL ANALYSES, NORTH PACIFIC CLAYS (ANALYSES SAMPLES 61-66 BY U.S.B.S. METHOD; SAMPLES 69-77 BY PIPETTE METHOD)

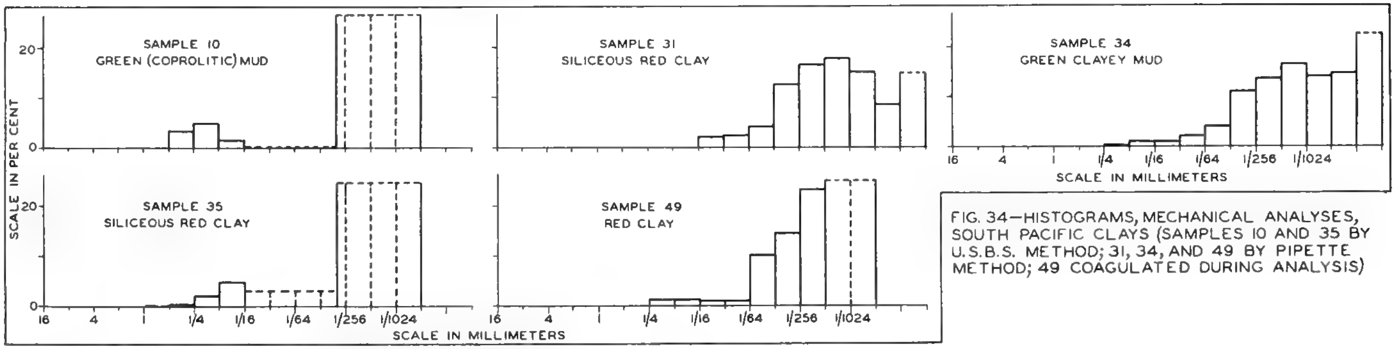


FIG. 34—HISTOGRAMS, MECHANICAL ANALYSES, SOUTH PACIFIC CLAYS (SAMPLES 10 AND 35 BY U.S.B.S. METHOD; 31, 34, AND 49 BY PIPETTE METHOD; 49 COAGULATED DURING ANALYSIS)

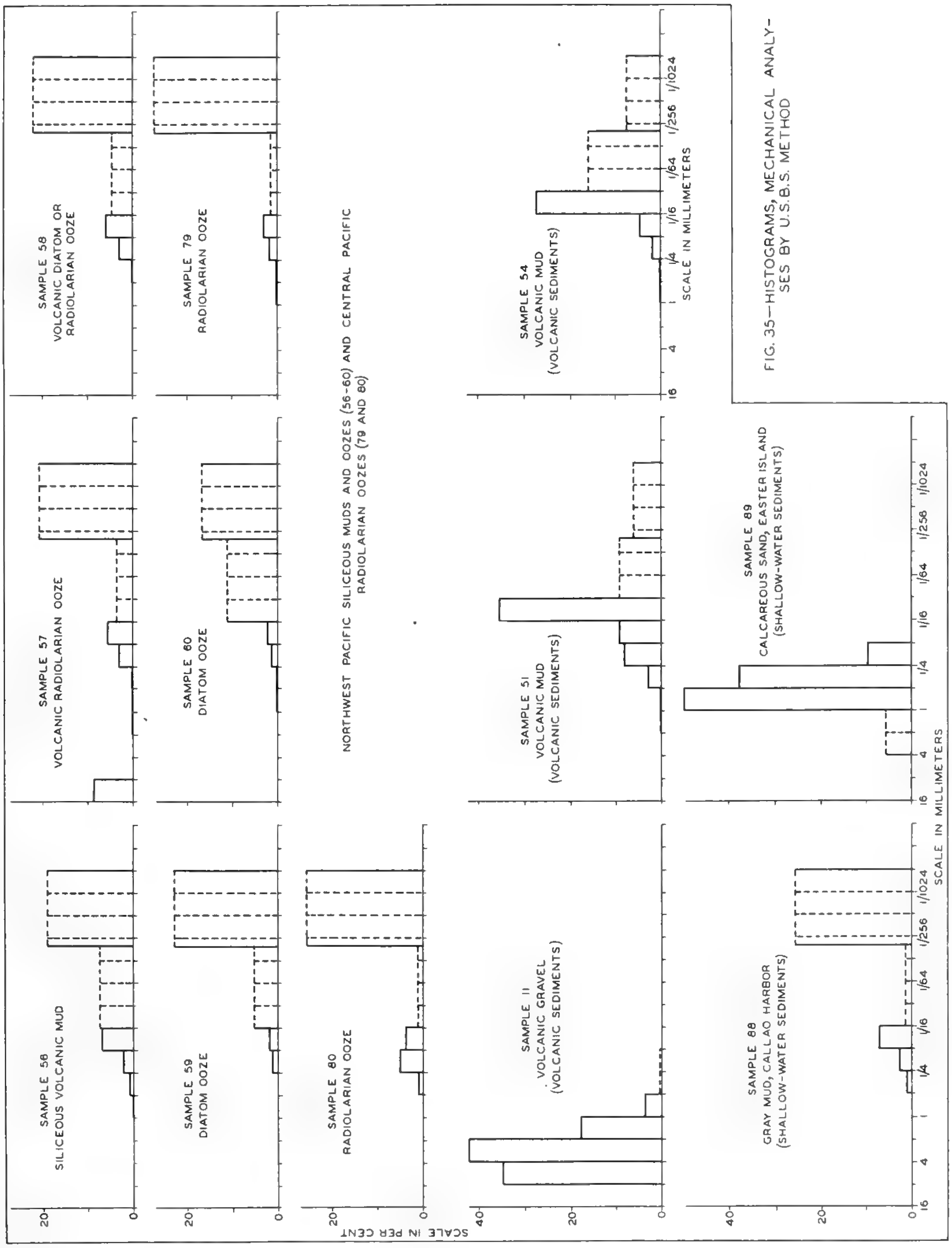


FIG. 35—HISTOGRAMS, MECHANICAL ANALYSES BY U.S.B.S. METHOD

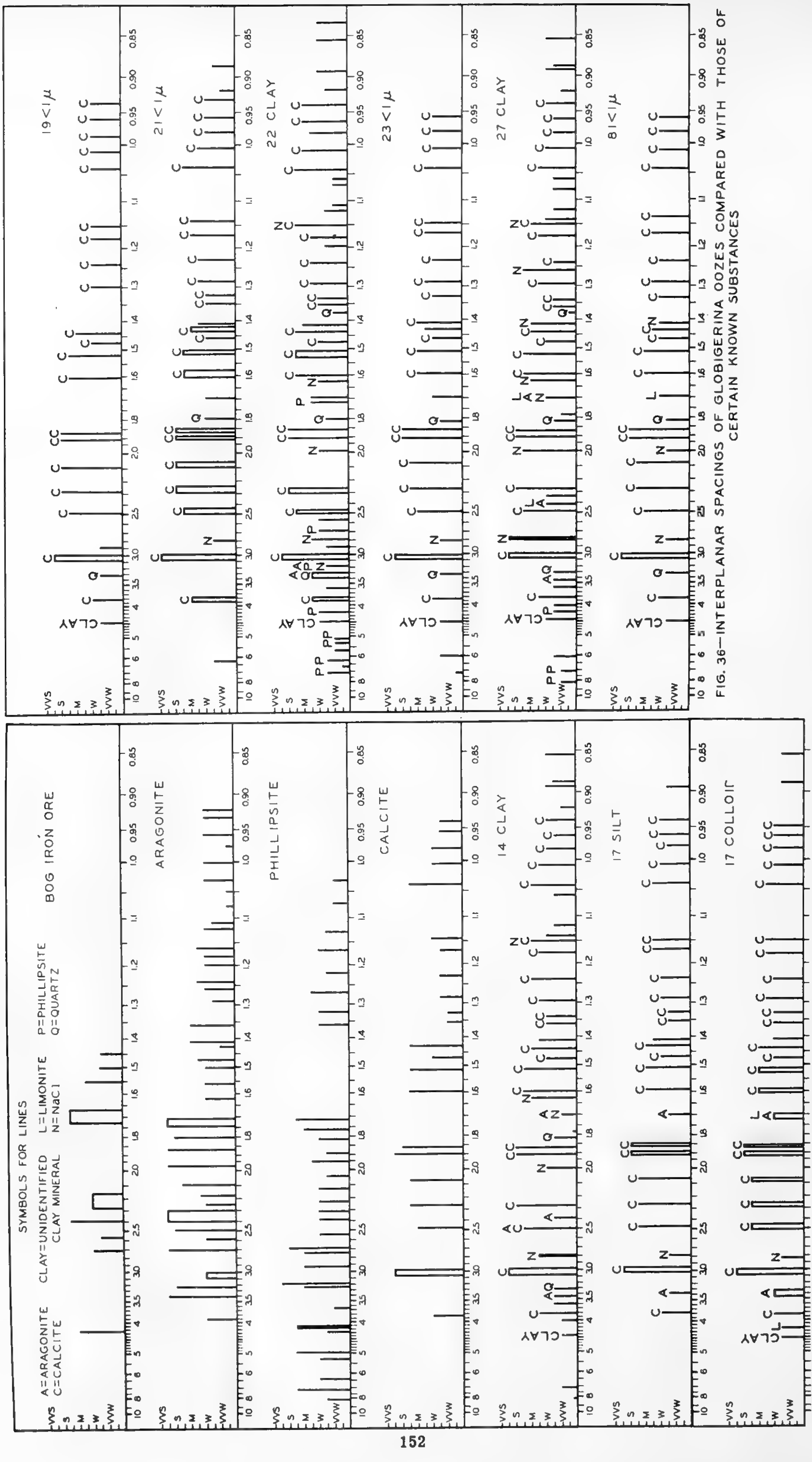


FIG. 36—INTERPLANAR SPACINGS OF GLOBIGERINA OOZES COMPARED WITH THOSE OF CERTAIN KNOWN SUBSTANCES

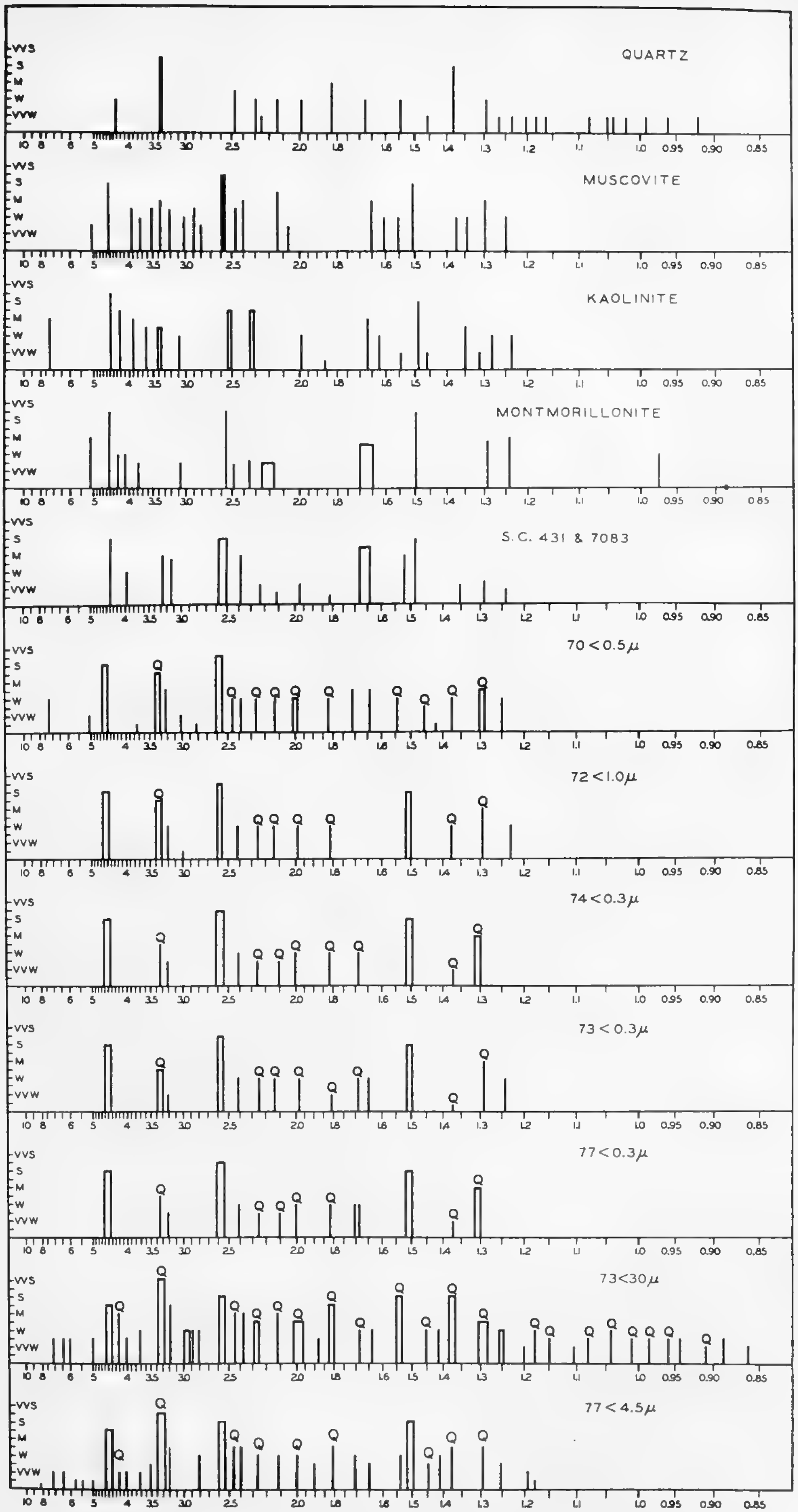


FIG. 37—INTERPLANAR SPACINGS OF RED CLAYS AND OF TWO CALIFORNIA SOILS, COMPARED WITH THOSE OF CERTAIN KNOWN SUBSTANCES

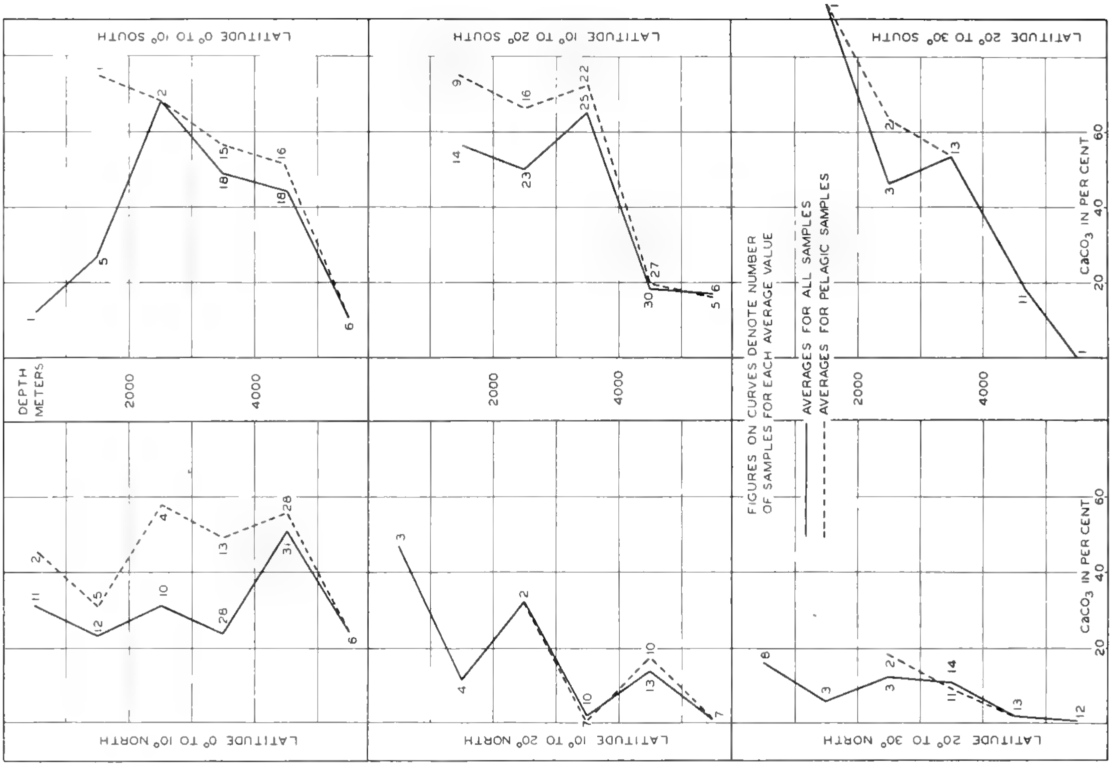


FIG. 38—RELATIONSHIP BETWEEN $CaCO_3$ CONTENT AND DEPTH, SAMPLES BETWEEN LATITUDES 0° TO 30° NORTH AND SOUTH, PACIFIC OCEAN

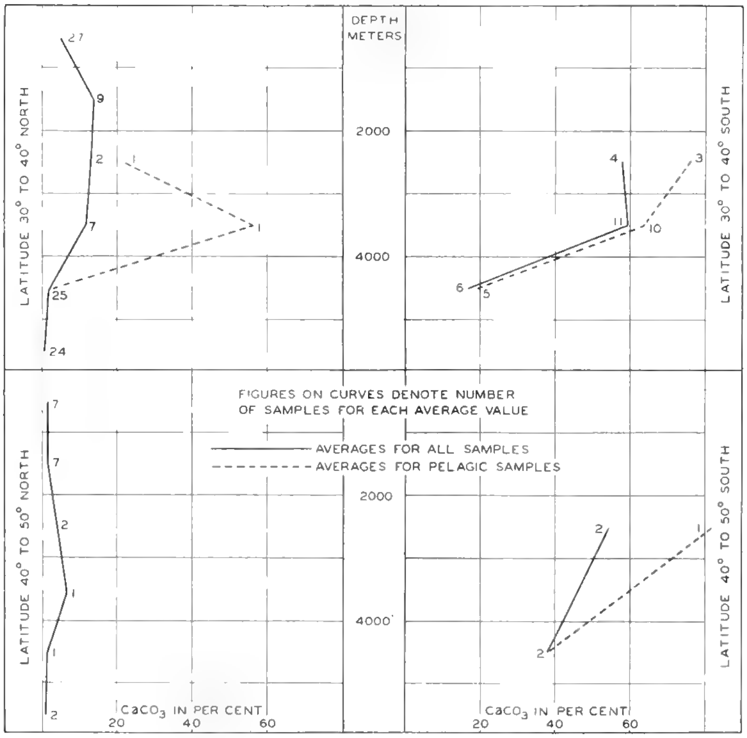


FIG. 39—RELATIONSHIP BETWEEN $CaCO_3$ CONTENT AND DEPTH, SAMPLES BETWEEN LATITUDES 30° TO 50° NORTH AND SOUTH, PACIFIC OCEAN

