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DEEP-SEA ENVIRONMENT

A thesis

Presented to

the Faculty of the Department of Geology

University of North Dakota

In Partial Fulfillment

of the Requirements for the Degree

Bachelor of Science of Geology

by

William Eugene Galambos

May 1958

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ABSTRACT

The deep-sea environment is divided into three zones: the abysso-pelagic, the abyssobenthic, and the hadal zones. The ocean floor is not a smooth featureless sedimentary plain as has been believed earlier, but instead it is of rough topography with numerous irregularites, deep depressions, many high seamounts, and elongate ridges and trenches, determined largely by tectonic movements and volcanic extrusions. The sea floor is the place of accumulation of solid detrital material of organic or inorganic origin, and it is virtually covered with unconsolidated sediments. These sediments are being deposited on the ocean floor at rates which vary from place to place and are the result of a variety of sources. The sediments are derived from continental areas, coasts, and marine life; the atmosphere, rivers, ocean currents, and ice are the media of transport. The sediments consist of muds of various colors, calcareaous and siliceaous oozes, and a distinctive red clay.

Life does exist, and abundantly in many places, in the abyssal and hadal areas of the oceans. In order for this life to exist it must adapt itself to the characteristics of its environment. Some of these characteristics are poor light, low temperature, high pressure, salinity, low oxygen content, and food.

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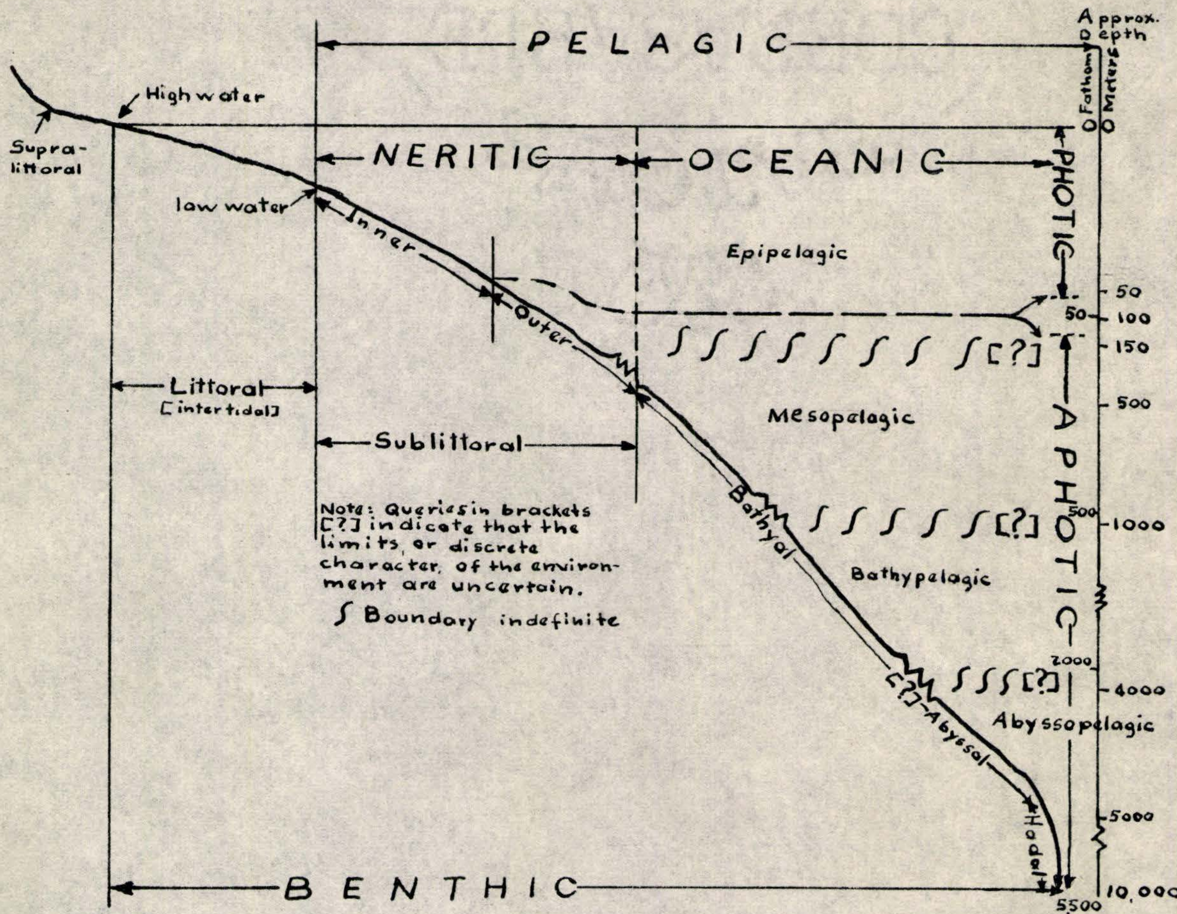
INTRODUCTION

Purpose and Scope of Report.

The aim of this report is to give a general description of the deep-sea environment. The geology and topography of the deep-sea floor and the physical, chemical, and biologic aspects of the deep-sea are discussed in detail.

Dunbar and Rodgers (1957, p. 46) say that "marine waters now cover about 70 per cent of the Earth's surface, and during much of the past they were even more extensive". The total area of the oceans and their adjacent seas is 361 million sq. km. The area of the abyss (area below 2000m) is 84 per cent of the total, or about 303 million sq. km. The area between 2,000 and 6,000 meters below the surface makes up 76 per cent of all the area , or approximately 273 million sq. km. The total land area is only slightly more than half of this (149 million sq. km.). "The total area of the globe is 510 million sq. km., so that more than half the globe is occupied by the abyss" (Bruun, 1957, p. 645).

The marine environment may be divided into two great zones: (1) the pelagic, pertaining to the subdivisions of the water above the bottom, and (2) The benthic, pertaining to subdivisions of the ocean floors. Figure 1. illustrates the two zones and their respective subdivisions. In this report the abyssopelagic, the abyssobenthic, and the hadal zones are discussed. The abyssopelagic zone is that zone which lies roughly between 2,000 and 6,000 meters, and in which the temperature is never above 4°C. The abyssobenthic zone is the complement of the abyssopelagic zone, only it is confined to the bottom. According to Hedgpeth, it was Bruun who proposed the term 'hadal' for environmental regions which are confined to deep trenches, and whose fauna have



PELAGIC (Water)
- Neritic
- Oceanic
  - Epipelagic
  - Mesopelagic
  - Abyssopelagic

BENTHIC (Bottom)
- Supra-littoral
- Littoral (intertidal)
- Sublittoral
  - Inner
  - Outer
- Bathyal
- Abyssal
- Hadal

Fig. 1. Classification of Marine Environments.
From: Hedgpeth, 1957, p. 18, fig. 1.

distinctly different characteristics from those of the above regions (Hedgpeth, 1957, p. 21). The hadal zone can also be classified as a zone which lies below about 6,000 meters of water.

The conditions of the abyss are not the same in all the oceans, A distinction must be made between the conditions of the broad ocean basins and of the mediterraneans-the deep basins enclosed within and between the continental platforms.

History of Deep-Sea Exploration.

Until recently very little research had been done in the investigation of the deep-sea. The first extensive study to any great extent was made between 1872 and 1876 by the HMS Challenger Expedition, and the information gathered during that expedition "...provided the backlog against which the geology of the sea floor has been built" (Shepard, 1948, p.2). Since that time many other expeditions have taken place, some of the more famous ones being the expeditions by the vessels Albatross (1888-1920), Meteor (post World War I), Galathea (recent), and various cruises of the Atlantis just before and since World War II. The boom in oceanographic expeditions and submarine geological expeditions came about as a result of World War II, when all the major powers carried out extensive explorations. (Shepard, 1948, p. 6).

Deep-sea research is rapidly developing, and in the next decade many advances will be made. Research in this field will influence many basic concepts in other fields of natural history. As soon as accurate bathymetric charts are made, a proper understanding of the deep-sea floor, the earth, navigation, studying of sedimentation, geophysical studies, and biological investigations can be made, and conclusions drawn (Wieseman, 1953, p. 3). Some of the problems which are being worked on by the scientists and are discussed in this report are:

1. "The morphology and stratigraphy of the deep-sea floor.
2. The general properties of the sediment carpet and its substratum.
3. The properties of the water layer next to the deep-sea floor.
4. The abyssal fauna inhabiting the deep-sea floor.
5. The organisms and processes important to deep-sea sediments." (Ovey, 1953, p. 1)

Acknowledgments.