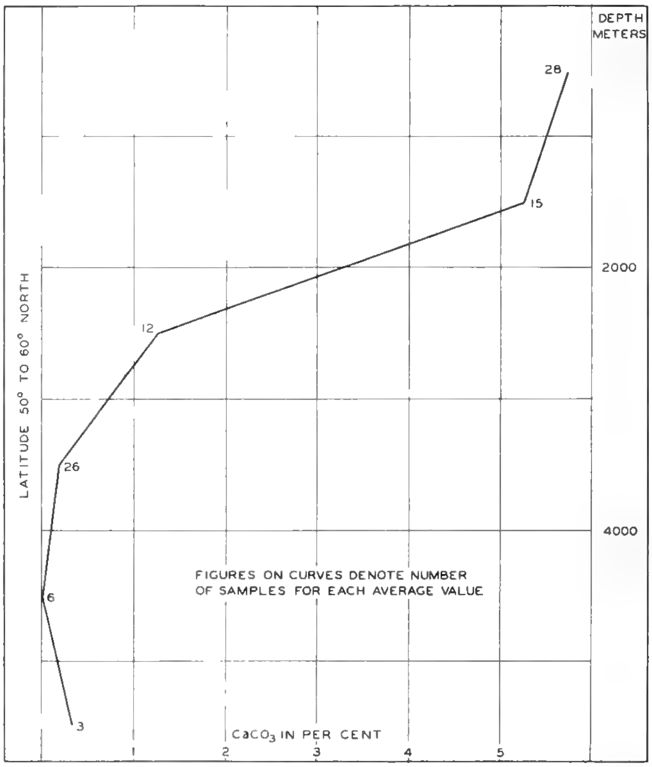


FIG. 40—RELATIONSHIP BETWEEN $CaCO_3$ CONTENT AND DEPTH, SAMPLES BETWEEN LATITUDES 50° TO 60° NORTH, PACIFIC OCEAN

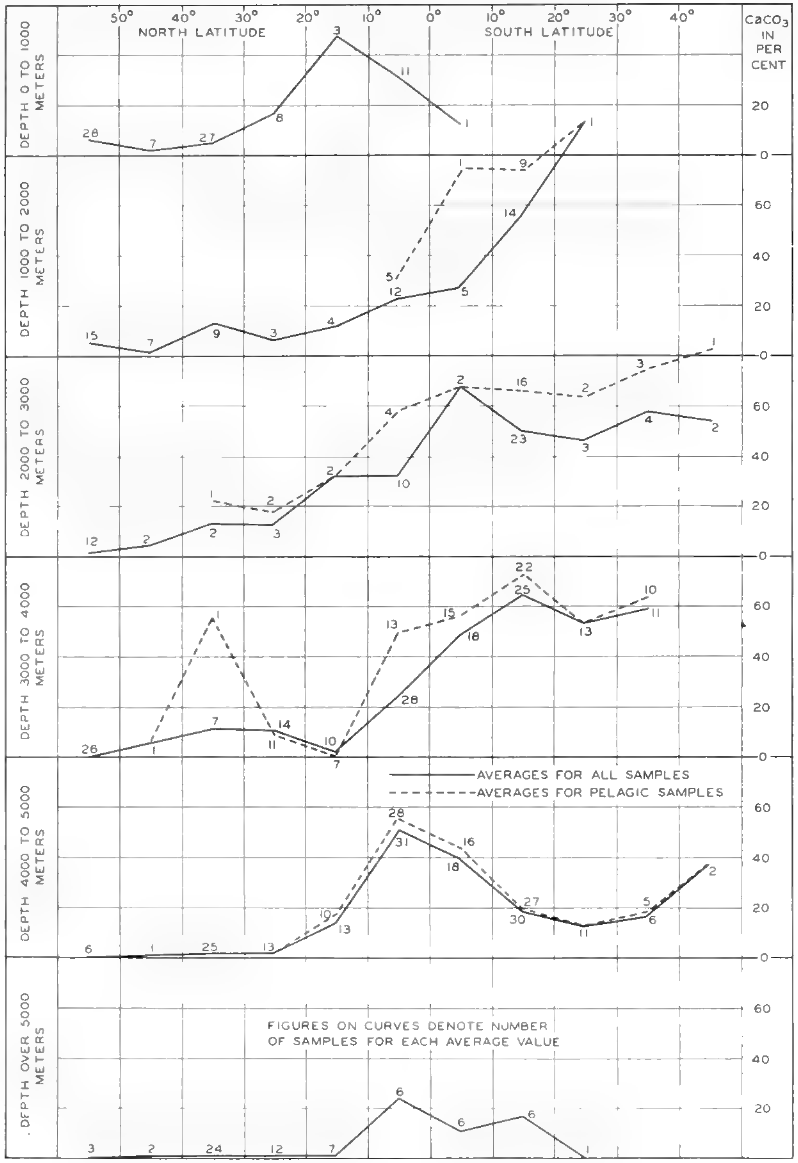


FIG. 41—RELATIONSHIP BETWEEN $CaCO_3$ CONTENT AND LATITUDE, SAMPLES OF VARIOUS DEPTHS, PACIFIC OCEAN

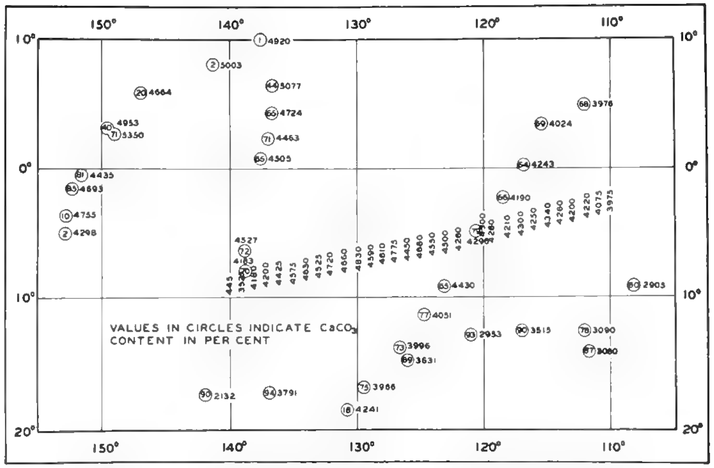


FIG. 42—CERTAIN SOUNDINGS MADE BY THE DANA, ALBATROSS, AND CARNEGIE BETWEEN LATITUDES 10° NORTH AND 20° SOUTH, AND LONGITUDES 105° WEST AND 155° WEST

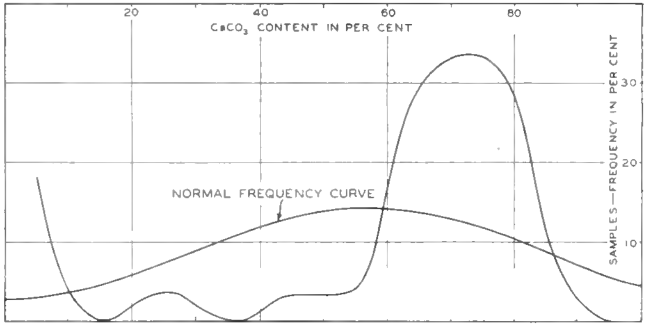


FIG. 43—FREQUENCY OCCURRENCE SAMPLES OF DIFFERENT PERCENTAGE CONTENTS $CaCO_3$ AT DEPTHS 4000 TO 5000 METERS, AND LATITUDES 0° TO 10° NORTH

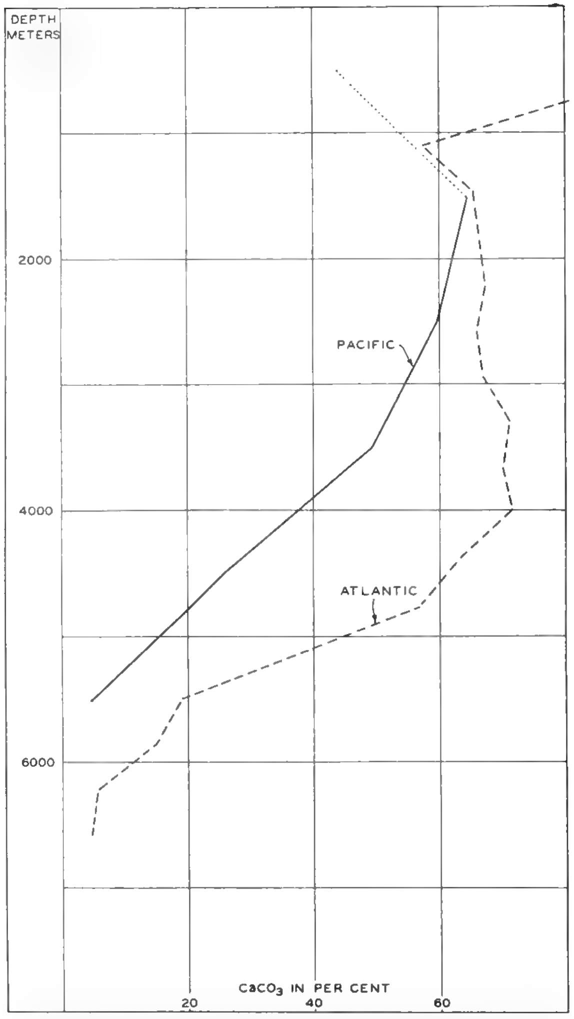


FIG. 44—RELATIONSHIP BETWEEN CaCO$_3$ CONTENT AND DEPTH FOR PELAGIC SAMPLES, ALL LATITUDES IN PACIFIC, COMPARED WITH ATLANTIC PELAGIC SAMPLES

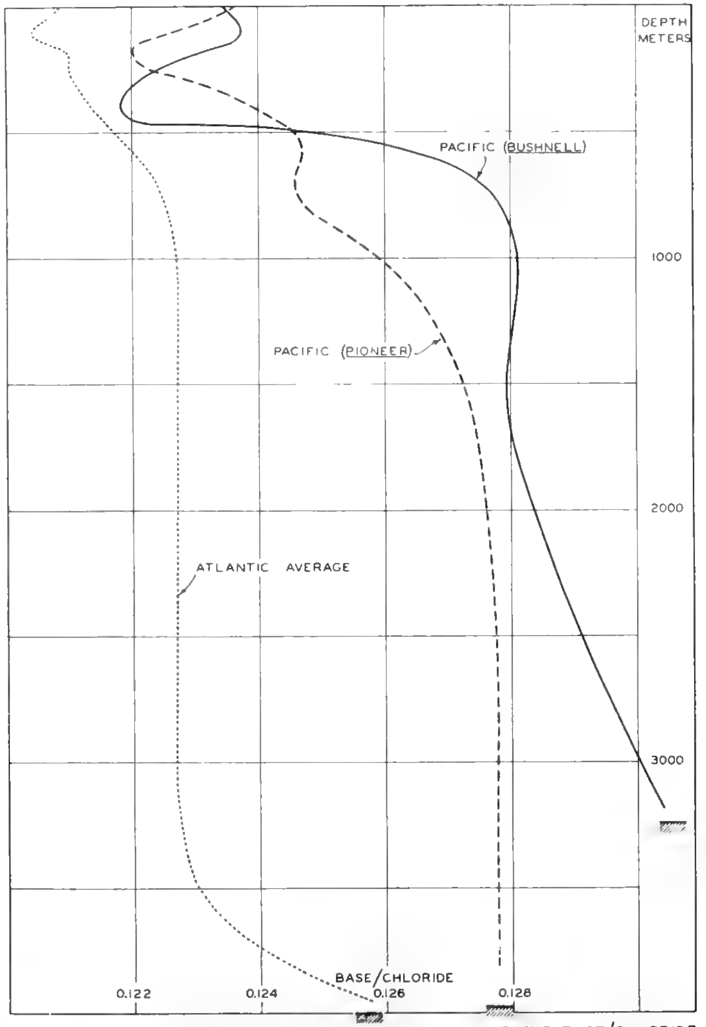


FIG. 45—RELATIONSHIP BETWEEN DEPTH AND RATIO, BASE/CHLORIDE, PACIFIC AND ATLANTIC WATERS

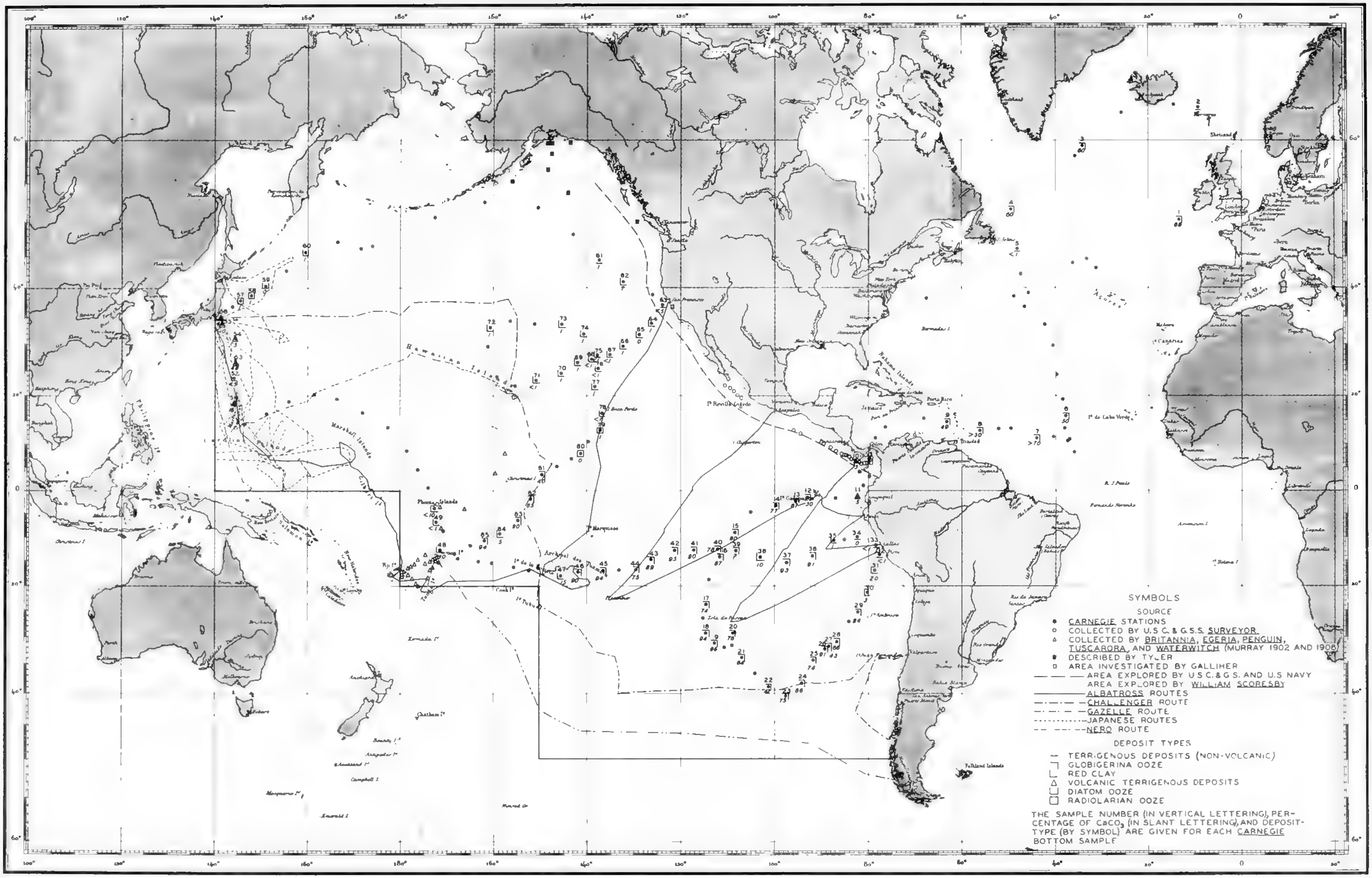


CHART 1—LOCATION, TYPE, AND PERCENTAGE OF CALCIUM CARBONATE ($CaCO_3$) OF BOTTOM SAMPLES COLLECTED ON CRUISE VII OF THE *CARNEGIE*, ALSO ROUTES OF OTHER EXPEDITIONS WHICH HAVE COLLECTED AND DESCRIBED BOTTOM SAMPLES

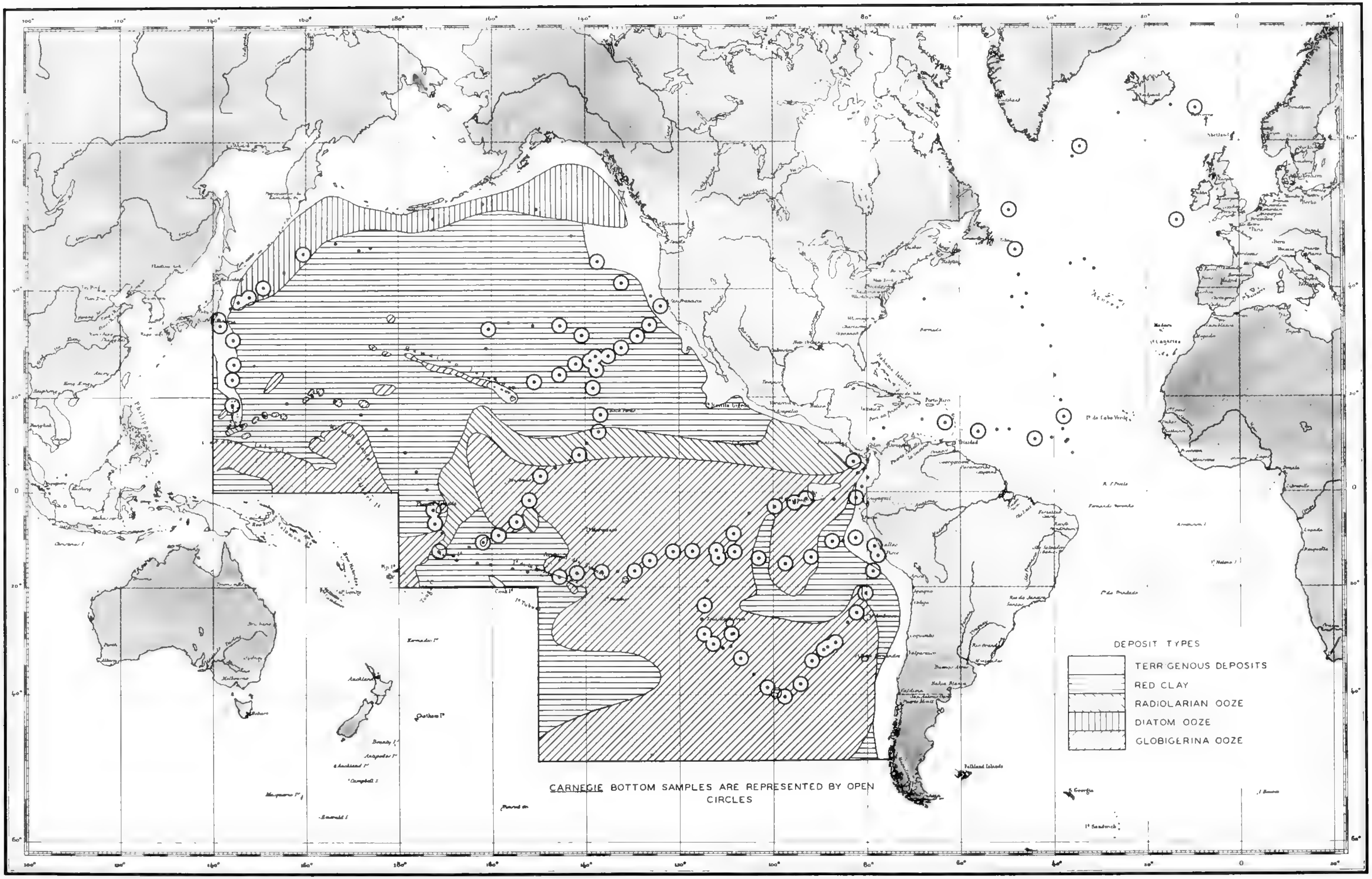


CHART 2—DISTRIBUTION OF MARINE DEPOSITS IN AREA COVERED BY THE CARNEGIE, CRUISE VII, IN PART AFTER MURRAY AND LEE, AND HANZAWA

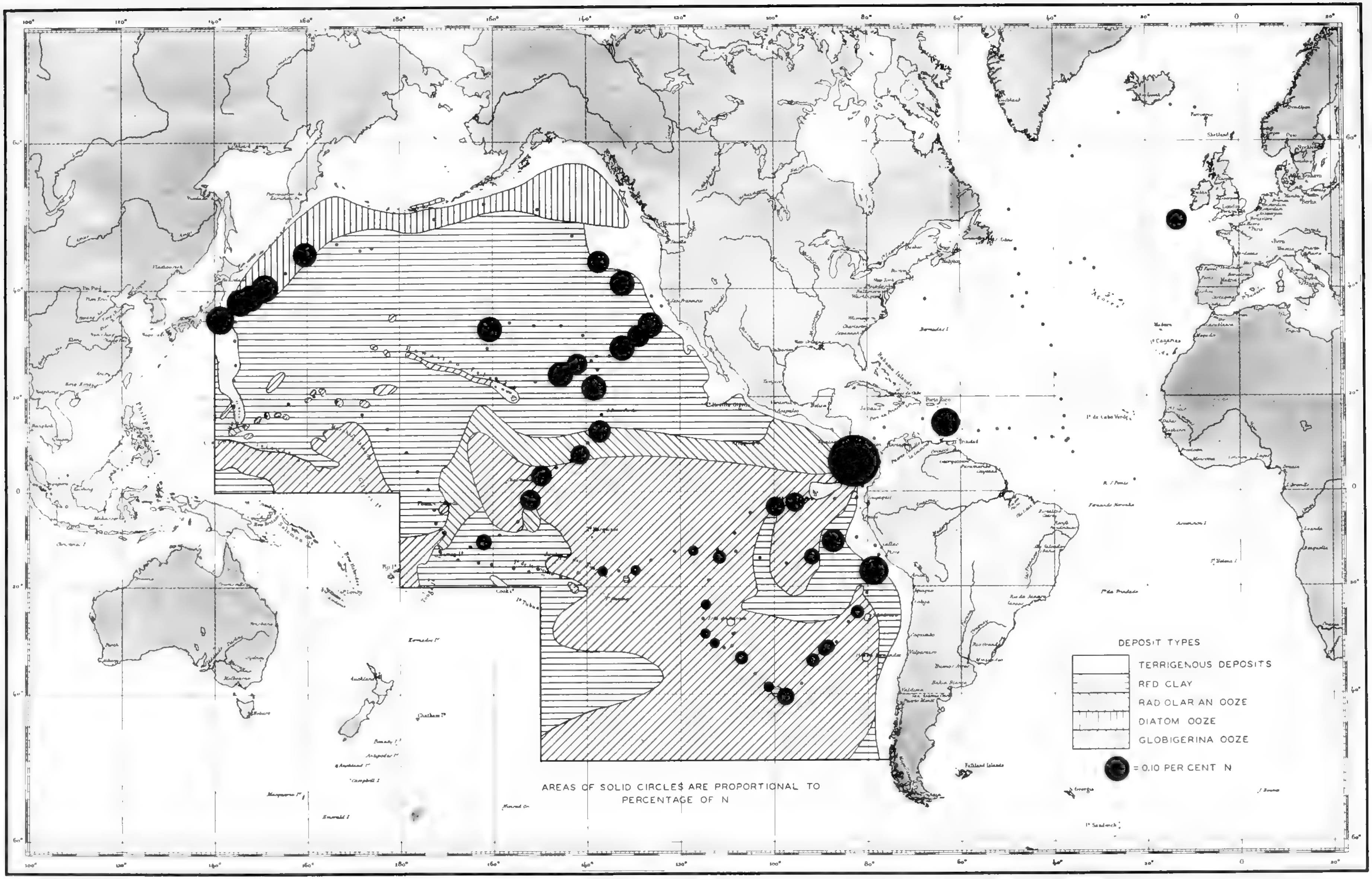
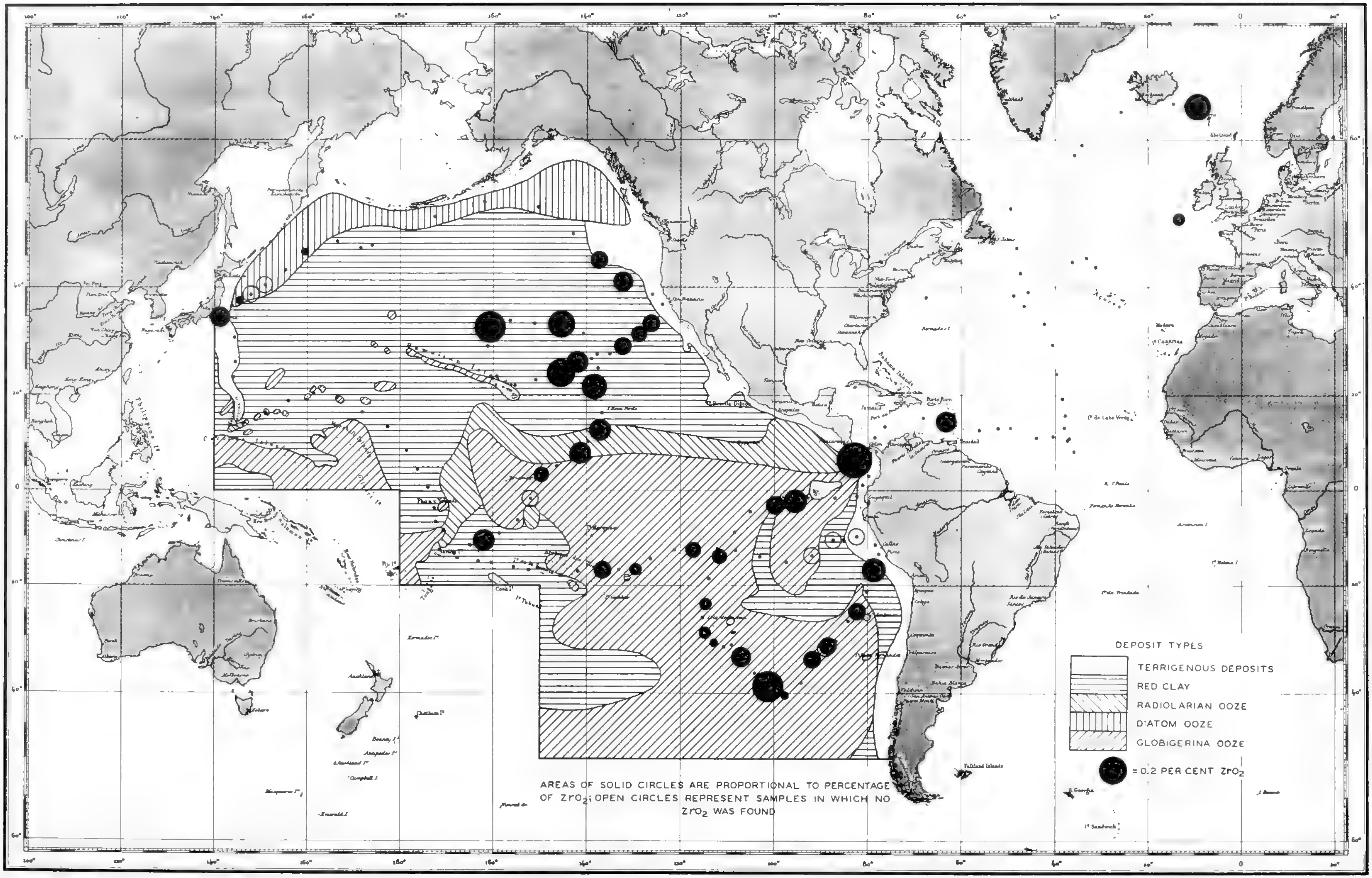


CHART 3—DISTRIBUTION OF NITROGEN (N) IN DEEP SEA BOTTOM DEPOSITS, PACIFIC OCEAN, <u>CARNEGIE</u> RESULTS, 1928-1929



AREAS OF SOLID CIRCLES ARE PROPORTIONAL TO PERCENTAGE OF ZrO_2; OPEN CIRCLES REPRESENT SAMPLES IN WHICH NO ZrO_2 WAS FOUND

CHART 4—DISTRIBUTION OF ZIRCONIUM DIOXIDE (ZrO_2) IN DEEP SEA BOTTOM DEPOSITS, PACIFIC OCEAN, CARNEGIE RESULTS, 1928-1929

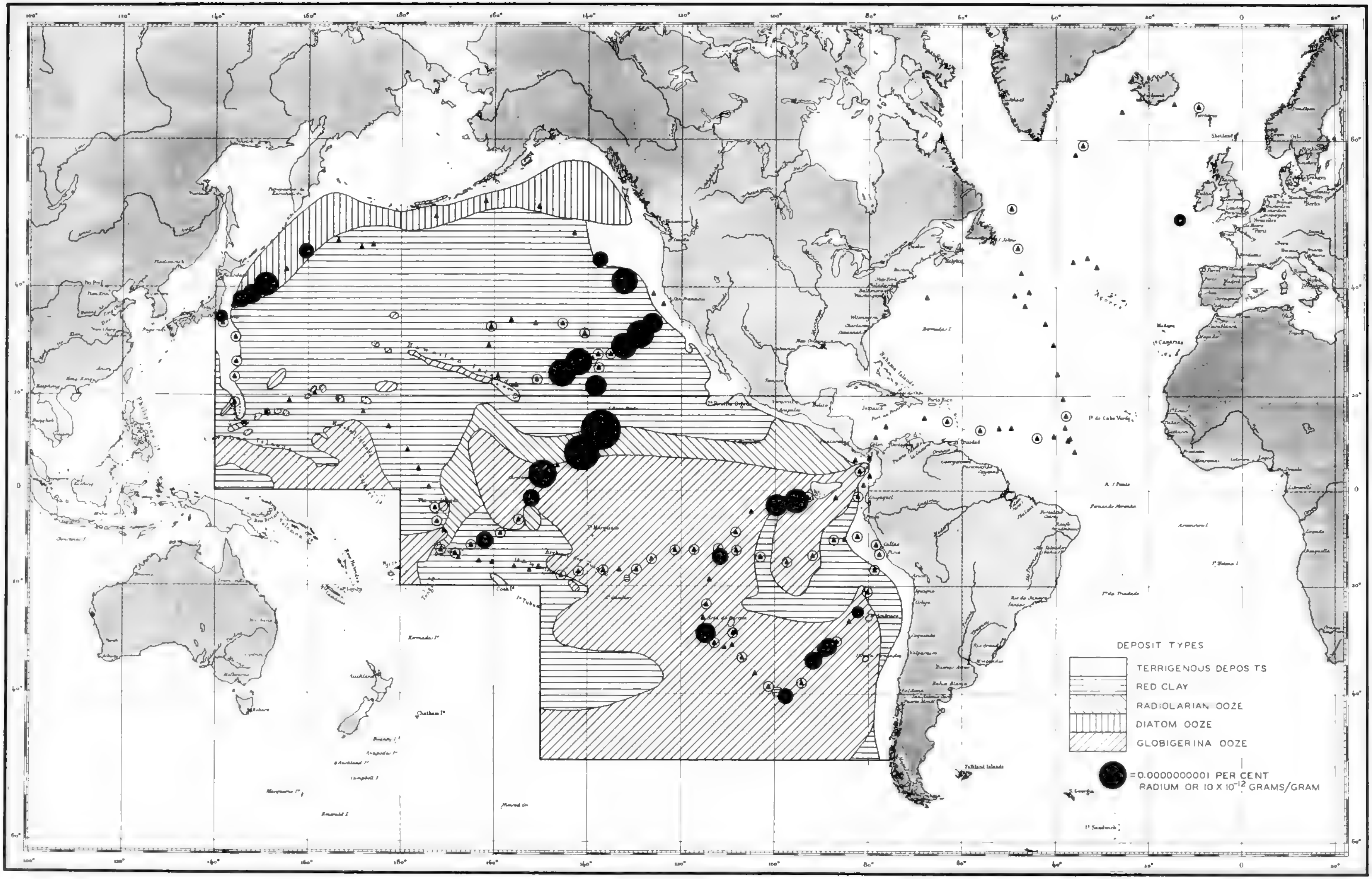


CHART 5—DISTRIBUTION OF RADIUM (Ra) IN DEEP SEA BOTTOM DEPOSITS, PACIFIC OCEAN, CARNEGIE RESULTS, 1928-1929
(AREAS OF SOLID CIRCLES ARE PROPORTIONAL TO AMOUNT OF RADIUM—OPEN CIRCLES REPRESENT SAMPLES IN WHICH NO DETERMINATION WAS MADE)

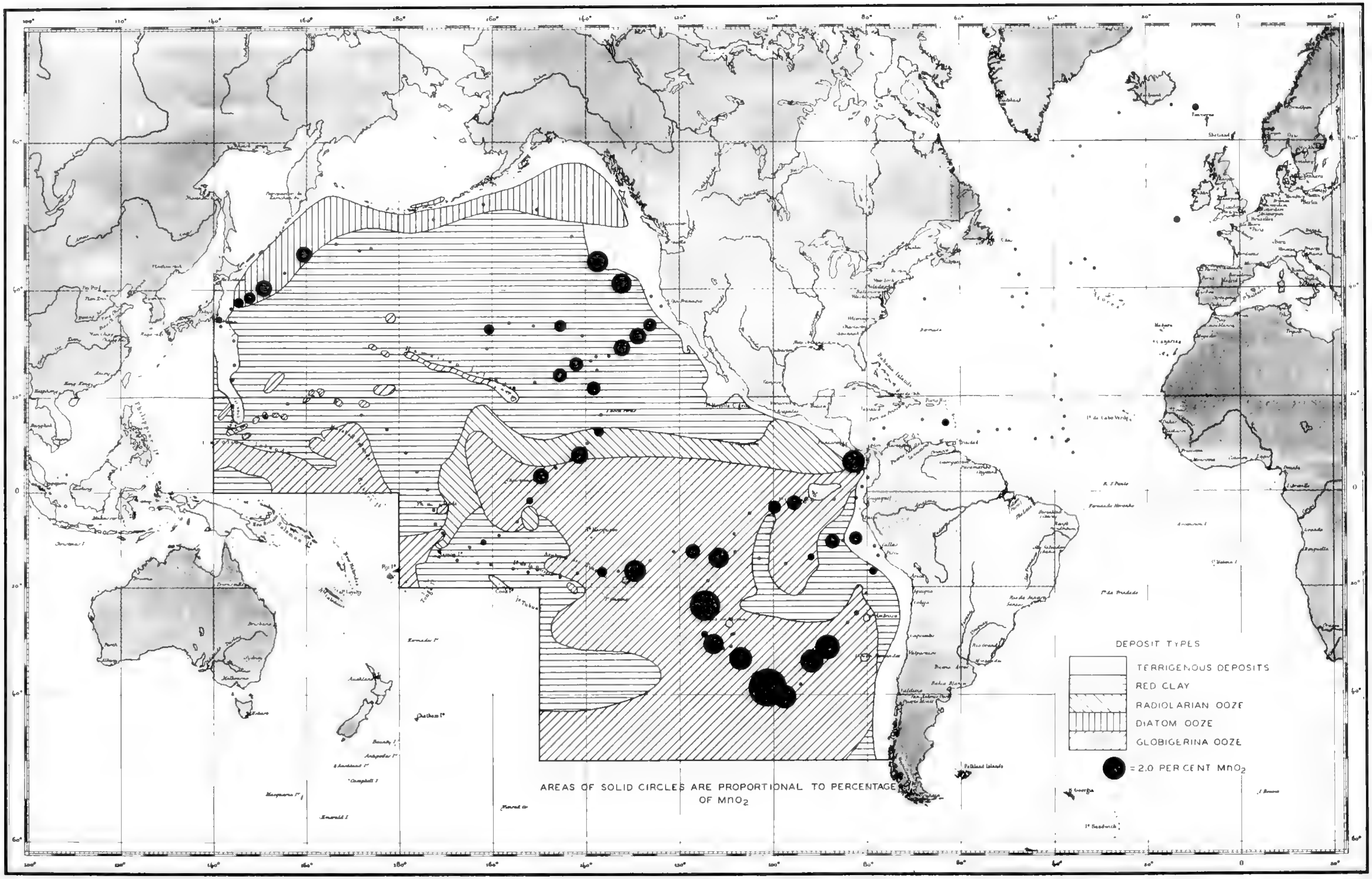


CHART 6—DISTRIBUTION OF MANGANESE DIOXIDE (MnO_2) IN DEEP SEA BOTTOM DEPOSITS, PACIFIC OCEAN, <u>CARNEGIE</u> RESULTS, 1928-1929