The writer is grateful to Mr. F.D. Holland, Jr., for his assistance and supervision of the writing of this report.

TOPOGRAPHY AND GEOMORPHOLOGY OF THE DEEP-SEA FLOOR

Topography.

Until recently the general trend of thought amoung most scientists has been that the ocean floor is a vast monotonous plain with only a few mountainous masses rising above it. This idea was based on the scattered soundings which were made by the HMS Challenger Expedition between 1872 and 1876 (Shepard, 1948, p. 2). Actually, from data compiled by the many recent expeditions, the ocean floor is not a smooth featureless sedimentary plain, but instead it is of rough topography with numerous irregularities, deep depressions, many high seamounts, and elongate ridges and trenches, determined largely by tectonic movements and volcanic extrusions (Dietz, 1954, p. 258, and Shepard, 1948, p. 280).

Since the ocean floors cover a vast area only the floors of the major oceans will be discussed, with particular attention being paid to a few of the major topographic features. Shepard (1948, p. 280) says that "all of the oceans are interconnected, but there are submerged ridges which separate the three large oceans: the Pacific, the Atlantic, and the Indian".

The Atlantic

The Atlantic is the second larges ocean with an area of about 32 million square miles. It has a mean depth of 10,920 feet; this is somewhat less than the mean depth of all the oceans which is 13,440 feet. According to Shepard (1948, p. 281) "the most striking feature of the topography of the Atlantic is the Mid-Atlantic Ridge which can be traced from Iceland south to the Antarctic continent." This ridge, 300-600 miles wide and 10,000 miles long, is the longest moutain system on earth. The ridge is a continuous moutain mass, the only break being the Romanche Trench at the equator. The base of the ridge is roughly three miles below the surface and the peaks rise 10,000 feet above it, emerging above the surface and forming islands at several localities (Azores, St. Paul Rocks, etc.). Ewing (1948, p. 275) thinks that the ridge is the center of earth quakes and probably was formed by heat and pressure. Figure 3.shows a part of the Mid-Atlantic Ridge near the equator.

A second striking feature of the floor of the Atlantic is the fabulous Romanche Trench. This trench is located west of A frica's Ivory Coast, and stradles the equator in Mid-Atlantic. It is 70 miles long and 25,354 feet deep, however, the greatest measured depth in the Atlantic is not in this trench, but in the Brownson Deep north of Puerto Rico, where the depth is 28,500 feet (Shepard, 1948, p. 281). Scientists have no explanation as to the origin of the trench at that location. The rest of the worlds great depth's occur near continental coasts or strings of islands, the titanic pressure that pushed the land up pushed the deeps down. According to Cousteau (1948, p. 373) the Romanche Trench

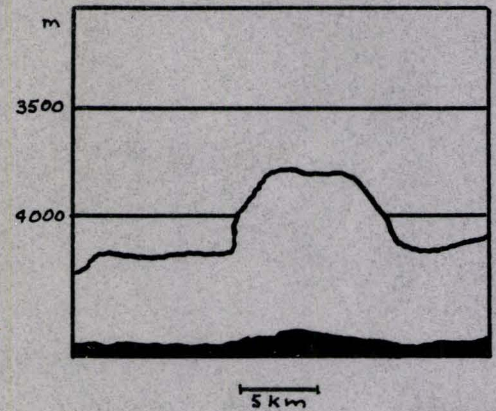


Fig. 2. Horst formation in the Eastern Pacific Ocean.

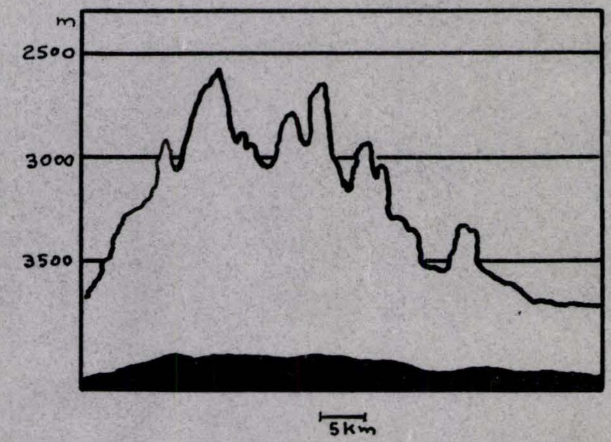


Fig. 3. A part of the Central Atlantic Ridge near the equator.

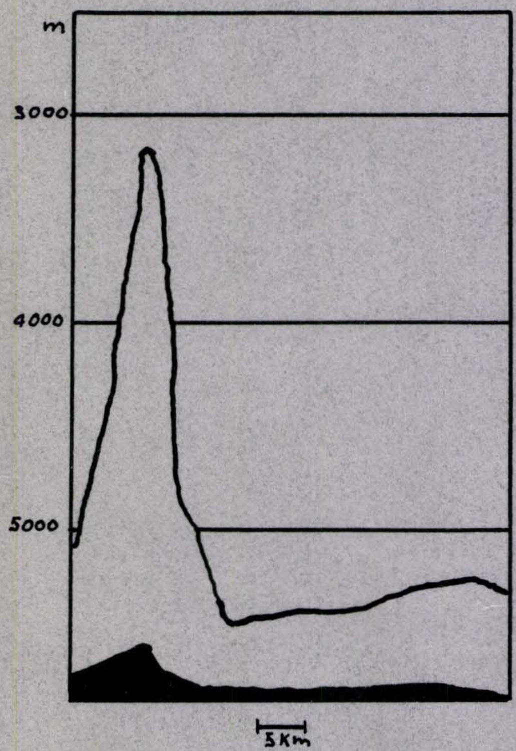


Fig. 4. Profiles across a sea mount in the Indian Ocean.

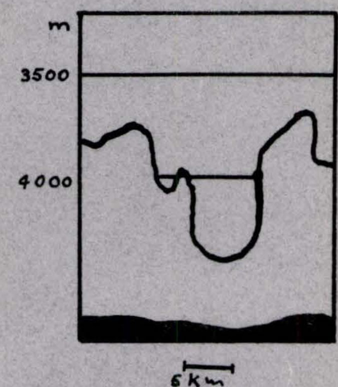


Fig. 5. A part of the Carlsberg Ridge in the Indian Ocean.

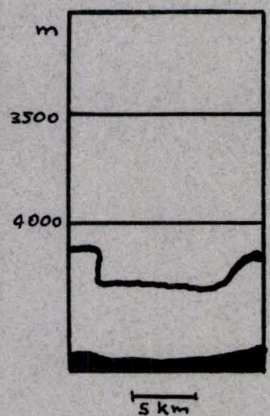


Fig. 6. A fault in the Eastern Pacific Ocean.

(From Koczy, 1954, p. 177-181, figs. 4, 7, 9, 10, and 12) lies in belt of seismic activity and it might be related to the upthrust of the Mid-A tlantic Ridge.

Another notable feature on the floor of the Atlantic, is a crack that is 20 miles wide, 2 miles deep, and 45,000 miles long. This crack was located by Maurice Ewing and his associates of the Lamont Geological Observatory in early 1957. The main line of the rift extends southward along the Atlantic from the Greenwhich Meridian in the Far North, bisecting Iceland, and running midway between North and South America on the west, and Europe and Africa on the east. It splits into two branches at the southerntip of Africa. See Figure 7. (Freeman, 1957).

Another topographic feature of the Atlantic is the North American Basin. This basin extends from the continental shelf off the north-eastern United States south to Bermuda and reaches eastward to the Mid-Atlantic (Northrop, 1954, p. 252). Minor features in the Atlantic are a number of transverse ridges which extend out from the continents on both sides (Shepard, 1948, p. 281).

The Pacific

The Pacific also has many rugged features; in fact few places can be found where the ocean floor is even. This ocean is the largest of all the oceans, occupying almost one-half of the Earth's surface (Shepard, 1948, p. 281). It has an area of 64 million square miles and a mean depth of 14,200 feet (Daly, 1942, p. 7). According to Shepard (1948, p. 283) a series of deep trenches skirt the Pacific, some of the main ones being the Japan, Marianas, Mindanao, Tongo, and Kermadec, "The deepest places yet sounded in the oceans are in the Marianas Trench in the Pacific. The Russian ship Vityaz reported in August, 1957, taking

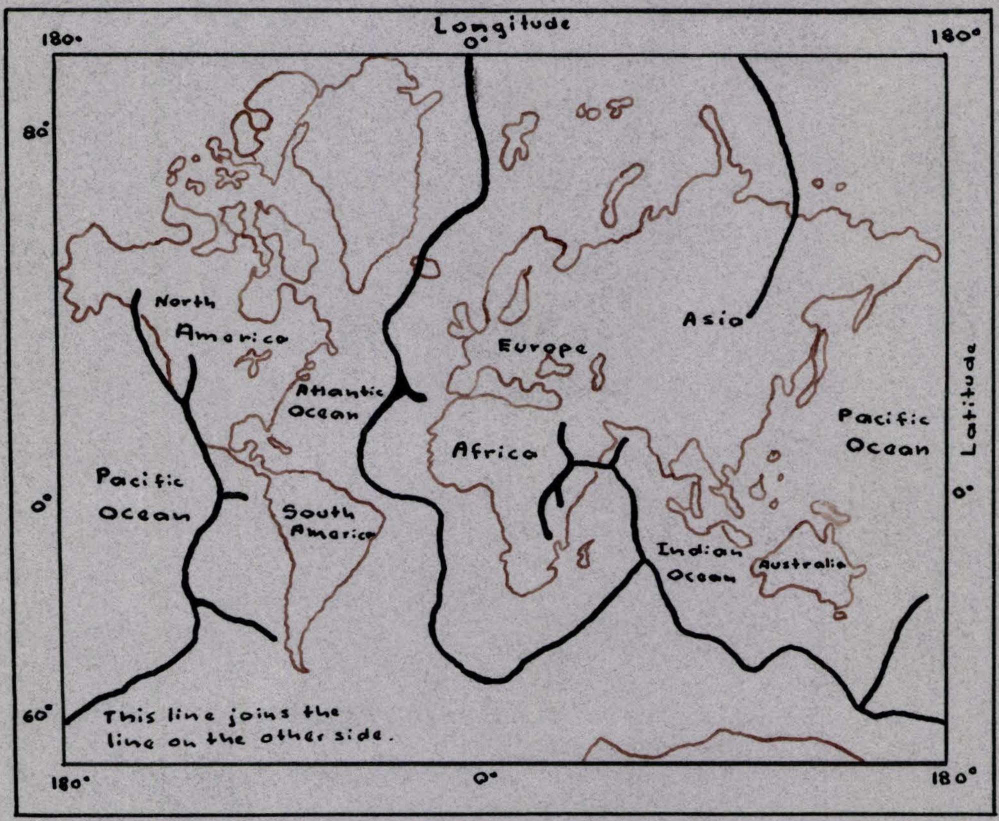


Fig. 7. Crack in the World is found at Sea.
From: Freeman, 1957, New York Times.

soundings off the Philippines that showed a depth of 35,948 feet. In October, 1951, HMS Challenger obtained a depth of 35,640 feet about 200 miles southwest of Guam." (Hansen, 1958, p. 507) From these depths one can see that the greatest oceanic depths far exceed the heights of the highest mountains on the continent. Mount Everest, the highest mountain on land, is only 29,028 feet high (Jenkins, 1927, p. 15). Shepard (1948, p. 283) says that "the nature of these deep trenches is not known, but the soundings indicate that they are relatively narrow, without any broad, flat floor". Most of the world-shaking earthquakes have their origin in these trenches.

The Pacific also contains many ridges which trend in all directions. The greatest of these are the ridges of the Hawaiian chain which lie almost in the center of the ocean and extend in a west-northwest direction for over 2,000 miles. Contrary to earlier beliefs, this ridge is not bordered by particularly deep water, the depths being about average for the Pacific. (Shepard, 1948, p. 285)

The Indian Ocean

The Indian Ocean is the smallest of the three major oceans. It has an area of 28 million square miles and a mean depth of 13,080 feet. The deepest part of the ocean is just off western Australia, and extends up along the coast of the Dutch East Indies. This ocean does not contain so many deep trenches, but it does contain a series of curving ridges on the western portion. "The Kerguelon-Gaussberg ridge virtually connects India and Antarctica and has a branch extending to Madagascar; another, the Carlsberg Ridge [see Fig. 5], runs almost at right angles to the first, extending from the Maldives, southwest of

India, to the northeastern point of Africa" (Shepard, 1948, p. 288).

Figure 8. shows a topographic profile of the floor of the Pacific and Atlantic ocean, and a comparison with the topography of the United States.

Geomorphology.

Submarine geomorphology is concerned with a number of topographic features, some of which are oceanic deeps and smaller basins, ridges, trenches, submarine canyons, seamounts, plateaus, swells, rises, and geguyots (Kuenen, 1950, p. 480). Sedimentation is also a dominant geomorphic process, but it will be discussed later. According to Thornbury (1956, p. 476) vulcanism and diastrophism are largely responsible for the major relief features on the floors of the ocean basins. Most of the features have sharp edges and express considerable angularity; this is probably due to the lack of, or reduction of, mass-wasting and weathering. That is why beneath the ocean the geomorphic features even of the smallest degree are preserved indefinitely (Thornbury, 1956, p. 476).

The features of the ocean floor can be divided into two groups, the negative and the positive.

The Negative Features

Thornbury (1956, p. 476) states that "the major negative features of the deep-sea floor are basins, trenches, and troughs". Basins are large depressions which are either circular or oval, or even elliptical in form; small depressions may be termed pits. Trenches are elongated narrow depressions with steep sides, whereas troughs are long, broad depressions with gently sloping sides. They are not to be confused with submarine canyons which are valley-like trenches on con-

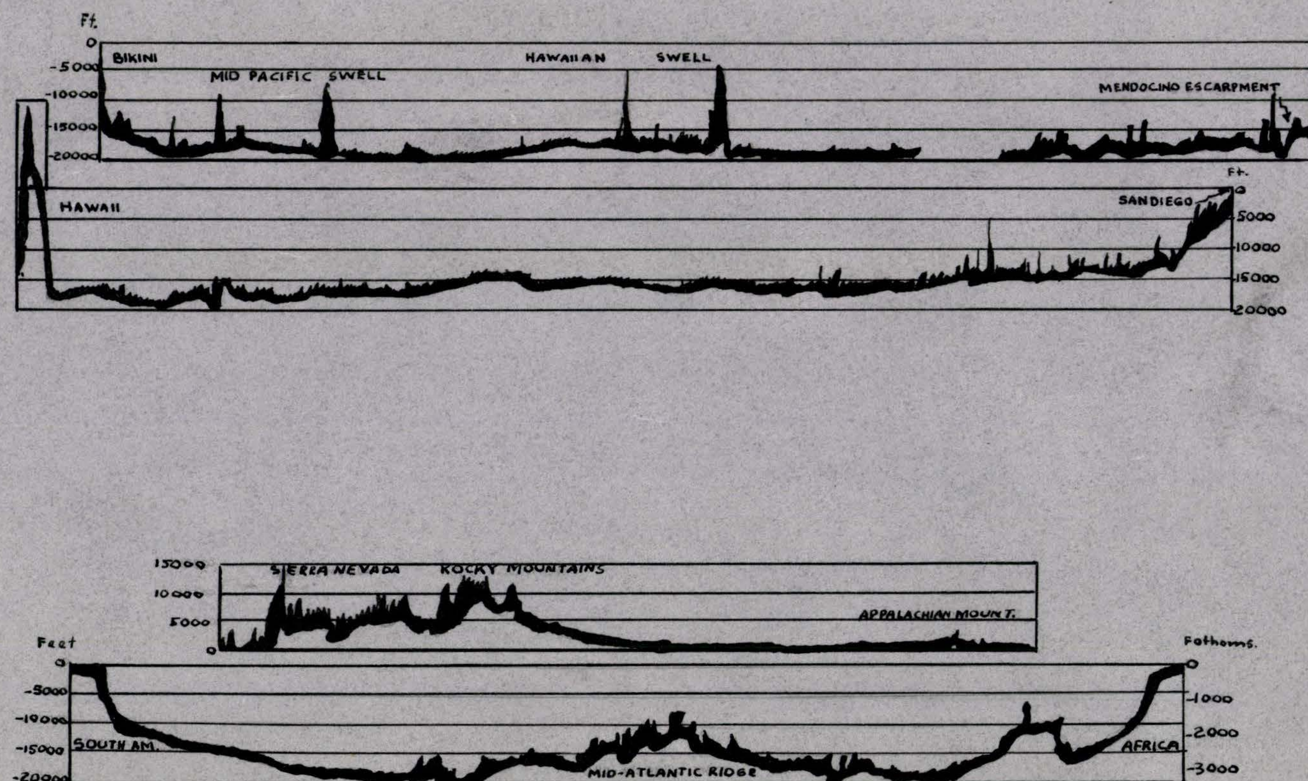


Fig. 8. Compressed profiles of portions of the bottom of the Pacific from the Mid-Pacific Expedition compared to profiles across the United States from Geological Survey topographic sheets and across the South Atlantic. Vertical exaggeration is 100 times. (From Dietz, 1954, p. 264, fig. 5)

tinental or isnular slopes. (Kuenen 1950, p. 98, and Thornbury, 1956, p. 476-478)

The Positive Features

The more prominent positive features of the deep-sea floor are ridges, rises, swells, plateaus, seamounts, and guyots. A ridge is a long narrow structure, with steep sides and rough topography. Rises are long and broad structures which rise gently from the floor; swells are almost the same, only they are smaller in height. The Hawaiian Swell is a good example of a swell [Fig. 8]. Thornbury (1956, p. 479) says that "submarine elevations of considerable extent with relatively flat tops are called plateaus". A good example of plateaus are the Azores Plateau in the North Atlantic and Albatross Plateau in the Pacific.