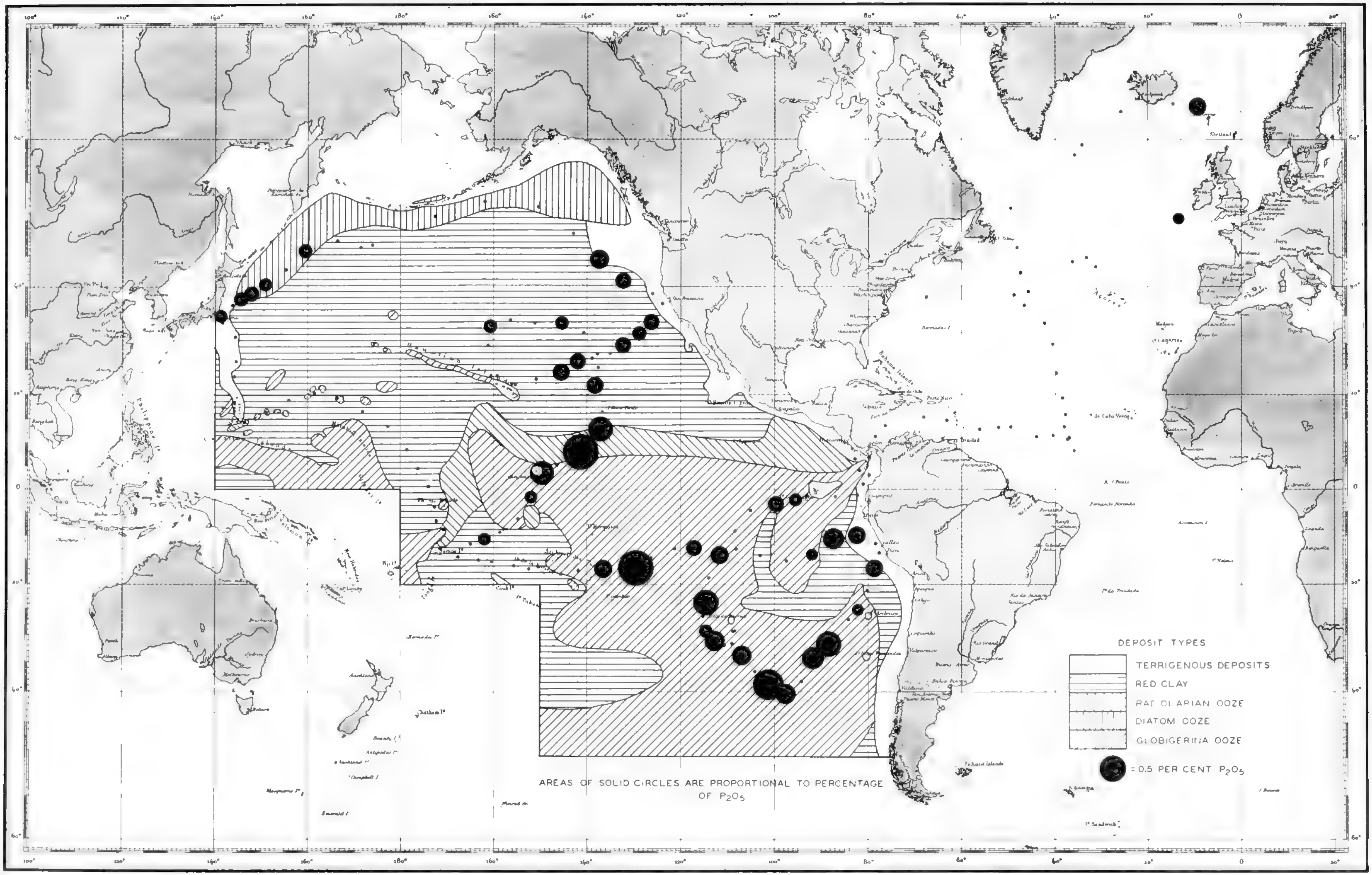


CHART 7—DISTRIBUTION OF PHOSPHOROUS PENTOXIDE (P_2O_5) IN DEEP SEA BOTTOM DEPOSITS, PACIFIC OCEAN, CARNEGIE RESULTS, 1928-1929