Lesser topographic features are seamounts and guyots. Seamounts [see Fig. 4] are isolated, conical shaped peaks that rise sharply from sediment covered plains. Some of them rise as much as 6,000 feet above the ocean floor. Northrop (1954, p. 256) thinks that seamounts are basaltic lava cones that have erupted on the ocean floor, the source of the lave being the same as that for the sima underlying the ocean basins. Guyots, or tablemounts, are flat-topped, deep-lying seamounts of more or less conical shape. This term was first used by Hess in 1946 (Howell, 1957, p. 133). Figures 2 and 6 show minor geomorphic features.

SEDIMENTS OF THE DEEP-SEA FLOOR

"The sea floor, being the place of accumulation of sloid detrital material of inorganic or organic origin, is virtually covered with unconsolidated sediments; therefore, the study of materials found on the sea bottom falls largely within the field of sedimentation, and the methods of investigation employed are those used in this branch of geology" (Sverdrup, et. al, 1942, p. 946).

In this discussion the term 'deep-sea sediments' is used in a very broad sense but generally to include those deposits which occur on the floors of the oceans below about 2,000 fathoms. Marine sedimentation is concerned with many problems, some of which are unique to the sea, and others are of more general character. Since most rocks exposed at the surface of the earth are sedimentary deposits laid down under the sea, it is important that marine sedimentation as it is going on now be investigated, so that the past history of the earth may be interpreted. (Sverdrup, et. al., 1942, p. 947)

Nature of Substratum.

Very little information has been gathered on the nature of the substratum upon which the deep-sea sediments are being deposited. The only information found by the writer was information gathered by a recent seismic exploration carried out by the Lamont Geological Observatory. This exploration took place between the eastern coast of the United States and the islands of Bermuda. Seismic reflection and refraction profiles were made by observing the velocity at which the seismic waves penetrated the sediments and the substratum. By examining these velocities in the laboratory and comparing them with continental seismic refraction and reflection velocities, conclusions were drawn as to the nature of the substratum. The basement beneath the sediments from Nova Scotia to New England is metamorphosed rock of Paleozoic and Precambrian ages, but this metamorphism decreases as one goes farther away from the orogenic belts of the continents. The basement thins and pinches out and the sediments become underlain by the simatic crust made up basaltic to ultrabasaltic rocks. "The Mohorovicic discontinuity, which is at a depth of around 130,000 ft. (40 km.) below sea level under eastern North America, is at a depth of 30,000 ft. (10 km.) under the ocean basin areas" (Officer, 1955, p. 2).

Of course no definite conclusions can be drawn as to the nature of the substratum throughout all of the oceans until further investigations are made, but one could conclude that orogenic belts probably have much to do with the type of substratum that might be present. Figures 9 and 10 show the geologic structure made from refraction and reflection profiles.

<u>Source of Deep-Sea Sediments</u>.

Sediments are being deposited on the ocean floor at rates which vary from place to place, and are the result of a variety of sources. "Viewing the earth as a whole, the main sources of sedimentary matter are the continental areas, the coasts, and marine life, while the atmosphere, rivers, icebergs, etc., are media of transport" (Kuenen, 1950, p. 210). The sources of marine sedimentary materials will be discussed under separate headings, but it should be realized that any grouping must be more or less arbitrary owing to the close interrelation of many geological processes. Moreover, it must be remembered that no sharp boundary can be drawn between the sources on one hand and the media of transport on the other. However, the writer believes that by discussing the sources first, and then transportation and sediments themselves, a clearer understanding can be gained of marine sedimentation.

GEOLOGIC INTERPRETATION OF A SERIES OF
SEISMIC REFLECTION PROFILES

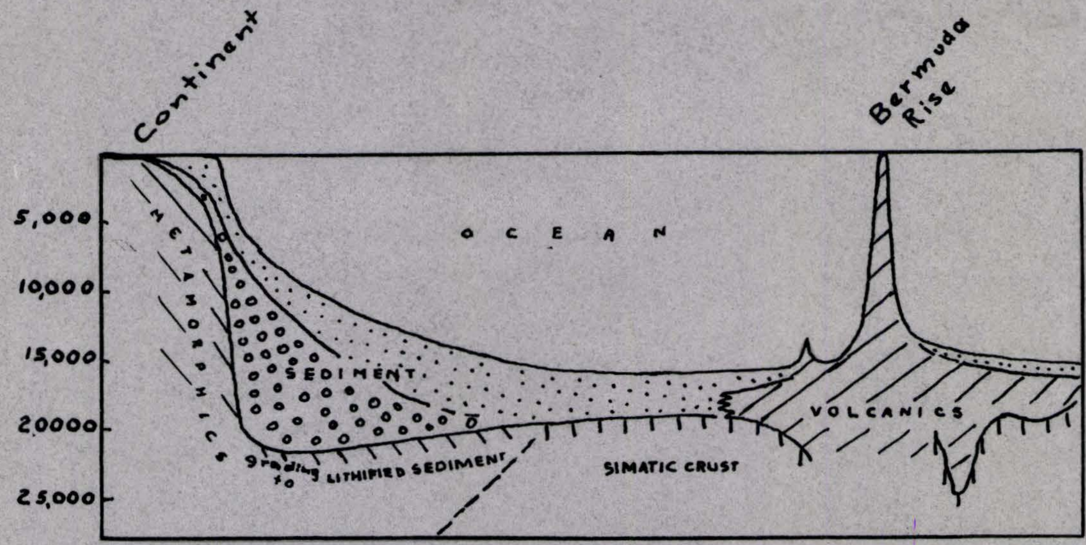


Fig. 9. Geologic structure from refraction profiles. Vertical exaggeration 160.

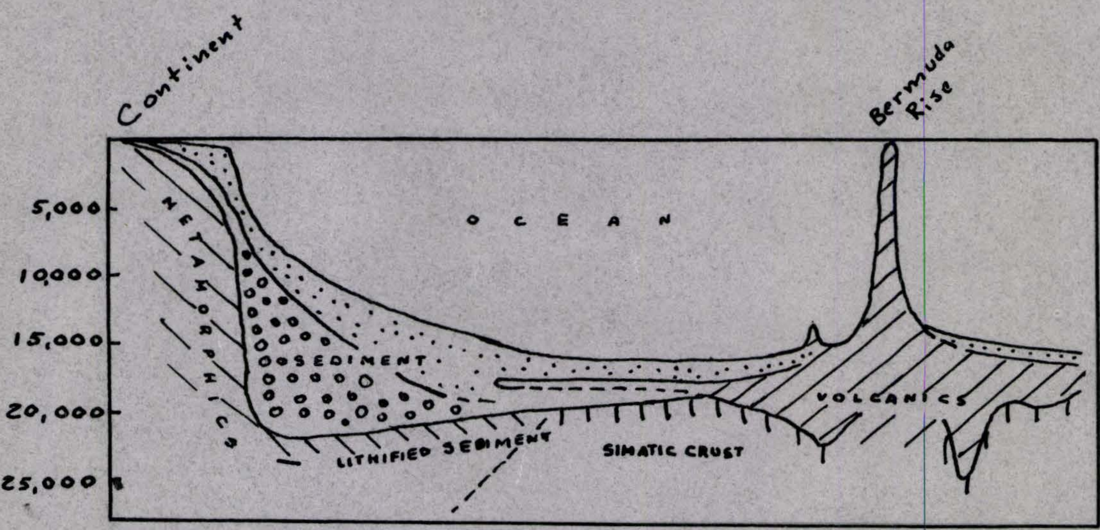


Fig. 10. Geologic structure from reflection profiles. Vertical exaggeration 160. (from Officer, 1955, p. 259, figs. 3&4)

Sources from the Atmosphere

The particles dropping from the atmosphere are of three different kinds, meteoric dust, volcanic ejecta, and wind blown deposits. Meteoric dust is of extraterrestial origin and forms a very small part of the sediment carpet. This dust is generally found in deep-sea lutites in the form of tiny globules from 1/10 to 1/2 mm in diameter. "The deep-sea deposit called red clay contains locally from 20 to 30 such spherules per liter, but in most red clays and the other types of deep sea sediments they are more scarce or even absent" (Kuenen, 1950, p. 212).

Volcanic ejecta make up a large quantity of sedimentary material on the ocean floor. During eruptions, bombs, fragments of pumice, or blocks of older rocks may be flung into the sea. These deposits are widespread, because the porous material will float before it becomes water logged and sinks to the bottom. Volcanic ash is probably the most important constituent of this type of deposit because it is thrown high into the air and then wind currents carry it all over the world before it is finally deposited. The Swedish Deep-Sea expedition in the Eastern Mediterranean during 1948 collected a series of cores down to a depth of 4,270 meters, and by correlating these cores, several volcanic ash layers were established. These volcanic ashes consist almost entirely of colorless glass fragments. By checking geologic literature on volcanic eruptions in this region, it could be possible that these ashes originated from nearby volcanoes, especially Santorin, just north of the isle of Crete. The date of the eruption is assumed to be around 1800-1500 B.C. (Mellis, 1955, p. 89).

"The third source of sedimentary particles in the atmosphere is dust and sand raised by wind on land and carried far out to sea" (Kuenen, 1950, p. 213). Some of this sand was found at depths of two and three miles; it is well sorted, with no large fragments, but varies in size. It was found 1,200 miles from land and is believed to be from 100,000 to 325,000 years old (Ewing, 1949, p. 611).

Sources from Skeletons and Tests of Organisms

Marine sediments from skeletons and tests of plants and animals make up an important part of the ocean floor. "In the deep-sea, ... it is the plankton, the drifting population of surface waters, that contributes the bulk of material to sedimentation" (Kuenen, 1950, p. 215). Diatoms play the major role in high latitudes and radiolarians in tropical waters. "The pelagic Foraminifera, especially the globigerinas, rank foremost amoung the suppliers of lime. In about half the recent deep-sea deposits the tests of these unicellular animals predominate. The tests of pteropods and loose plants (coccoliths) of a certain type of planktonic algea, the Coccolithophridea, also have a wide distribution, although they hardly ever attain to half the total bulk of a deposit." (Kuenen, 1950, p. 215)

Sources from Terrigenous Material

Disintegration and decomposition are two processes that are involved in the breaking down of terrigenous rocks of either igneous or sedimentary types. Disintegration is the mechanical breakdown and decomposition involves chemical change. Both of these processes cause rocks to be broken down into small fragments, and that way make it possible for water and wind to carry the fragments out to sea and deposit them there. The smaller the rock fragments the more likely they are to be carried out to sea, but actually those found in the sea vary from large boulders to particles of colloidal dimensions. Quartz, mica, feldspar, pyroxenes and amphiboles, heavy minerals, clay minerals, free hydroxides of iron alumina, colloidal silica, and material in various stages of transformation can be found on the ocean floors, directly the results of these two processes. (Sverdrup, et. al., 1942, p. 949)

Sources from other Materials

Marine sediments also contain sediments which are derived from various other sources. Decomposable organic matter of plants and animals, precipitation from sea water, glaciers and ice, and weathering on the sea floors are some of the sources and agents which contribute to deep-sea sediments. Through mineralogical studies new light has been thrown on the origin of the coarser mineral fragments of the sediments at great depths. "It appears that they are largely due to 'mylonization', a curshing effect of the basic rocks probably due to the differential movement of same." (Pettersson, 1953, p. 17)

Transportation of Deep-Sea Sediments.

Sverdrup, Johnson, and Fleming (1942, p. 953) say that according to Twenhofel the following agencies transport material to the sea:

1. "Rivers and streams carrying both particulate and dissolved material.
2. Rainwash, slumping along river banks and sea coasts, and large scale landslides.
3. Shoreline erosion by waves.
4. Glaciers and sea-ice carrying rock fragments.
5. Biological activity which may also increase the transport by other agencies.
6. Winds, which pick up large amounts of fine-grained debris from barren arid areas.
7. Volcanic activity, which may discharge large amounts of fine grained dust."

Most of the agencies are indirectly responsible for the movements of deep-sea sediments. Sedimentary debris which has been transported to the sea settles through the water and is at the same time carried laterally by currents, horizontal currents, currents created by storm waves, currents created by submaring slumping, and eddy currents. (Ericson, 1951). Transportation also takes place along the sea bottom. In certain places on the ocean floor erosion and transportation by bottom currents is evident. These currents displace sediment layers and are responsible for certain local occurrances of pre-Quaternary bottom sediments in or near the surface (Pettersson, 1953, p. 17). Mud flows also represent a movement of material on the sea bottom. They occur in areas where sediments are accumulating rapidly on steep slopes and break down stratification that may have developed in the deposit. Sediments are also transported by suspension, sliding, rolling, and saltation.

Classification of Deep-Sea Sediments.

According to Kuenen (1950, p. 336) deep-sea deposits may be classified in the following manner:

Hemipelagic and terrigenous sediments;
    Blue, red, yellow, green, coral, calcareaous, and volcanic muds,
(Eu) Pelagic sediments:
Calcareaous oozes: Globigerinan, pteropod, coccolith oozes.
Siliceous oozes: radiolarian, diatom oozes.
Red clay.

Shepard (1948, p. 293) also gives a classification of deep-sea deposits as suggested by Murray and Renard:

1. Pelagic deposits (formed in deep water far from land).

red clay
diatom ooze
radiolarian ooze
globigerinan ooze
pteropod ooze

2. Terrigenous deposits (formed close to the continents and made up largely of transported materials).

blue mud
green mud
red mud
volcanic mud
coral and sand mud.

Hemipelagic and Terrigenous Sediments

The mud deposits which are found in the deep oceans around the borders of the continents are not much different from those of the continental shelf and the continental slope. According to Shepard (1948, p. 298) "they consist largely of detrital silt and clays derived from the land." These muds differ from the oozes in that the silt fraction is largely of mineral grains with only small amounts of organisms.

"The muds vary widely in color. Blue colors are due to organic matter and to the alteration of the ferric sulphate to ferrous oxide or ferrous hydrate. Black muds are due to a higher amount of organic compounds and sulphides of iron present. Black muds usually have a strong hydrogen sulfide odor. Red mud contains an abundance of ferric iron oxides, indicative of oxidizing conditions in contrast to the reducing conditions of the blue muds. Green muds are characterized mostly by the presence of glauconite, although the glauconite may be so finely divided as to be detectable only by special methods of analysis. The green color is due to ferrous iron and moderate amounts of organic matter. White muds consist predominatly of calcareous material around coral islands" (Shepard, 1948, p. 298).