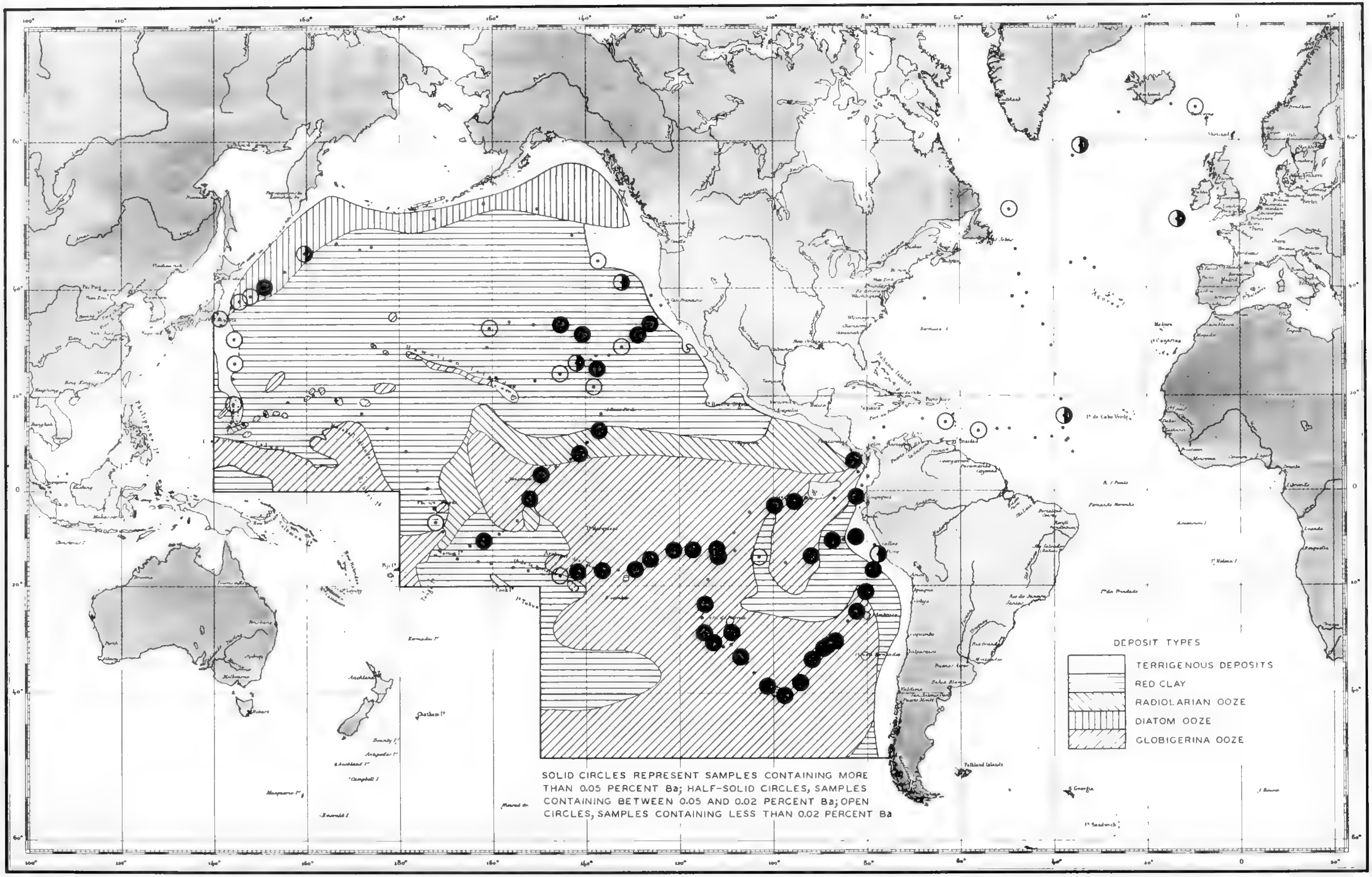


CHART 8—DISTRIBUTION OF BARIUM (Ba) IN DEEP SEA BOTTOM DEPOSITS, PACIFIC OCEAN, CARNEGIE RESULTS, 1928-1929

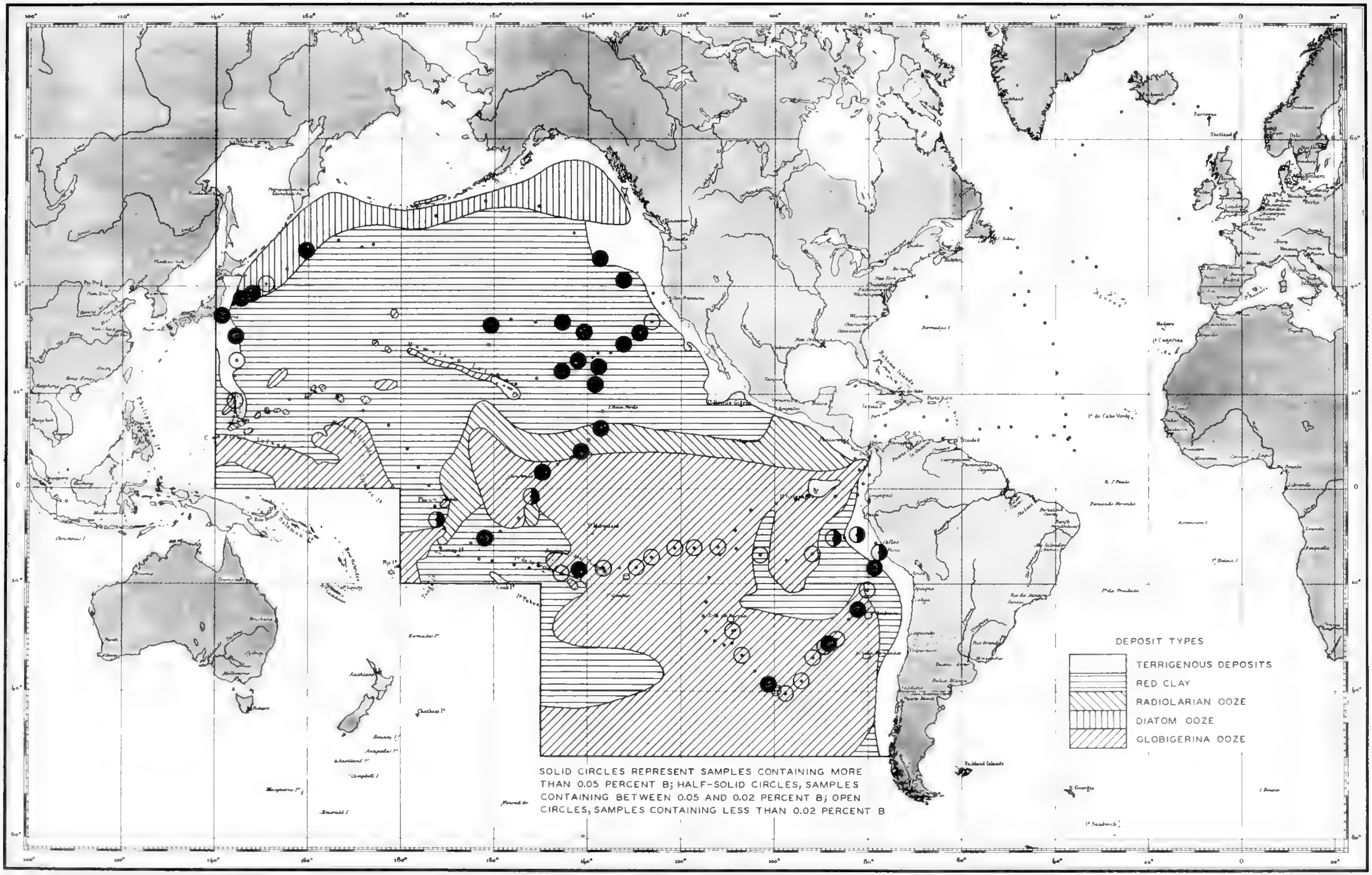


CHART 9—DISTRIBUTION OF BORON (B) IN DEEP SEA BOTTOM DEPOSITS, PACIFIC OCEAN, <u>CARNEGIE</u> RESULTS, 1928-1929

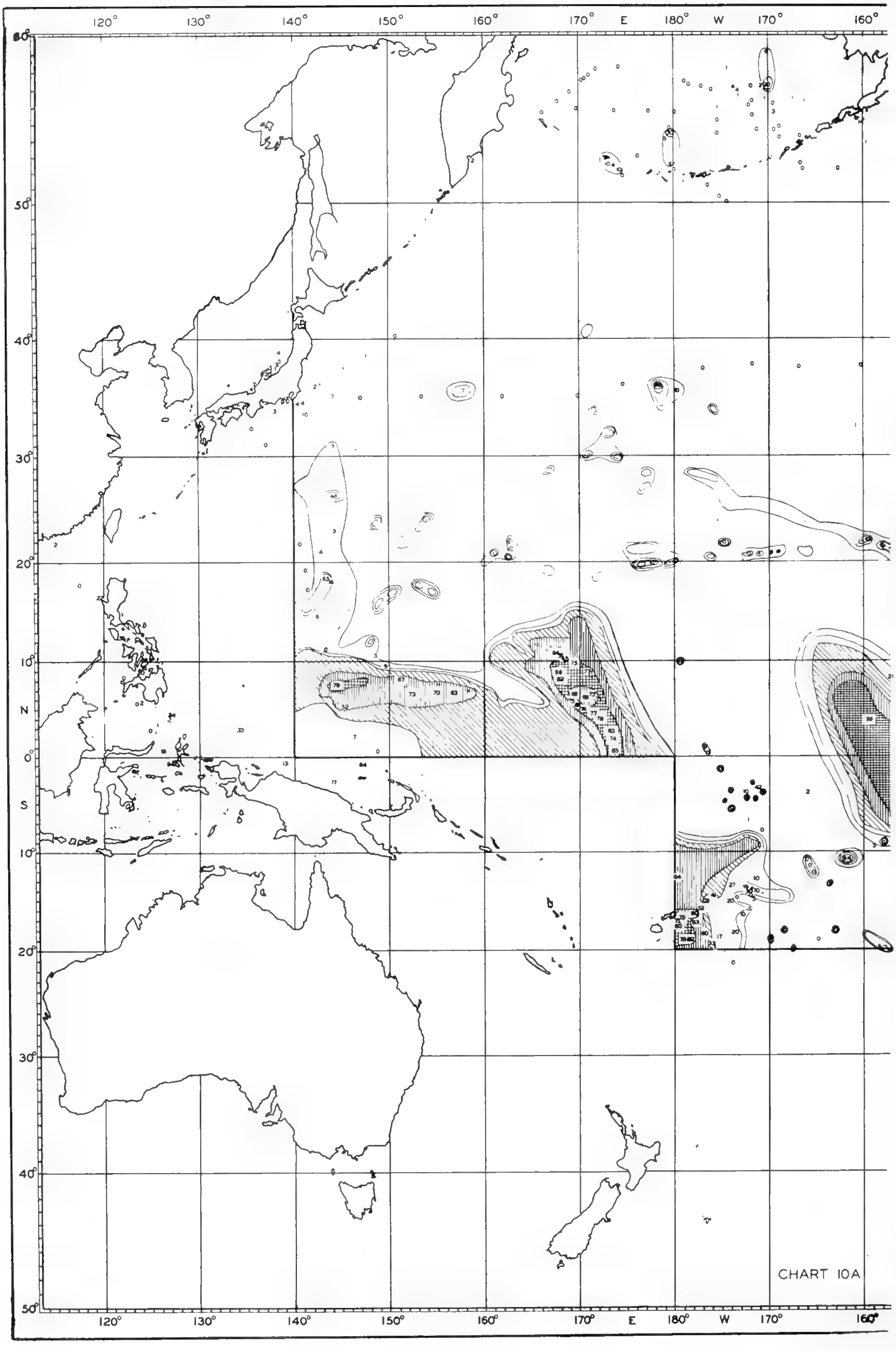

120°
130°
140°
150°
160°
170°
E
180°
W
170°
160°
60°
50°
40°
30°
20°
10°
N
0°
S
10°
20°
30°
40°
50°

CHART 10A

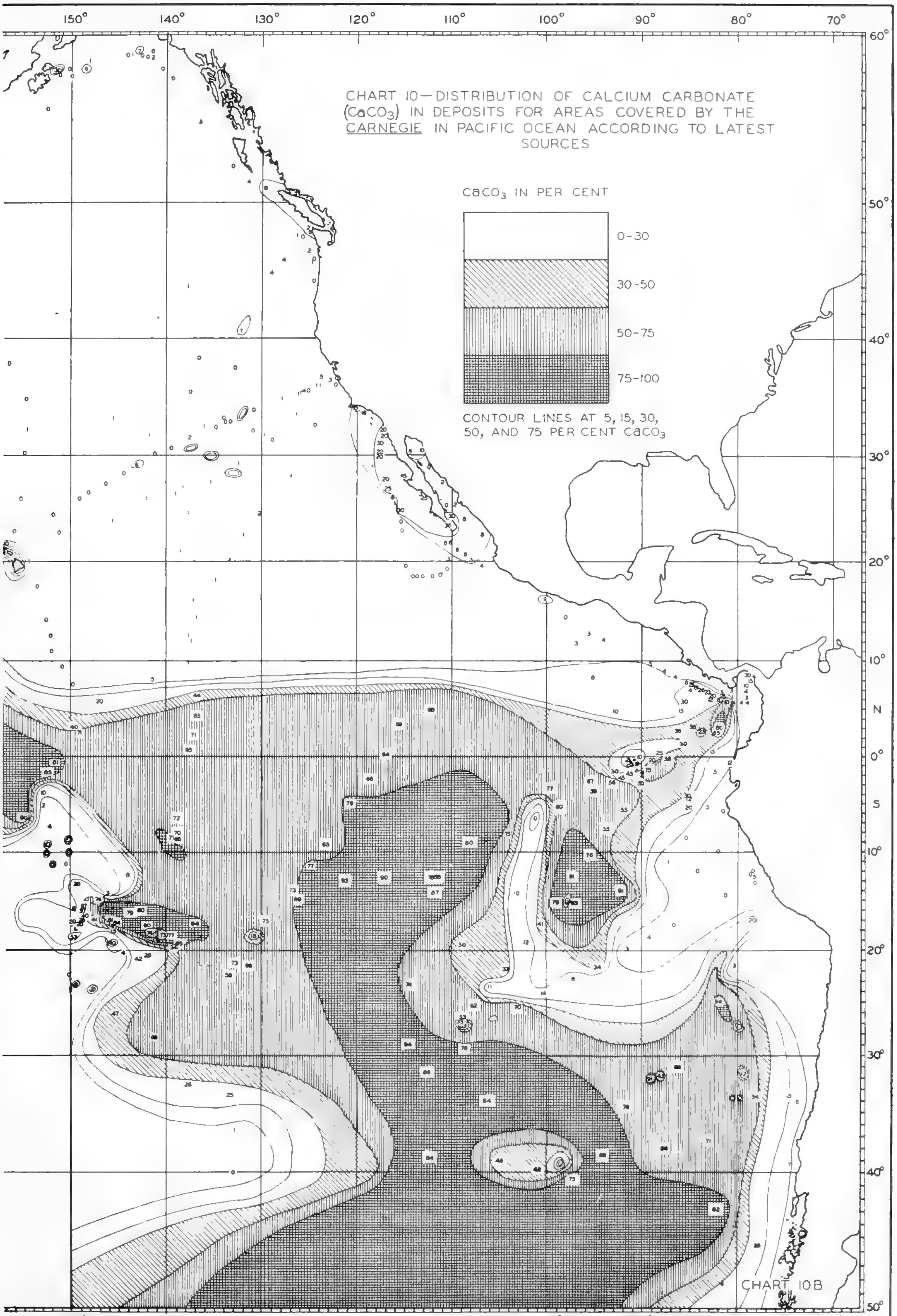


CHART 10—DISTRIBUTION OF CALCIUM CARBONATE ($CaCO_3$) IN DEPOSITS FOR AREAS COVERED BY THE <u>CARNEGIE</u> IN PACIFIC OCEAN ACCORDING TO LATEST SOURCES

PLATE I

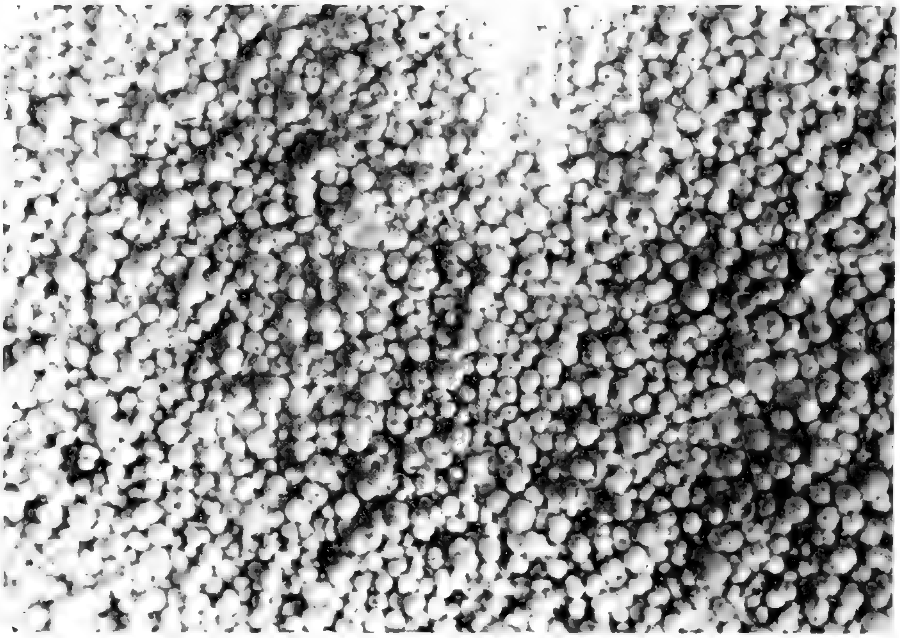


Fig. 1. Sample 85, Globigerina ooze, south central Pacific, depth 2614 meters; 0.25- to 0.12-mm size grade; entire shells of immature pelagic foraminifera ($CaCO_3$ content of sample, 94 per cent)

Fig. 2. Sample 43, Globigerina ooze, southeast Pacific, depth 3631 meters; 0.25- to 0.12-mm size grade; mostly entire shells of immature pelagic foraminifera ($CaCO_3$ content of sample, 89 per cent)

PLATE II

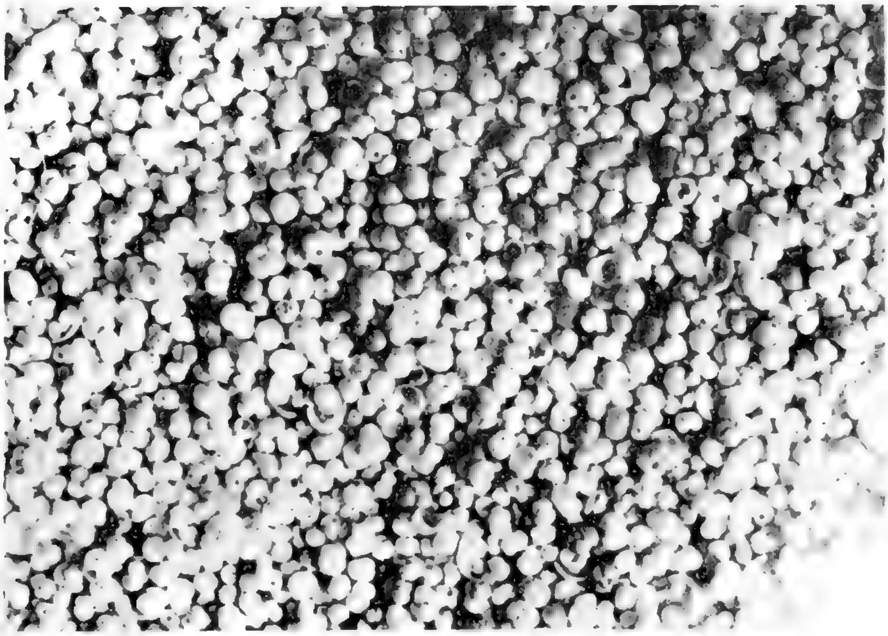


Fig. 1. Sample 42, Globigerina ooze, southeast Pacific, depth 2953 meters; 0.25- to 0.12-mm size grade; entire shells of immature pelagic foraminifera ($CaCO_3$ content of sample, 93 per cent)

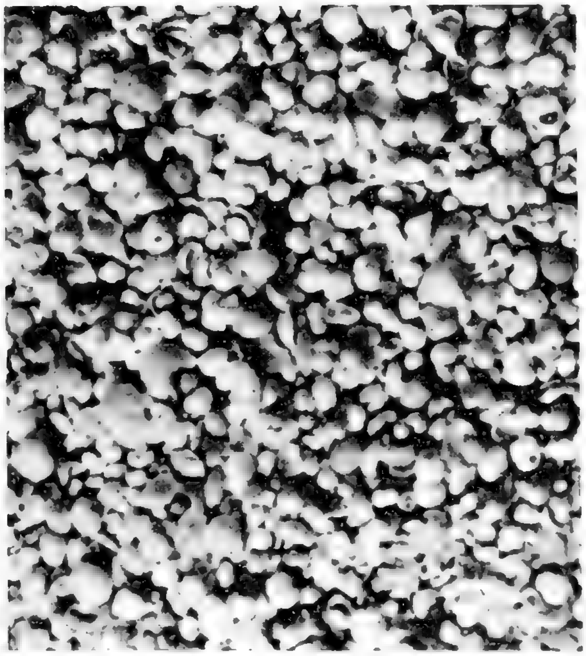


Fig. 2. Sample 29, Globigerina ooze, southeast Pacific, depth 1089 meters; 0.25- to 0.12-mm size grade; mostly entire shells of pelagic foraminifera ($CaCO_3$ content of sample, 94 per cent)

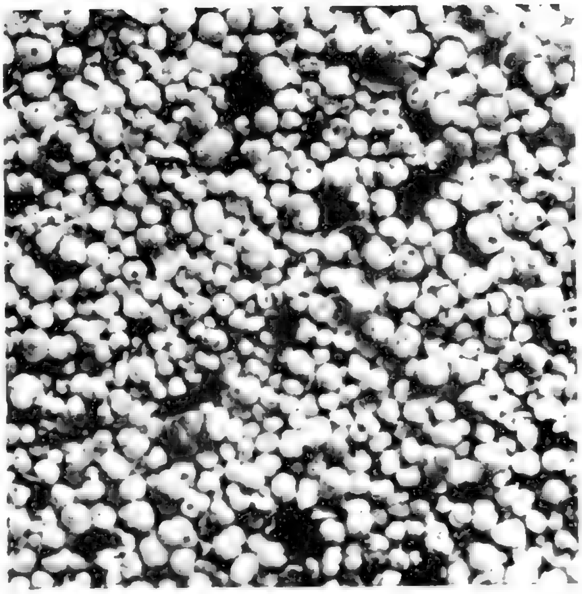


Fig. 3. Sample 17, ferruginous (volcanic) Globigerina ooze, southeast Pacific, depth 3098 meters; 0.25-to 0.12-mm size grade; entire shells of immature pelagic foraminifera, a few benthonic foraminifera, shards of basic volcanic glass ($CaCO_3$ content of sample, 74 per cent)

PLATE III

Fig. 1. Sample 82, siliceous Globigerina ooze, central Pacific; depth 4693 meters; 0.25- to 0.12-mm size grade; broken shells of pelagic foraminifera, a few echinoid spines ($CaCO_3$ content of sample, 85 per cent)

Fig. 2. Sample 62, red clay, northeast Pacific, depth 3806 meters; 0.25- to 0.12-mm size grade; mostly broken shells of pelagic foraminifera, radiolaria, sponge spicules ($CaCO_3$ content of sample, 7 per cent)

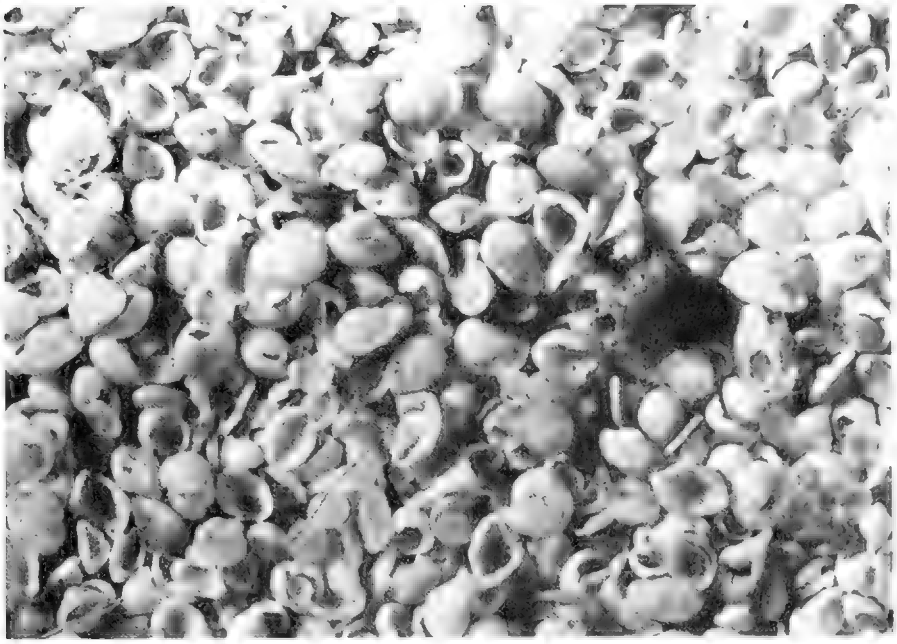


Fig. 1. Sample 81, siliceous Globigerina ooze, central Pacific, depth 4953 meters; 0.5- to 0.25-mm size grade; broken and entire shells of pelagic foraminifera, including Globorotalia tumida and Pulleniatina obliquiloculata, arenaceous foraminifera, radiolaria, sponge spicules, manganese grain ($CaCO_3$ content of sample, 40 per cent)

Fig. 2. Sample 22, ferruginous Globigerina ooze, southeast Pacific, depth 4116 meters; 0.5- to 0.25-mm size grade; broken and entire shells of pelagic foraminifera, including Orbulina universa, Globorotalia truncatulinoides, Globigerina conglomerata, inflata, rotundata, Globigerinoides conglobata, benthonic foraminifera, including Pyrgo fragment, Lagena seminiformis, Uvigerina sp.; abundant manganese grains ($CaCO_3$ content of sample, 42 per cent)

PLATE V

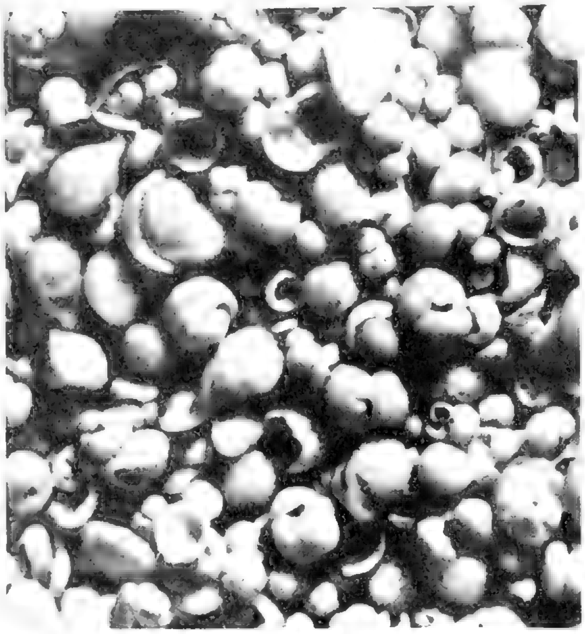


Fig. 1. Sample 45, ferruginous Globigerina ooze, southeast Pacific, depth 3791 meters; 0.5- to 0.25-mm size grade; mostly entire shells of pelagic foraminifera, including Globorotalia tumida, Globigerina rotundata, Pulleniatina obliquiloculata ($CaCO_3$ content of sample, 94 per cent)

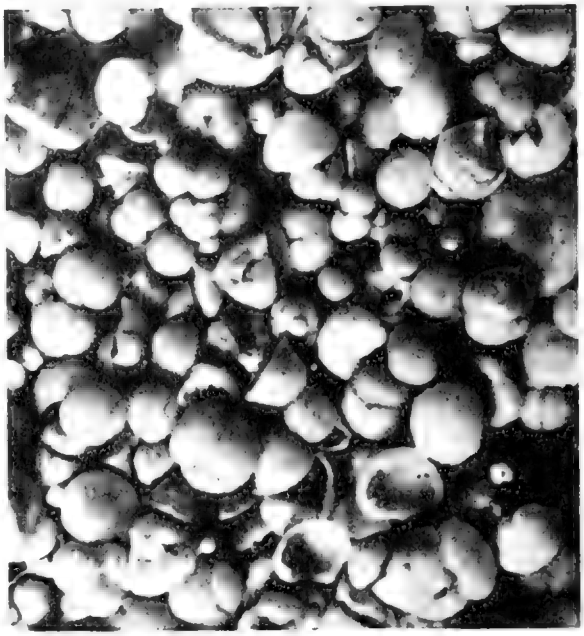


Fig. 2. Sample 19, ferruginous Globigerina ooze, southeast Pacific, depth 2851 meters; part greater than 0.12 mm in particle-size; entire shells of pelagic foraminifera, including Globorotalia truncatulinoides, Globigerinoides conglobata, Globigerina rotundata ($CaCO_3$ content of sample, 86 per cent)