In the Antarctic and Arctic, deep-water sediments have been found which contain an abundance of coarse material. This mud is made up of silt rather than clay. The deposits are believed to be of glacial origin. They were transported by glaciers and icebergs and then deposited. Cores which were taken in the North Atlantic show that postglacial deposits can be identified as far as the Mid-Atlantic Ridge in the form of globigerinan ooze (Dunbar, and Rodgers, 1957, p. 57). At some places in the North Atlantic four zones of glacial marine sediments have been found; the interpretation is that each zone represents a cold or glacial stage of the Pleistocene, (Shepard, 1948, p. 299)

Pelagic Deposits

Kuenen (1950, p. 347) says that "the pelagic (or eupelagic) sediments are characterized by the absence of terrestrial mineral grains larger than the colloida l fraction. The most common constituents are clay minerals and remains of planktonic unicellular organisms." Most parts of the abyss are covered with these pelagic sediments of fine ooze or clay. Calcareous oozes cover about 128 million sq. km., siliceaous oozes 38 million sq. km., and the abyssal clay 102 million sq. km, (red clay is better called abyssal clay, because most of it is not red, but brownish). Clay is found only at depths greater than 4,000 meters and ooze at depths of less than 4,000 meters. (Bruun, 1957, p. 645)

According to Shepard (1948, p. 293) "the deposits of deep basins far from land which are low in calcium carbonate are called red clay". These clays are soft, plastic, and greasy to the touch. They cover most of the A tlantic, Indian, and Pacific ocean floors, almost entirely below 12,000 feet. The clays are fine grained, and approach the composition of the average igne ous rocks. The source of this red clay may be from windblown dust, from meteoric dust, from volcanic ashes, or from terrigenous sediments of colloidal dimensions. The red color is due to oxidation which can take place readily because the cold deep water carries free oxygen in solution and sediments which settle very slowly have ample time to be oxidized. The red clay remains oxidized because of the lack of organic matter at such great depths to use up the oxygen. (Dunbar and Rodgers, 1957, p. 57)

The deposits which contain more than 30 per cent of material of organic origin are referred to as oozes. These oozes may be divided into calcareous and siliceous oozes. Calcareous oozes generally include globigerina, pteropod, and coccolith; siliceaous oozes include radiolarians and diatoms. These oozes, like red clay, are soft. Under the microscope they reveal myriads of small shell, largely Foraminifera, Radiolaria, and diatoms (Shepard, 1948, p. 297).

Calcareous oozes contain more than 30 per cent calcium carbonate; the calcium carbonate coming mostly from planktonic animals and plants. In the globigerinan ooze the calcium carbonate is in the tests of pelagic foraminiferans; the pteropod oozes contain conspicuous shells of pelagic mollusks; coccolith oozes contains large numbers of coccoliths and rhabdoliths that form the protective structures of the minute Coccolithophoridae. Siliceous oozes are pelagic deposits which contain a large percentage of siliceous skeletal material derived from planktonic plants and animals. The diatom oozes contain large amounts of diatom frustules produced by planktonic plants. Radiolarian oozes is made up of radiolarian skeletons produced by these planktonic animals. (Sverdrup, <u>et</u>. <u>al</u>., 1942, p. 972)

Figure 11 shows the distribution of sediment types in the oceans. "The dominant bottom type sediment of the North Pacific is red clay, whereas globigerina ooze covers a little more than 50 per cent of the Atlantic, Indian, and South Pacific" (Shepard, 1948, p. 301). Radiolarian ooze is found mostly along the line of the north equatorial current, almost entirely a deep water area; pteropod ooze is found mostly near shoal portions of the Atlantic.

"Green muds are found off coasts lacking large rivers, such as the west coast of North America; blue muds are found around the continents of the Atlantic; red muds occur off the great rivers of South America and off the Yellow Sea; white muds are found around coral islands; and volcanic muds around volcanic islands which lack coral reefs." (Shepard, 1948, p. 303)

Rates of Deposition of Deep-Sea Sediments.

The same factors affect the rate of deposition in the oceanic environment as affect deposition on land: "...variations in supply of material, variations in transporting agencies, and general geographic position" (Phleger, 1949). Most studies made on rates of deposition have been made from cores. Radioactive measurements have been made of globigerinan ooze and rates have been established. Rate of sedimentation can also be determined by the ionium content of deep-sea cores. Cores can be taken which are about 20 meters in length from the deep-sea floor, and if conditions have not been disturbed in any way, an unrivalled history of the changing conditions is left for investigation. By this method the world's past climatic changes can be traced, paleocirculation of the ocean and atmosphere can be

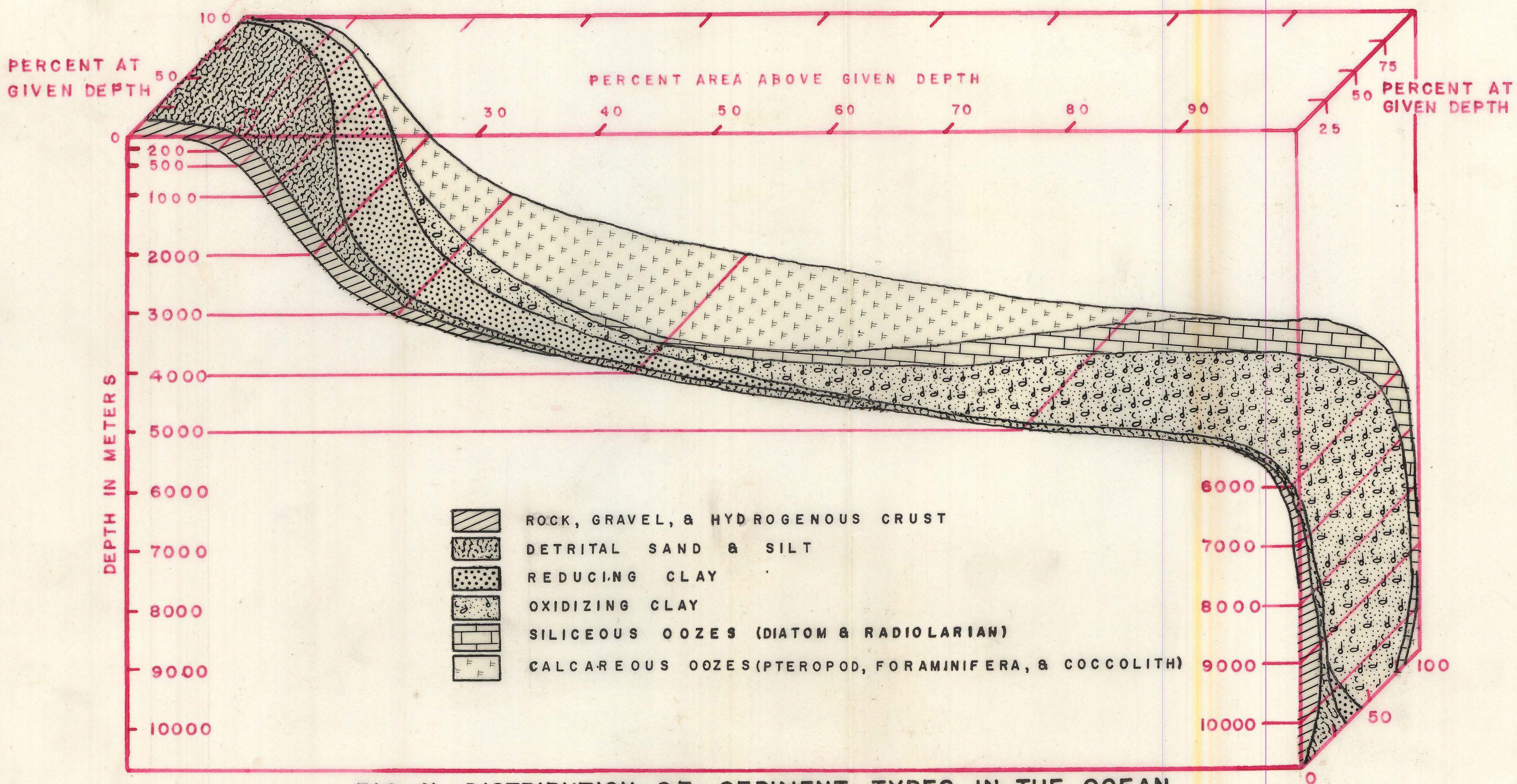


FIG. II DISTRIBUTION OF SEDIMENT TYPES IN THE OCEAN
DISTRIBUTION PLOTTED ON HYPSOMETRIC CURVE TO INDICATE APPROXIMATE PERCENTAGE OF GIVEN DEPTH AND APPROXIMATE AREA OCCUPIED BY VARIOUS INDICATED TYPES.
FROM: BRUUN, 1957, P. 668, PL. 3.

studied, the causes of climatic change can be determined, and future changes can be forecasted.

"The rate of sedimentation of the clay component has remained essentially constant with time" (Wiseman, 1953, p. 3). According to Pettersson (1953, p. 17) "the rate of sedimentation found, either from investigations of the micro-fossils in the sediments, or from radioactive measurements show that a normal rate of sedimentation in true oceanic sediments varies from a minimum in the Pacific red clay of about 1 mm (or less) in 1,000 years, to a maximum in calcareous ooze of between 15 and 25 mm in 1,000 years." In continental seas such as the Mediterranean, the rate of sedimentation may rise locally to 100 mm in 1,000 years. Rates of sedimentation could be studied ideally if cores could be taken to the bedrock in various places, and then much more accurate conclusions could be drawn.

Thickness of Deep-Sea Sediments.

Very little information is available on the thickness of deep-sea sediments, because not enough measurements have been made, however, some data is available. Under the abyssal plain portion of the North America Basin the sediments are from 3,000 - 4,000 feet thick. Under the Bermuda rise the sediments are 1,000 feet thick and are underlain by a layer of volcanics and possibly consolidated sediments, varying in thickness from 5,000 - 10,000 feet. Investigations over the continental rise from Nova Scotia to Georges Bank have shown extensive sediments of geosynclinal proportions with a maximum thickness of upward of 15,000 feet. The age is assumed to be Tertiary or Jurassic, but for the most part Upper Cretaceous. (Officer, 1955, p. 253)

Individual layers of well-sorted sands at abyssal depth far from land have been discovered in the Atlantic. Such layers have been observed at depths ranging from 2,000 - 2,700 fathoms. These layers are about a meter thick and are intermixed with layers of clay and globigerinan ooze (Ericson, 1951). At certain places in the eastern Atlantic Valley the deep-sea sediments are 3,500 meters thick. In general, the sediments in the Pacific and Indian oceans are not that thick Pettersson, 1953, p. 17).

Miscellaneous Remarks about Deep-Sea Sediments.

During a recent expedition in the Pacific, fifty-five rock fragments were dredged at about 2,700 fathoms near Jimmu Seamount, 700 miles southeast of Kamchatka. Tuffaceaous shale, andecidic and dacitic tuff, pyroxene-hornblende dacite pumice, and augite-hypersthene andesite were the most abundant rock types present. The haul also included augite-pigeonite basalt, augite-olivine basalt, olivine dolerite, quartz syenite porphry, metabasalt, sandstone, and chert. Petrographic and chemical analysis indicated a colser affinity with Kuril islands and Kamchatka volcanic rocks than with Cenozoic Japanese or Pacific Basin type rocks. These rocks were probably dropped by Pleistocene icebergs and carried south and east by ocean currents.

Of these rocks "...nineteen are flat, angular fragments of comparatively soft rocks, ten are well-rounded pumice, twenty-four are well-rounded pebbles of hard rocks, and two are ragged fragments of scoria and slagg." (Kuno, _et_. _al_., 1956, p. 126)

Rocks have also been dredged from ridges in the Indian ocean and they consisted largely of basalt, but continental rocks have also been found (Shepard, 1948).

The sediments on the bottom of the ocean are so fine that clouds of sediment are thrown up to heights of several meters following the jettisoning of iron pellet ballst on the botton (Picard and Dietz, 1957, p. 221).

Recently a new method of investigating the ocean deeps has come into use. It involves the use of the camera in taking pictures of the deep-sea. The recent Calypso Expedition (Cousteau, 1958, p. 373) used such a camera exclusively and several pictures were taken. The camera was an automatic camera in a steel-tube housing capable of withstanding pressures of $8\frac{1}{2}$ tons per square inch. A photograph at 24,600 feet, revealed an area of about nine square feet, seemingly showed terraces by submarine landslides or water currents. Thick oozes cover oceans at lesser depth, and scientists were surprised by the fresh appearance of these angularities, suggesting erosion. Another picture showed an ocean bottom of granular texture with smooth and angular pebbles at several places. The terracing could also be a result of solifluction, a slow, downward creeping of wet soil, common on land in arctic regions, but rarely attributed to submarine earth.

Several rocks of varying shades were also shown in one of the pictures which seemed to look like manganese nodules. (Cousteau, 1958, p. 373) Deep-sea photographs from the eastern and southeastern Pacific also showed manganese nodules in the clays and oozes. (Shipek, 1958, p. 45)

By studying faunas in the cores, the sequence of events can by represented. A thick layer of tropical and sub-tropical faunas about 800 - 1,000 cm thick and 4,800 feet deep in the Carribean seems to represent the second interglacial stage of the Pleistocene; this was warmer than the present stage and it is thought that it lasted 200,000 years. By assuming that this was the second interglacial stage, then the next layer above it, the sub-tropical and cool-temperature faunas represent the third glacial stage, the third interglacial, and the fourth glacial. By comparing many of these cores one can conclude that 1 cm of deposit represents anywhere from 500 - 1,000 years (Phleger, 1949).

CHARACTERISTICS OF THE DEEP-SEA ENVIRONMENT

Just like the characteristics of the continental environment, the deep-sea also has its special characteristics. Some of these characteristics are the same as those of the continents, but they are different in a sense because of the presence of water. On the continents, life depends on these characteristics, and the same is true for the oceans, therefore, before life can be discussed, it is necessary to discuss some of the factors which affect life. The major environmental characteristics which will be discussed are light, heat-flow, pressure, temperature, salinity, oxygen content, and other chemical elements.

Light.

Sunlight does not penetrate very far below the surface of the ocean. By using specially constructed instruments illumination was measured at depths as great as 610 meters. Results show that there is a uniform and high transparency for the water between 100 and 600 meters. Measurements made at night showed that the illumination decreased within the upper layers at about the same rate as during the day. At depths between 300 and 600 meters, the background light remained about constant or tended to increase. (Clarke, 1956, p. 189)

Bioluminescence is hardly of much importance and does not penetrate very far. At the surface many luminous organisms live, but they are probably rare in the deep. "Some animals, like Umbellula, produce light but the general rule that true abyssal animals have reduced eyes or are blind must mean that any form of light is sparse and of little ecological importance" (Bruun, 1957, p. 645).

Heat-Flow.

The measurement of heat-flow involves the determination of the rate of increase of temperature downward into the sediments and of the conductivity of the sediments. The conductivity is measured in the laboratory from cores collected from the bottom. According to Bullard (1954, p. 65) "the temperature gradient is determined by forcing a probe carrying recording thermometer inth the bottom." These thermometers are commected to a galvanometer in a pressure tight case. The deflection of the galvanometer is recorded on photograhic film on a rotating drum. From this information calculations can be made.

Results from measurements which have been made in the Central Pacific show that heat-flow through the ocean floor averages $1.2X10^{-6}$ cal/cm^2-sec. In the Northwestern Atlantic the average is $1.0x10^{-6}$ cal/cm^2-sec. These values are almost the same as the values found on the continents, which are $1.2x10^{-6}$ cal/cm^2-sec. These values are not to be taken at their face value since the results might be the after affects of a climatic change. (Bullard, 1954, p. 66)

Although the number of measurements made is small, it is noteworthy that most of the measurements that have been made covering a total distance of 3,000 miles, show that the computed heat-flow lies within 10 per cent of the average value for the continents.

"The heat flowing from the deep Pacific floor could represent at least in part a 'fossil' temperature gradient in the sediments, remaining from a time when the bottom-water gradient was higher than the present 1.6°C" (Revelle, et. al., 1952, p. 199). Heat might also be generated by biologic activity within the sediments, But such heat would account for only 0.05×10^{-6} cal/cm^2-sec., or 4% of the observed heat-flow. If the heat does not come from the sediments, it must come from the underlying rocks of the erath's curst and mantle. Radioactivity might also create heat.

This heat-flow through the ocean floor should heat the bottom water mass about one-tenth of a degree, but not enough observations have been made to establish this fact. (Revelle, et. al., 1952, p. 200)

Pressure.

Pressure is an important characteristic of the deep-sea. Pressure increases steadily and rapidly as depth increases. Each foot of depth adds nearly a half a pound of pressure per square inch to a body. Organisms can withstand great pressure, expecially humans, because the human tissue is almost incompressible.

As a comparison of pressure for land and sea, "...a man on land bears an atmospheric pressure of several tons on the surface of his body without noticing it. The oceanic fluid doubles atmospheric pressure thirty-three feet down. At sixty-six feet pressure is tripled; it is fourfold at ninety-nine feet, and so on down in multiples of thirty-three feet" (Cousteau, 1953). From this one can see that hydrostatic pressure, the weight of the overlying water, is a function of depth. Another relationship might be to equate ten meters of water to one atmosphere of pressure. Therefore, the pressure ranges from 200 to 600 atmospheres in the abyssal zone, increasing toward 1,000 atmospheres in the hadal zone, (Bruun, 1957, p. 645). Animals living at a depth of thirty thousand feet have a pressure of seven tons per square inch exerted on their body.

Temperature.