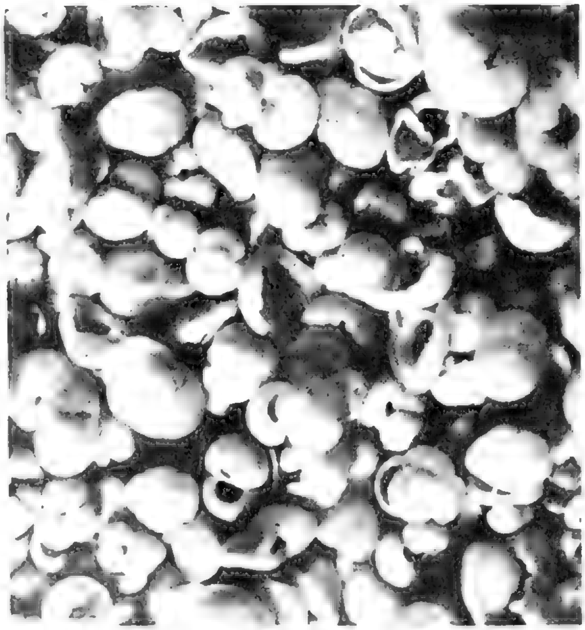


Fig. 3. Sample 44, Globigerina ooze, southeast Pacific, depth 3966 meters; 0.5- to 0.25-mm size grade; entire and broken shells of pelagic foraminifera, including Globorotalia tumida and menardii, Globigerina conglomerata, Globigerinoides sacculifera, Pulleniatina obliquiloculata, Orbulina universa ($CaCO_3$ content of sample, 75 per cent)

Fig. 4. Sample 31, siliceous (calcareous) red clay, southeast Pacific, depth 3657 meters; 0.5- to 0.25-mm size grade; broken and entire shells of pelagic foraminifera, including Globorotalia tumida, Globigerina conglomerata and inflata, Globigerinoides conglobata, Orbulina universa; arenaceous foraminifera; benthonic calcareous foraminifera, including Unigerina proboscidea; radiolaria, and sponge spicules ($CaCO_3$ content of sample, 20 per cent)

PLATE VI

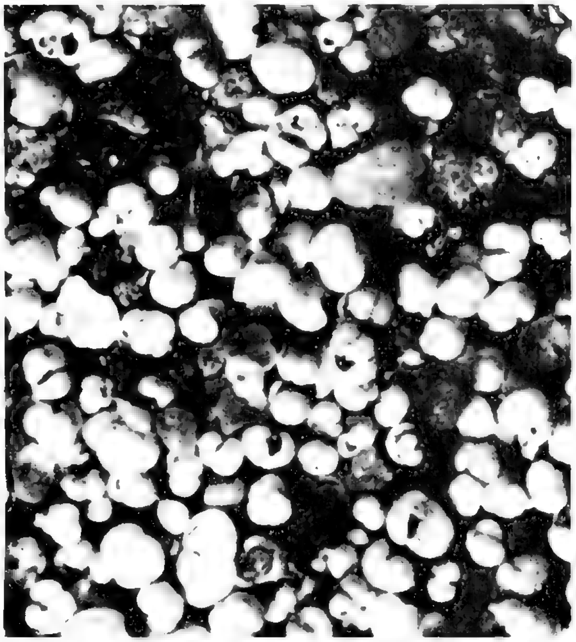


Fig. 1. Sample 54, brown volcanic mud, northeast Pacific, depth 6008 meters; 0.25- to 0.12-mm size grade; grains of pumice and volcanic glass, radiolaria, sponge spicules ($CaCO_3$ content of sample, 5 per cent)

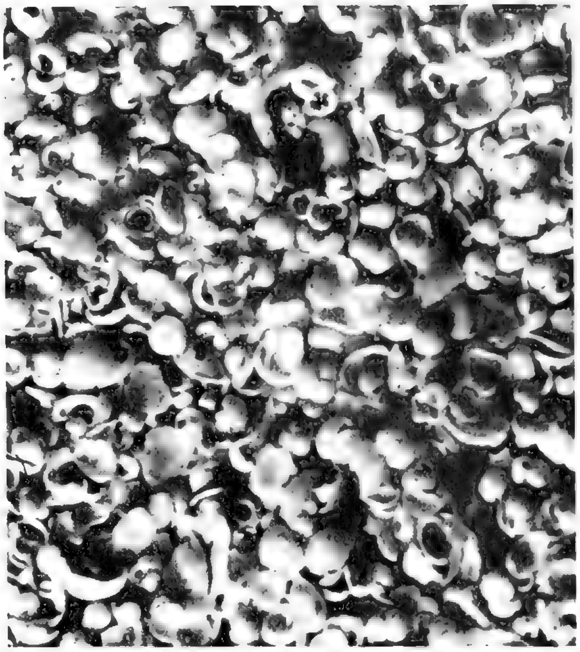


Fig. 2. Sample 44, Globigerina ooze, southeast Pacific, depth 3966 meters; 0.25- to 0.12-mm size grade; mostly broken shells of pelagic foraminifera together with some unbroken young forms ($CaCO_3$ content of sample, 75 per cent)

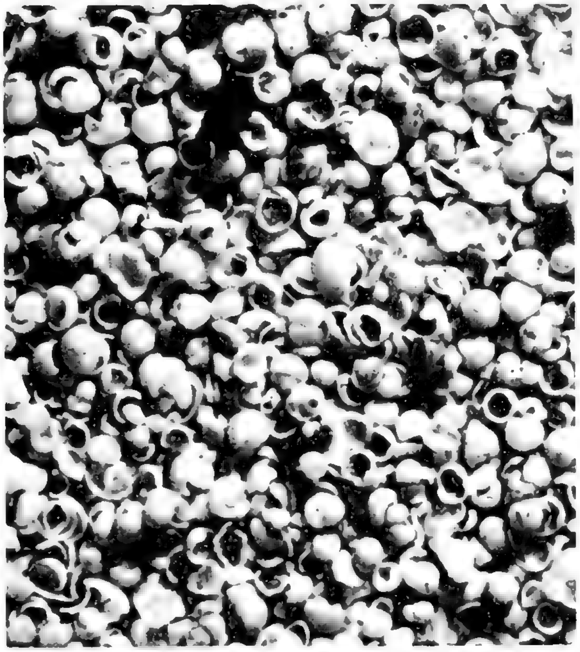


Fig. 3. Sample 23, Globigerina ooze, southeast Pacific, depth 4007 meters; 0.25- to 0.12-mm size grade; entire and broken shells of pelagic foraminifera and common benthonic foraminifera including Eponides, Pulvinulinella and Uvigerina; few manganese grains ($CaCO_3$ content of sample, 75 per cent)

Fig. 4. Sample 31, siliceous (calcareous) red clay, southeast Pacific, depth 3657 meters; 0.25- to 0.12-mm size grade; mostly broken shells of pelagic foraminifera; benthonic foraminifera, including Pullenia; radiolaria and skeletons of sponge spicules ($CaCO_3$ content of sample, 20 per cent)

PLATE VII

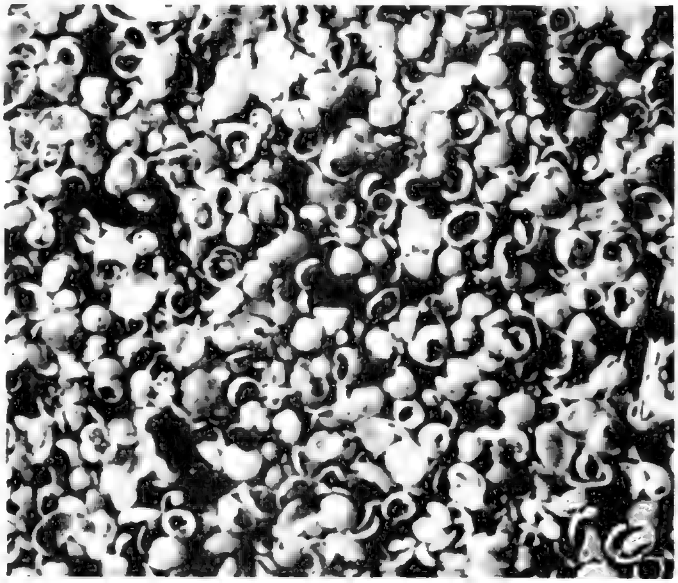


Fig. 1. Sample 22, ferruginous Globigerina ooze, southeast Pacific, depth 4116 meters; 0.25- to 0.12-mm size grade; broken and entire shells of pelagic foraminifera; common benthonic foraminifera including Eponides, Pulvinulinella and Lagena; abundant manganese grains ($CaCO_3$ content of sample, 42 per cent)

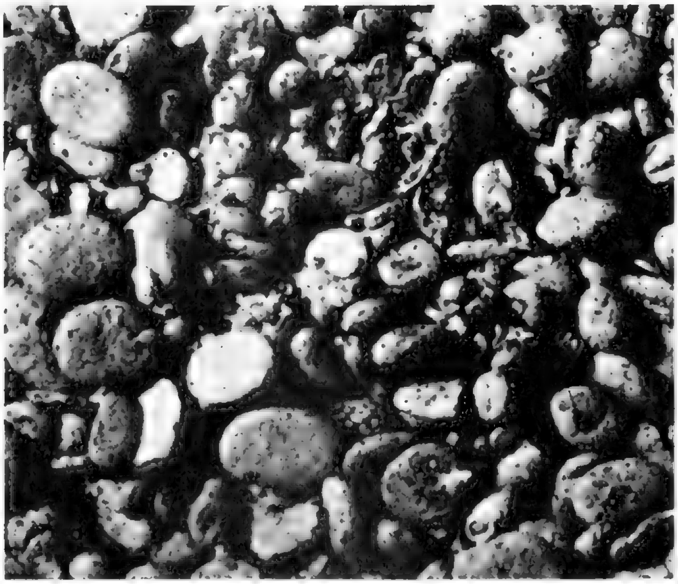


Fig. 2. Sample 10, green (coprolitic) mud, east central Pacific, depth 3324 meters; 0.5- to 0.25-mm size grade; faecal pellets ($CaCO_3$ content of sample, 3 per cent)

PLATE VIII

Fig. 1. Sample 51, volcanic mud, northeast Pacific, depth 3573 meters; 0.5- to 0.25-mm size grade; grains of pumice and volcanic glass; shells of pelagic foraminifera, including Globorotalia tumida and menardii, Globigerina inflata, Globigerinoides conglobata and sacculifera ($CaCO_3$ content of sample, 16 per cent)

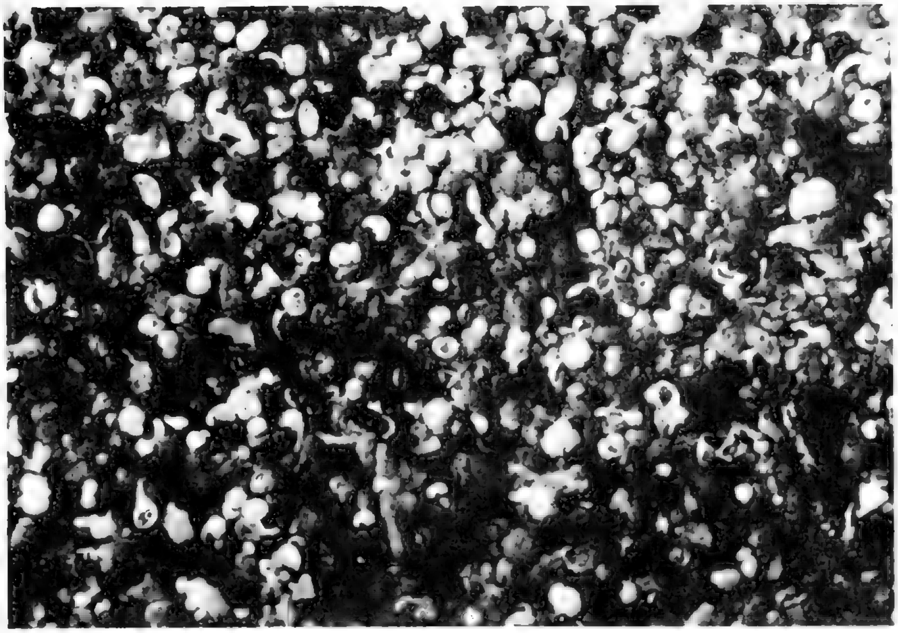


Fig. 2. Sample 51, 0.25- to 0.12-mm size grade; pumice, volcanic glass, broken and entire shells of pelagic foraminifera

PLATE IX

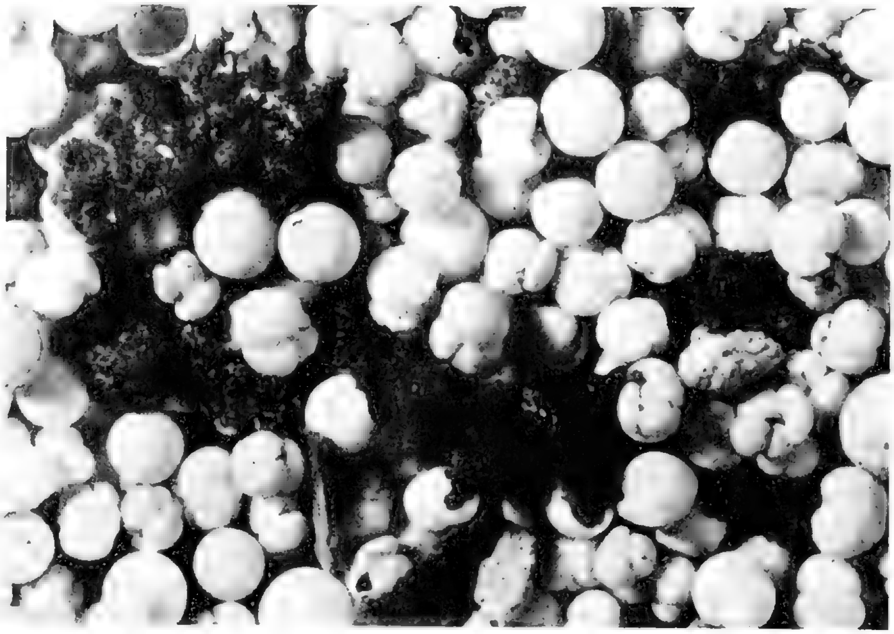


Fig. 1. Sample 17, ferruginous (volcanic) Globigerina ooze, southeast Pacific, depth 3098 meters; 1- to 0.5-mm size grade; whole shells of pelagic foraminifera, including Orbulina universa, Globigerinoides conglobata and sacculifera, Globigerina conglomerata; manganese flakes from coating of lava-fragments, volcanic glass shards ($CaCO_3$ content of sample, 74 per cent)

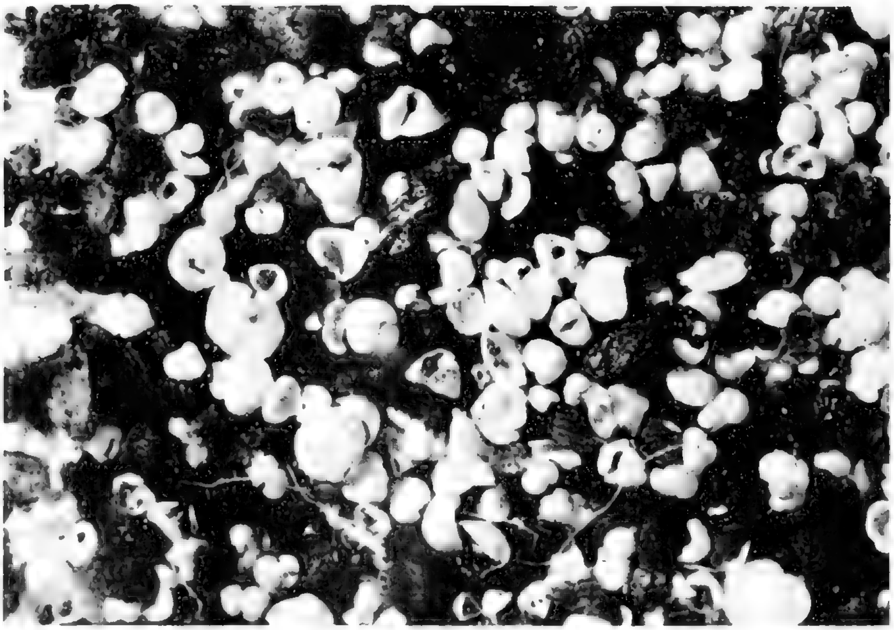


Fig. 2. Sample 53, volcanic Globigerina mud, northeast Pacific, depth 3036 meters; 0.5- to 0.25-mm size grade; volcanic glass and pumice, pelagic and benthonic foraminifera, including Globorotalia truncatulinoides and tumida, Globigerinella aequilateralis, Cassidulina fava ($CaCO_3$ content of sample, 48 per cent)

PLATE X

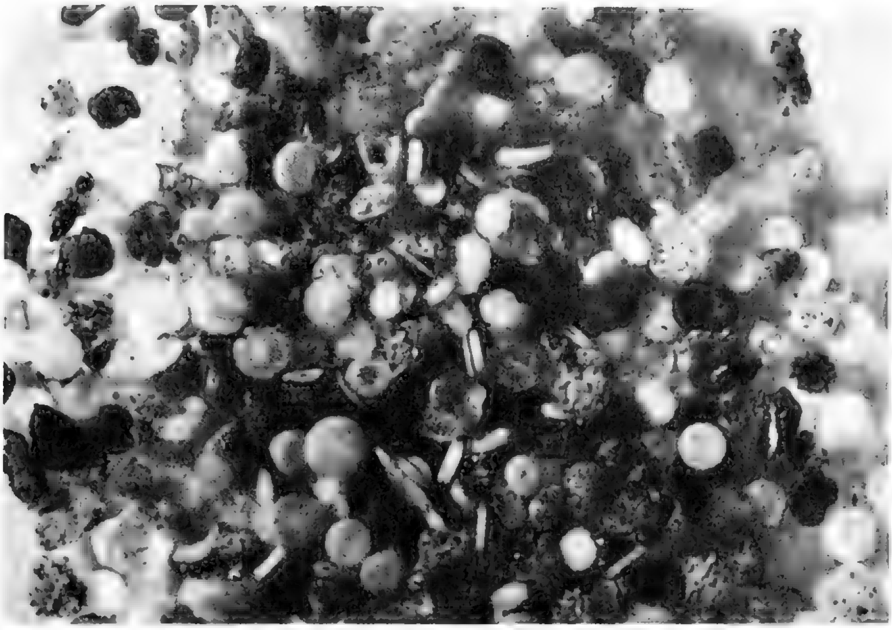


Fig. 1. Sample 59, diatom ooze, northeast Pacific, depth 5296 meters; 0.5- to 0.25-mm size grade; radiolaria, arenaceous foraminifera, diatoms, volcanic glass, fresh grains of feldspar ($CaCO_3$ content of sample, 5 per cent)

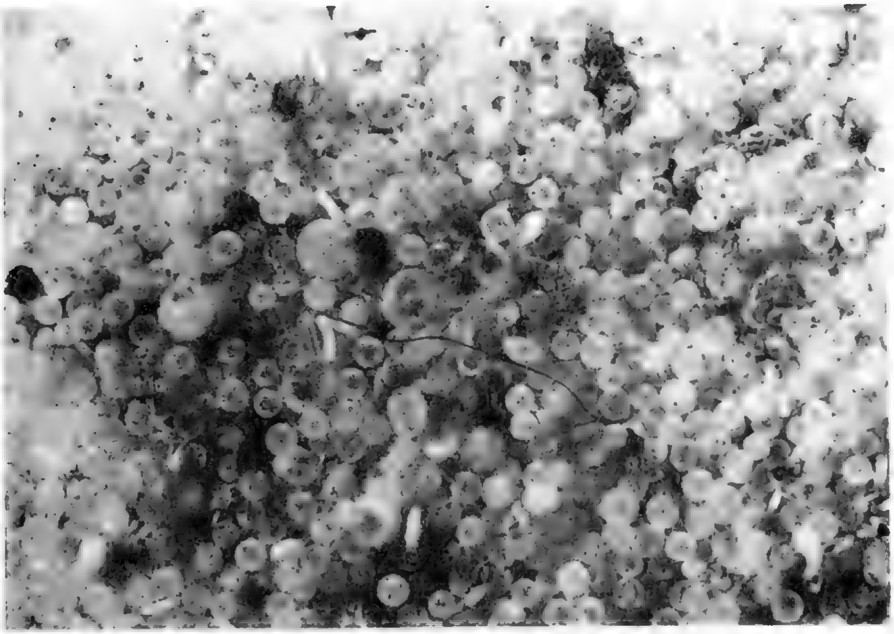


Fig. 2. Sample 60, diatom ooze, northeast Pacific, depth 5198 meters; 0.5- to 0.25-mm size grade; radiolaria and a few diatoms ($CaCO_3$ content of sample, 0.9 per cent)

PLATE XI

Fig. 1. Sample 60, diatom ooze, northeast Pacific, depth 5198 meters; 0.25- to 0.12-mm size grade; almost entirely diatom frustules (Coscinoidiscus)

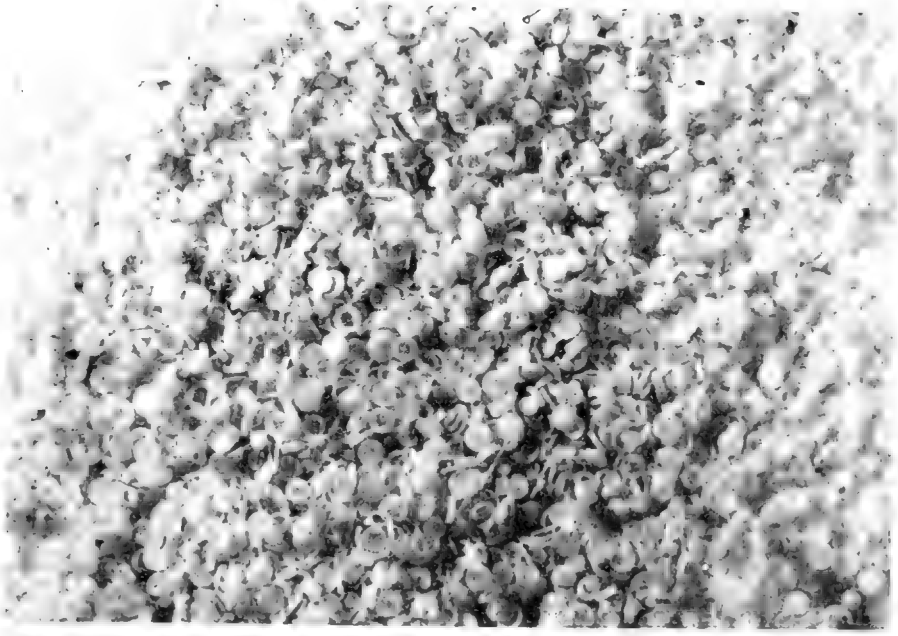


Fig. 2. Sample 59, diatom ooze, northeast Pacific, depth 5296 meters; 0.25- to 0.12-mm size grade; frustules of diatoms and skeletons of radiolaria

Fig. 1. Sample 81, siliceous Globigerina ooze, central Pacific, depth 4953 meters; 0.25- to 0.12-mm size grade; skeletons of radiolaria, sponge spicules, a few shells of pelagic foraminifera ($CaCO_3$ content of sample, 40 per cent)

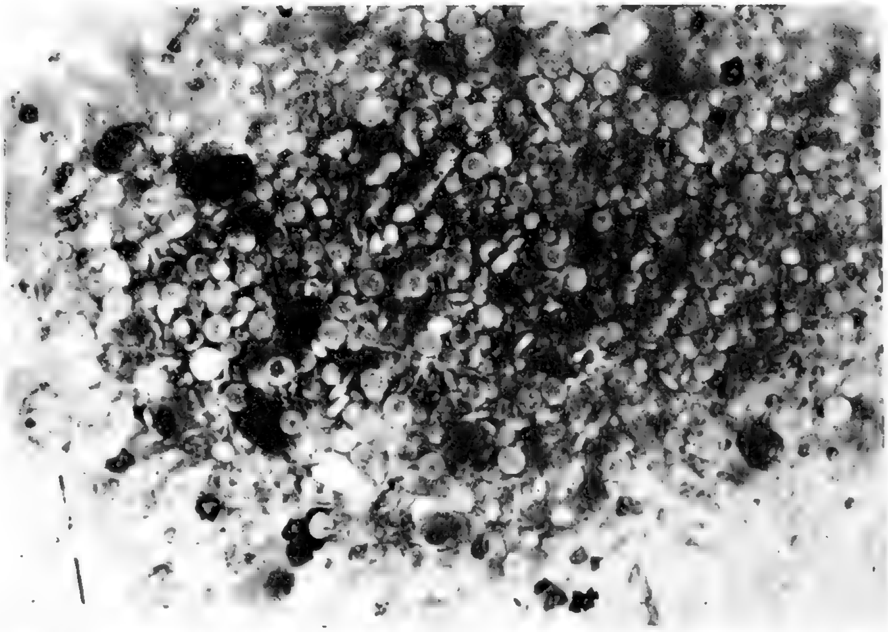


Fig. 2. Sample 61, gray clayey mud, northeast Pacific, depth 4026 meters; 0.25- to 0.12-mm size grade; skeletons of radiolaria, shells of arenaceous foraminifera, manganese flakes, volcanic glass ($CaCO_3$ content of sample, 1 per cent)

PLATE XIII

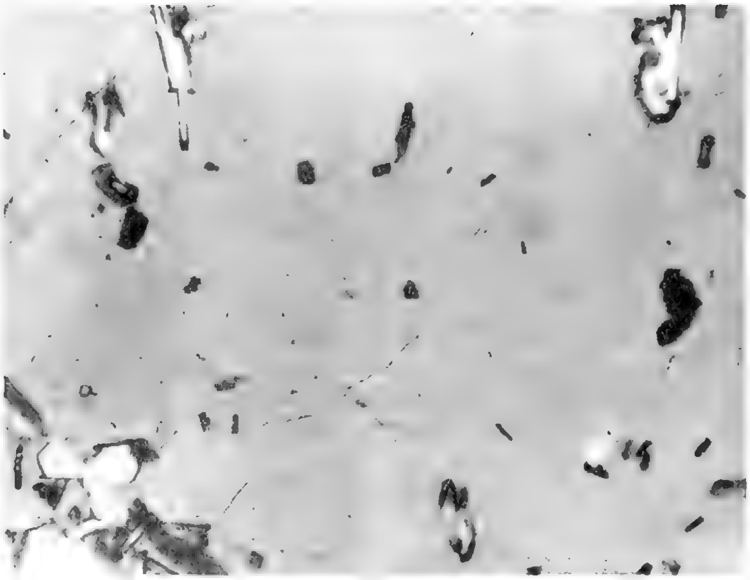


Fig. 1. Volcanic glass from sample 17; light-colored clustered and individual phenocrysts of basic plagioclase feldspar, surrounded by reaction rims; dark-colored crystals and microlites of augite and olivine; plane polarized light (× ca. 50)

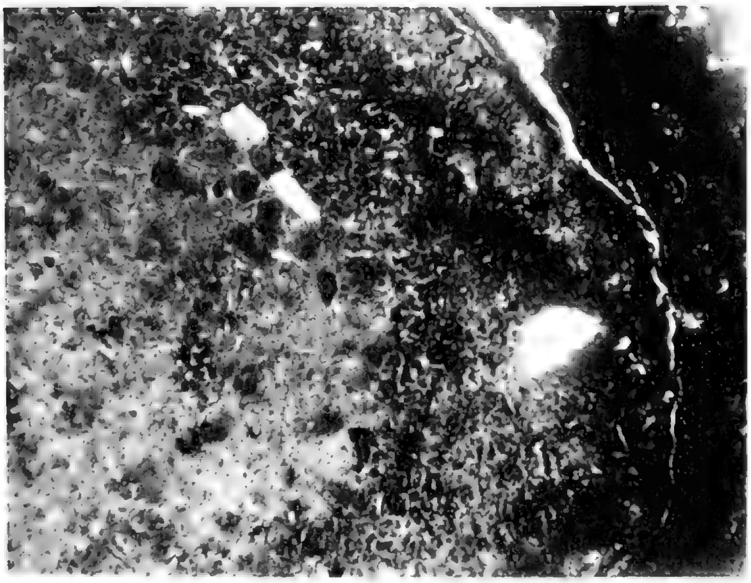


Fig. 2. Manganese-palagonite nodule from sample 57; showing alteration of light-colored spherulites of volcanic glass to darker palagonite, usually surrounded by manganese and often replaced by it; note isolated fragments of spherulites in black manganese coating, laminar distribution of manganese, and relatively clear rectangular phenocrysts of feldspar, in palagonite; plane polarized light (× ca. 20)

II. RADIUM CONTENT OF OCEAN-BOTTOM SEDIMENTS

CHARLES S. PIGGOT

CONTENTS

RADIUM CONTENT OF OCEAN-BOTTOM SEDIMENTS

Many determinations of the radium content of various rocks from many localities on the continental surfaces of the earth have been made, but very few such measurements have been made on the materials comprising the ocean-bottom sediments.

The reason is obvious, but when the vast area of these sediments is considered, and especially their high radium content, it is most desirable that more such measurements should be made. Joly (1908) has reported twelve such determinations on samples taken by the Challenger and Albatross; Hans Pettersson (1930) twenty-eight determinations on samples, some of which were from the Challenger collection and others from the collection of the Prince of Monaco which were taken by his yacht, the Princess Alice II.

Two of Pettersson's analyses were of the same Challenger sample as used by Joly, and in each case Pettersson's figure is lower than Joly's.

This accords with Joly's own opinion that his early figures were too high and he has subsequently, in some cases, revised them downward.

To these meager data the writer is able to add twenty-eight other determinations made on samples secured by the Carnegie on her last cruise.[1] Of the many bottom samples taken by the Carnegie, only those which were of sufficient bulk to permit other studies as well were used for radium determinations, since these tests, of necessity, destroy the material used.

The data of Joly and Pettersson are repeated in tables 1 and 2; those of the Carnegie samples, which with one exception (station 6) were taken in the Pacific Ocean, are given in table 3.

All these determinations are shown on the accompanying map (fig. 1). This map also indicates the character of the ocean-bottom sediment as taken from various publications on oceanography. The diameters of the circles are proportional to the radium content as reported.

The paucity of these data, when considered in relation to the vast areas covered by ocean-bottom sediments, and, furthermore, these sediments being of an unknown thickness, renders futile any general conclusions regarding their geophysical significance.

The most striking fact is the extraordinarily high concentration of radium in these sediments compared with that in ordinary rocks of the earth's structure. Whereas the average concentration in granites might be placed at about 2.5×10^{-12} grams Ra per gram of rock, and for basalts at about 1.0×10^{-12} grams per gram, the general average for all these sixty-eight determinations is the astonishingly high figure of 11.76×10^{-12} grams per gram of dry material. Some samples contain considerably more than this, such samples usually coming from the deeper parts of the bottom and those parts more remote from land areas delivering detrital material into the sea.

This high radioactivity is the more astonishing when it is remembered that the sedimentary materials of the continents, even the clays, shales, and limestones, contain less radium than do the igneous rocks (Strutt, 1907; Joly, 1912; Fletcher, 1912).

The geophysical significance of this highly radioactive material depends on the thickness of these sediments and their history subsequent to being formed. If they are of relatively shallow depth and have not become incorporated into crustal or subcrustal materials, their radium content is of little geophysical significance. If, on the other hand, they are of great thickness and have served to take such concentrations of radium into the structure of the earth's crust, their influence must be considerable either as blanketing or insulating the flow of heat into the oceans, as is necessary for Joly's thermal cycles, or as providing sources of intense energy for any part of the earth's crust within which they may become incorporated.

Obviously the elucidation of such questions awaits considerable further research, and the development of some technique which will give some idea of either the thickness of these sediments or the rate of their deposition.

The sample from Station 153 was separated into three parts by suspension in distilled water. That which settled quickly consisted of relatively coarse skeleton remains, small clay balls resembling excreta, skeletons packed with clay, and small manganese nodules in the form of black specks resembling finely ground pepper. All this first fraction was of so small amount as to be insufficient for a test run.

A second fraction was of intermediate size and remained suspended in the distilled water longer. It consisted of the bulk of the clay intermixed with broken skeleton fragments, and contained 10.92×10^{-12} grams Ra per gram of material. The third fraction remained suspended more than twelve hours and consisted of very fine clay material. It contained 10.56×10^{-12} grams Ra per gram of dry material. Apparently the treatment with distilled water removed some of the radium.

After drying, the fractions were kept for thirty days before being tested.

These tests would indicate that the uranium is fairly evenly distributed throughout the material constituting the sample. Probably the fraction containing the manganese would show a somewhat greater radium content, as these nodules are reported to be high in radioactivity (Joly, 1908). This is substantiated in the sample from Station 149. This sample contained no coarse material of the nature of skeleton remains or other debris. It consisted almost entirely of fine clay in which were a great many very small crystals. It contained enough manganese dust to concentrate and remove as a separate fraction. Though not entirely pure, this fraction was predominantly manganese nodules of very small size. It contained 11.11×10^{-12} grams of Ra per gram of dry material, which is considerably greater than the 6.04×10^{-12} gram/gram of the material as a whole.

The sample from Station 151 (plate I) contained a large manganese nodule weighing 62 grams and of 65 × 35 × 40-mm dimensions, which appeared to have formed by concentric concretions, the 40-mm dimension being the vertical one. On being sawn in two along the long dimension, the structure revealed no nucleus or starting point and reminded one very much of the appearance of tree rings. One of these "rings" was a thin layer of

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[1] The samples were made available for study through the kindness of Dr. J. A. Fleming, Director of the Department of Terrestrial Magnetism, of the Carnegie Institution of Washington.

clay which completely separated one part from the remainder. Apparently the accretion of manganese oxide had gone on, keeping the same configuration, after the coating of clay had been deposited. These features are apparent in the accompanying photographs. The sawdust obtained from sectioning this nodule contained 12.0×10^{-12} grams of radium per gram.

Various mechanisms have been suggested to account for this high concentration of radium on the ocean bottom, some of which seem to have lost sight of the fact that the significant chemistry involved is the chemistry of uranium and not that of radium per se.

It has been suggested that the concentration is brought about by the numerous minute living organisms in the sea. These extract, more or less selectively, the salts of uranium and radium from the sea water, incorporate them in their skeletons, and when they die their remains take the radioactive material to the bottom along with them. In opposition to this reasoning are the calculations of Bischof that an oyster requires the lime from

Table 1. Radium in ocean-bottom sediments collected by Challenger and Albatross (Joly)

Latitude	Longitude	Depth, meters	Type of sediment	Radium $g \times 10^{-12}$ per g
° ′	° ′			
38 34 N	72 10 W	2268	blue mud	3.1
51 37 N	12 10 W	1040	Globigerina ooze	6.6
38 06 S	88 02 W	3338	Globigerina ooze	7.4
21 13 S	14 02 W	3640	Globigerina ooze	6.7
48 17 N	39 49 W	4560	Globigerina ooze	7.0
22 11 S	133 21 W	3735	Globigerina ooze	7.1
21 04 S	133 01 W	4069	calcareous mud	22.2
10 38 N	105 47 W	3575	red clay	13.0
24 20 N	24 28 W	5010	red clay	15.4
24 28 N	149 30 W	4298	red clay	52.6
2 48 S	152 56 W	4755	radiolarian ooze	22.8
7 25 S	152 15 W	5030	radiolarian ooze	50.3
General average				17.8

Table 2. Radium in ocean-bottom sediments collected by Challenger and by Princess Alice II (Pettersson)

Latitude	Longitude	Depth, meters	Type of sediment	Radium $g \times 10^{-12}$ per g
° ′	° ′			
24 20 N	24 28 W	5011	red clay	4.3
36 48 S	42 45 W	5303	red clay	21.9
37 38 N	39 36 W	5303	red clay	49.5
26 37 N	36 35 W	5382	red clay	9.3
22 49 N	65 19 W	5413	red clay	1.5
32 18 N	23 58 W	5422	Globigerina ooze	1.4
30 50 N	27 27 W	5430	red clay	2.1
14 00 N	30 01 W	5443	red clay	3.7
25 57 N	35 08 W	5580	red clay	8.5
43 08 N	19 52 W	5930	Globigerina ooze	4.4
43 05 N	19 41 W	5940	Globigerina ooze	3.3
12 05 N	33 31 W	6035	red clay	7.8
38 06 S	88 02 W	3337	Globigerina ooze	4.9
13 28 S	149 30 W	4298	red clay	39.1
3 48 S	152 56 W	4755	radiolarian ooze	18.3
42 42 S	134 10 E	4755	red clay	9.6
25 05 S	172 56 W	5304	red clay	13.1
35 22 N	169 53 E	5303	red clay	27.2
35 18 N	144 08 E	6629	red clay	5.4
11 24 N	143 16 E	8184	radiolarian ooze	8.0
		Location or type not given		
				8.9
				4.4
				2.2
				3.9
				4.3
				6.7
				3.0
				30.3
General average				10.96

76,000 times its weight of sea water. If the uranium in this bulk of water were taken into the shelly limestones, their radioactivity would be much greater than it is found to be. If the concentration is brought about by sea organisms one would expect to find some connection between the radium content and the character of animal remains comprising the sediment. Examination of the tables and the map does not support this reasoning. Although a few high figures are associated with Globigerina or radiolaria deposits, the red clays, which are predominantly mineral in composition, show more consistently higher radium contents. If we confine our averages to the more recent analyses, we arrive at the figures given below:

27 red clays average 12.1×10^{-12} grams Ra per gram;
13 Globigerina oozes, 4.1×10^{-12} grams Ra per gram

The uranium in the sea water must come ultimately from the igneous rocks. It exists in the water in solution, and some process is operating to remove it from this solution and to cause it to accumulate in the bottom sediments at a concentration considerably greater than in the igneous rocks.

The fact that the radium concentration falls off near shore and there approaches more or less the concentration found in sedimentary rocks, indicates that the process is not one of detrital accumulation or sedimentation. Furthermore, the fact that the higher concentration is found in the red clays, which are assumed to accumulate very slowly and the minerals of which are thought to be largely formed in place, indicates that the skeletal remains of organisms tend to dilute an otherwise higher concentration.

Pettersson (1930, pp. 41, 44) does not think that the red clays are rich in uranium per se, nor does he believe that a process of extraction or precipitation from the sea water is operating, but that these high concentrations are the result of submarine volcanism associated with excessive and rather specialized hydrolytic action at that surface where hot rock and sea water meet. This explanation involves a mechanism and sequence of events which seems rather too specialized to account for the observed conditions. It is true that in the two or three core samples which Pettersson had the good fortune to secure he found a stratified condition with respect to radium content, and the high radium strata were principally volcanic debris; but a differential dilution of a continuing process is quite as likely as a sudden and unusual concentration. These observations serve to emphasize again the great desirability of the development of some technique which will produce core samples for detailed study.

Chemically, uranium, iron, and manganese are similar, in so far as their oxides are among their less soluble compounds, and it is usually in those parts of the ocean bottom where the oxides of manganese and iron are separated (as revealed by the nodules of these elements) that the uranium concentration (as revealed by the radium content) is the higher.

If we accept the radium content of sea water to be about 0.02×10^{-12} grams per cc—which is probably high -(Joly, 1908), which corresponds to a uranium con-

Table 3. Radium in ocean-bottom sediments collected by the <u>Carnegie</u> (Piggot)

Carnegie station no.	Latitude	Longitude	Depth, meters	Type of sediment	Radium $g \times 10^{-12}$ per g
	° ′	° ′			
6	50 22 N	13 31 W	2604	terrigenous	1.80
43	2 30 S	95 43 W	3352	Globigerina ooze	7.84
44	3 15 S	99 48 W	3423	Globigerina ooze	5.96
47	14 07 S	111 50 W	3080	Globigerina ooze	3.64
51	29 06 S	114 48 W	2898	Globigerina ooze	5.00
60	40 24 S	97 33 W	4007	red clay	3.20
62	34 35 S	91 52 W	3610	Globigerina ooze	4.40
63	32 10 S	89 04 W	3393	Globigerina ooze	3.40
64	31 54 S	88 17 W	3879	red clay	3.96
67	24 57 S	82 15 W	1089	Globigerina ooze	1.92
113	34 44 N	141 04 E	2911	terrigenous	1.88
115	37 40 N	145 26 E	5396	terrigenous	4.12
116	38 41 N	147 41 E	5545	terrigenous	4.76
117	40 20 N	150 58 E	5296	red clay	7.12
119	45 24 N	159 36 E	5198	diatomaceous and terrigenous	3.00
127	44 16 N	137 37 W	4026	blue mud	3.08
128	40 37 N	132 23 W	3806	red clay	9.60
131	33 49 N	126 20 W	4418	red clay	5.80
132	31 38 N	128 48 W	4251	red clay	10.40
133	29 21 N	132 30 W	4426	red clay	8.96
136	26 13 N	142 02 W	4713	red clay	9.48
137	24 02 N	145 33 W	5208	red clay	10.40
149	21 18 N	138 36 W	5320	red clay	6.04
151	12 40 N	137 32 W	4918	red clay	21.40
153	7 45 N	141 24 W	5003	red clay	16.72
156	3 01 N	149 46 W	4953	red clay	10.92
157	1 48 S	152 22 W	4693	Globigerina ooze	3.96
160	10 54 S	161 53 W	2614	Globigerina ooze	3.88
General average					6.52

centration of 6×10^{-8} grams per cc, we find that the uranium is not greatly different from other well-known metallic constituents such as:

SiO_2	1×10^{-6}	g per cc
Silver	1×10^{-7}	g per cc
Gold	6×10^{-10}	g per cc

There are probably several factors aiding in its separation and concentration in those places where it is found to be most abundant. Skeletal remains may take down some, also dust particles of volcanic or other origin adsorb some and sweep it to the bottom, but probably the greater proportion comes out as the result of oxidation. Water which is near enough to continents or shallow enough to have sufficient organic material at the bottom to maintain a slightly reducing environment tends to keep its uranium in solution, whereas the very deep bottom waters far from land do not contain organic material either washed from the land or as undestroyed organisms, consequently they afford an oxidizing environment. That these waters are oxidizing is borne out by the direct measurements of the oxygen content with depth made by the Carnegie, a typical graph of which findings is shown in figure 2. This shows that the environment at the bottom of the ocean is of an oxidizing rather than reducing nature. In the deeper parts of the ocean where there is little movement, the water at the bottom must be at saturation with respect to the oxides of uranium. There is, therefore, a tendency for them to separate out just as the iron and manganese do. Volcanic dust, detrital material, and skeletons of organisms modify the possible concentration by diluting it.

Summary

The radium content of twenty-eight (twenty-seven from the Pacific) samples of ocean-bottom sediments was determined, and similar determinations reported by Joly and Pettersson are included for comparison. These comprise practically all such determinations that have been made, and the paucity of these data in comparison with the extent, importance, and high radium content of the material is emphasized. Those bottoms composed mostly or entirely of red clay generally contain more radium. A mechanism for explaining the high radium content of deep-sea sediments is suggested which does not coincide with the opinions of either Joly or Pettersson.

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FIGURES 1 - 2, PLATE I

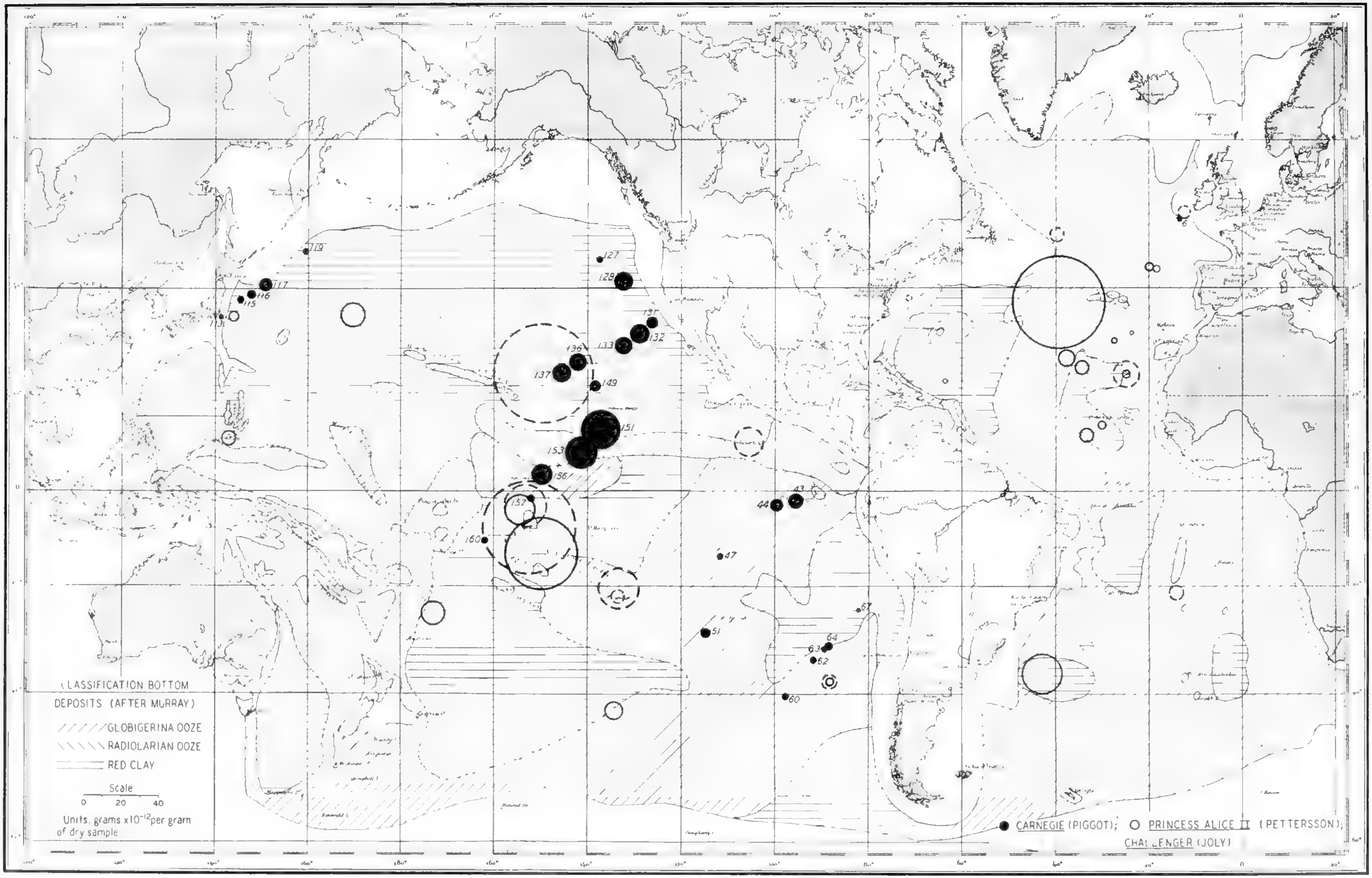

FIG. 1—RADIUM CONTENT OCEAN BOTTOM DEPOSITS

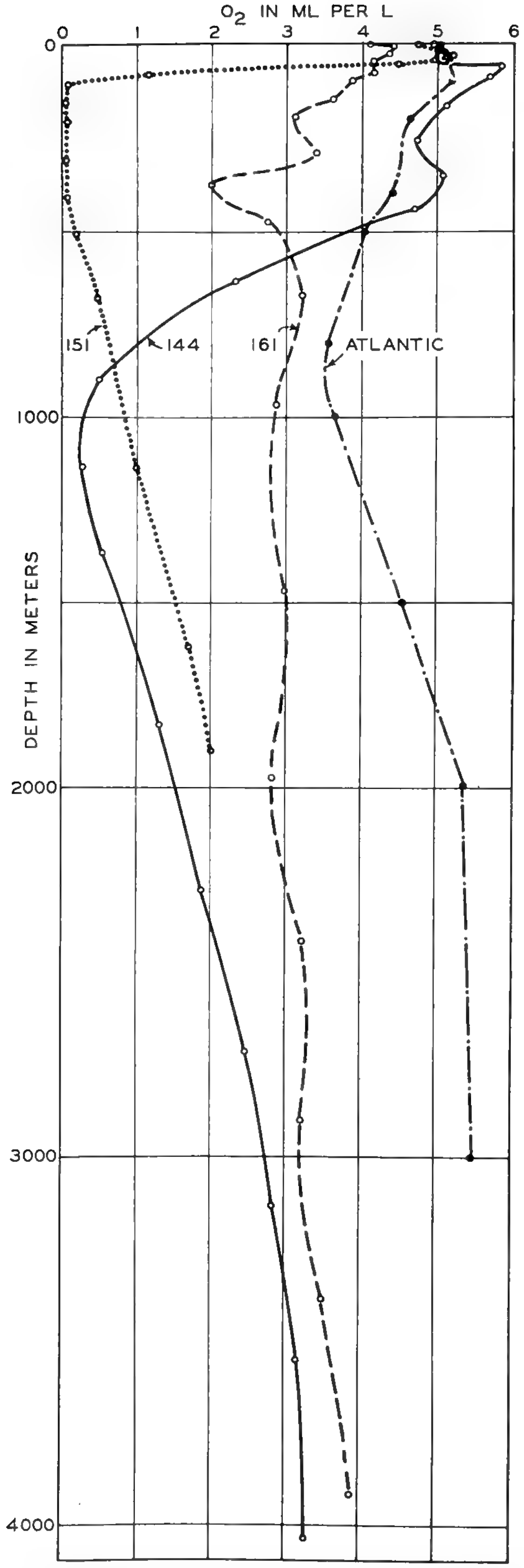

FIG. 2—THE OXYGEN CONTENT OF THE ATLANTIC AND VARIOUS PARTS OF THE PACIFIC; NUMBERS REFER TO CARNEGIE STATIONS IN THE PACIFIC

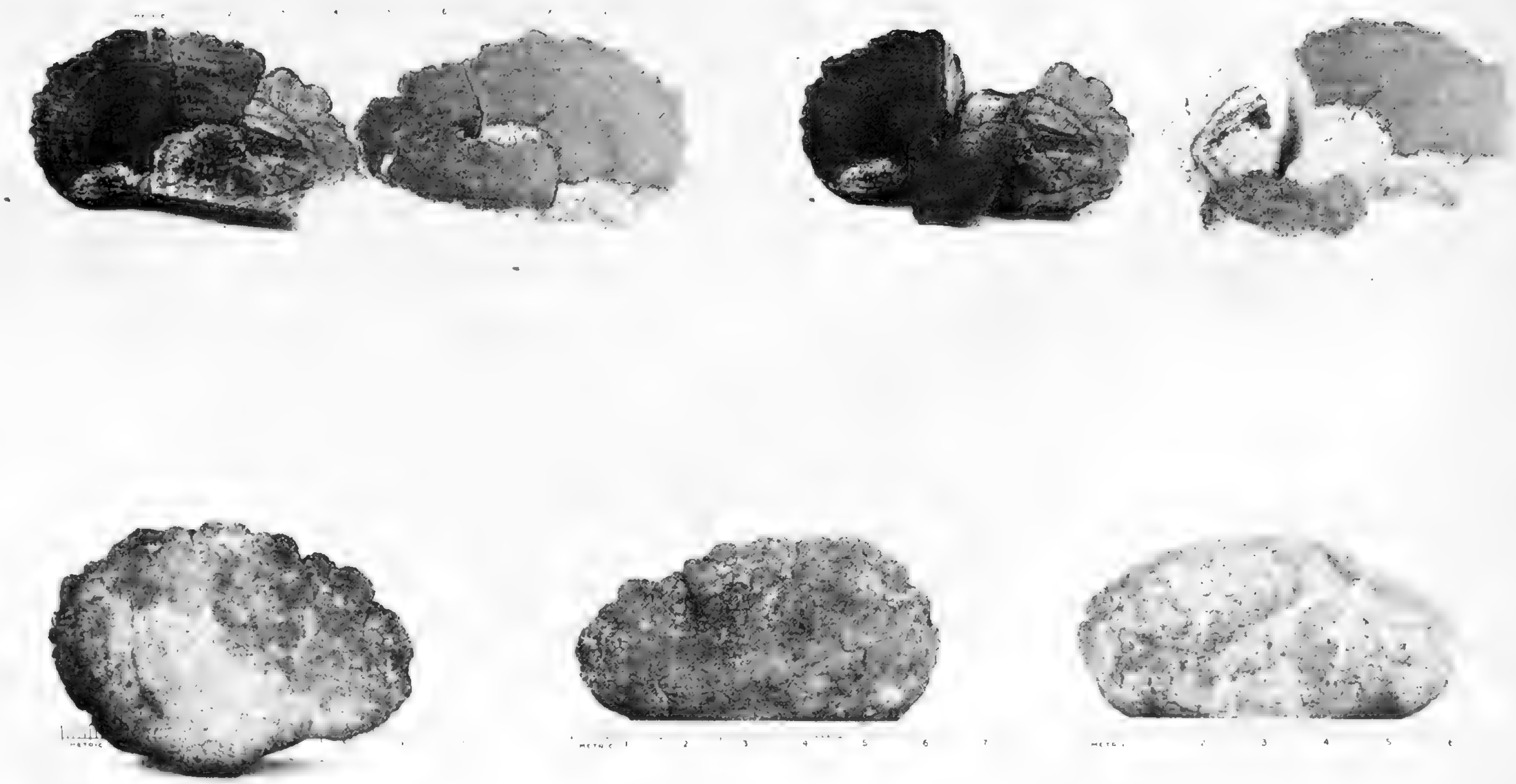

PLATE I—MANGANESE NODULE FROM CARNEGIE STATION 151; LATITUDE 12°40′N, LONGITUDE 137°32′W, DEPTH 4918 METERS, RED CLAY BOTTOM

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