The abyssal zone was delimited toward the bathyal zone by the temperature of about 4°C; therefore it is a typical cold water zone, which has its corresponding counterpart only in the shallow waters of the polar regions. Cold water circulates from these polar regions through the entire ocean floor. This cold water movement is slow, but it does reach the tropics and produces a general density stratification in the ocean based upon temperature. The density currents due to water masses of unequal salinity cause a non-uniform decrease in temperature with increasing depth. In general, at depths below 600 feet the water is everywhere within a few degrees of freezing. The transition between the surface water zone and the cold water zone is almost like night and day-there is a very sharp break, and it is of such magnitude that it can be detected by the touch of human flesh (Cousteaue, 1953).

Table 1 shows temperatures (Centigrade) recorded at various depths and latitudes in the Atlantic Ocean, between the latitudes of Spitzbergen and the South Orkney Islands.

Measurements taken in the Carribean show a slight increase in temperature from 1933 to 1954. Table 2 shows the average temperature at various depths from the Carribean region.

Table 1. Temperatures at Different Depths and Latitudes in the Atlantic Ocean. After Schott from Dunbar and Rodgers(1957, p. 56, table 3).

Depth in Meters	Latitude							
	80°N	60°N	40°N	20°N	0°	20°S	40°S	60°S
0	2°	9°	16°	20°	27°	17°	15°	<0°
200	2°	6°	12°	15°	15°	11°	10°	<1°
400	1°	9°	12°	12°	9°	9°	10°	<1°
800	0°	8°	11°	8°	5°	5°	4°	<1°
1000	<0°	7°	9°	6°	5°	4°	3°	<1°
2000	-1°	3°	4°	4°	3.3°	3°	2°	<0°

Table 2. The average temperature at various depths in the Carribean. (After Worthington, 1955, p. 83, table 2)

Depth in Meters	Temperature		
	1933	1954	Gain
2,000	4.061	4.075	0.014
2,500	4.070	4.078	0.008
3,000	4.118	4.122	0.004
3,500	4.176	4.172	0.005

The temperature gradient of deep-sea sediments can be studied by a means of a geothermometer of special construction. In the Central Pacific Ocean, close to the Equator, in a depth of about 4,400 meters, the temperature rose in the sediment 1°C in about 21 meters; in the Western Pacific Ocean in a depth of 5,300 meters a rise of 1°C in 26 cm was observed, and in the Indian Ocean a rise of 1°C in 4 meters. The low conductivity found in deep-sea sediments by these gradients shows that in the first two examples named, a geothermal current comparable in intensity with that found on an average in the continents is present. (Petterssen, 1953, p. 17)

Salinity.

According to Sverdrup (1942, p.8) "salinity is defined as the ratio between the weight of the dissolved material and the weight of the sample of sea water, the ratio being stated in parts per thousand or per mille." When parts per mille are used the symbol $^{o}/oo$ is used.

The water of the ocean can be divided into two layers: (1) the 'troposphere', which refers to the upper layer of relatively high temperature found in the middle and lower latitudes and within which strong currents are present, and (2) the 'stratosphere', which refers to the nearly uniform masses of cold, deep and bottom waters. Salinity within the stratosphere is very uniform as compared to the troposphere, where it varies due to excess of evaporation over precipitation. (Sverdrup, *et. al.*, 1942, p. 141)

"The variation of the salinity in the abyss is, from an ecological point of view, extremely small. An average figure may be set a $34.8^{o}/oo$, and the variation is only about $o.2^{o}/oo$" (Bruun, 1957, p. 647). This applies in time to a single place, and also when passing from one ocean to another, if special bodies of water like the Mediterranean are excluded. "It does not seem that the slight variations in the salinity close to the bottom (Bruun, 1957) can be of biological importance,"

Oxygen Content.

Oxygen is present in sufficient quantities to support life in bottom waters of the deep oceans. If a correlation between the oxygen concentration and the distribution of the species could be made a clearer understanding of the oxygen content could be had, but at the present this is impossible. It could also be that many animals live anaerobically for short periods of time when they invade areas of low oxygen content. There seems to be a sudden decrease of oxygen in the water layer from about 20 to 25 meters above the bottom down to layers one meter above the bottom (Bruun, 1957, p. 645). Recent studies by Miyake and Sarahashi (1956) showed that there is an occurrence of minimum oxygen concentration at intermediate depths, down to about 2,000 meters.

Minor Environmental Characteristics.

Sea water within a few meters of the deep-sea floor contains phosphates, silicates, alkalines, nitrogen, and carbon-dioxide, but there is no indication so far that the presence of these factors has much to do with the distribution of animals.

LIFE IN THE DEEP-SEA

Recent investigations of the deep-seas reveal that life does exist, and abundantly in many places, in the abyssal and hadal areas of the oceans. In the Romanche Trench of the Mid-Atlantic life was found to exist at depths of 24,600 feet, and other investigations have shown that life is also present in intermediate layers all the way up to the surface. Life is most abundant between 500 and 900 meters below the surface, but this does not rule out the possibility that once more investigations are made, the abundance of life can also be established at greater depths. As has been mentioned earlier, life is dependent upon certain characteristics, and the abundance of life definitely depends upon availability of these characteristics.

Food.

"All organisms living below the photosynthetic zone must depend upon food that falls from this uppermost zone" 'Bruun, 1957, p. 649).

When speaking of food in this connection, it must be understood to mean food as energy stored in organic matter, because such energy can be utilized by heterotrophic bacteria when they assimilate plant and animal remains or dissolved organic matter. According to Bruun (1957, p. 649), ZoBell says that "bacteria oxidize approximately 60 - 70 per cent of organic carbon to carbon dioxide, whereas the remaining 30 - 40 per cent of the organic carbon is converted into bacterial cell substance (particulate protoplasm), consisting primarily of proteins and lipids that may untimately serve as important sources of food for deep-sea animals." Some food is also incorporated in the sediments, and bottom dwellers probably thrive on that type, and some animals may even live off sinking dead bodies of plankton organisms.

It was first assumed that the greater the depth, the less the food supply, but later proof shows that this is not necessarily true; the amount of food available is largely independent of the depth below the bathypelagic zone. "On the whole the food supply in the abyssal and hadal zones is not plentiful; it may even be called precarious, but it is no more scarce than in any other region of the ocean below the layers that are in fairly close contact with the photosynthetic zone" (Bruun, 1957, p. 651).

Kinds of Life.

Many kinds of fauna are present in the abyssal and hadal regions. A recent haul made at 4,820 meters on a light colored Foraminifera ooze between Madagascar and Mombase included all kinds of life. Some of the types present were the echinoderms, holothurians, asteriods, coelenterates, crinoids, molluscs, crustaceans, cephalopods, and fishes.

Most of the hadal fauna has been studied only in seven of the trenches, and much of the material has been studied only in a preliminary manner. The investigations showed that the species fell sharply with increasing depth, however some, such as the holothurians are very abundant. The hadal fauna include sponges, ophiurans, holothurians, polychaetes, anemones, asteroids, crustaceans, bivalves, gastropods, ascidians, hydroids, echiuroids, and fish. A haul from 9,000 meters contained the following number of animals: "...2,850 Elpidia, nearly 2,000 Pogonophora, 84 echiuroids, 150 crinoids, 160 polychaetes; the 5,700 specimens represented 17-18 species." (Bruun, 1957, p. 661)

Ecological Groups.

According to Bruun (1957, p. 661) "the abyssal and probably the hadal animals can be divided into two ecological groups." The first group is the true abyssal species, those which spend their entire life in this zone, and second group which spawns somewhere else and then moves into these zones. Some animals are caught in the abyssal zone which just manage to live, but can never reproduce there.

The abyssal fauna have also been classified according to geographical distribution. They can be divided into Atlantic, Indo-Pacific, Antarctic, and Arctic regions.

Adaptations of Deep-Sea Animals.

Bruun (1957, p. 666) says that "morphologically the abyssal and hadal animals are in many ways characteristic at first glance: the lack of bright colors characteristic of shallow-water animals, the reduction of the eyes, often total blindness, and several other characters are conspicuous: closer inspection reveals that probably each single character or complex of characters is also found in some related animal from the ba thyal zone or even coastal regions or fresh water, expecially caves."

An interesting sideline in the discussion of deep-sea life, is the depth at which whales make their dives. Several whales have been found entangled in deep-sea cables at depths of 500 and 620 fathoms. From this one can conclude that larger animals do penetrate the deeper waters of the oceans. (Heezen, 1957, p. 105)

SUMMARY

The deep-sea environment is divided into two main zones, the pelagic or water zone, and the benthic, or bottom z one. The deep-sea floor is of rugged terrain, with many rises and deeps. The A tlantic Ridge is one of the largest rises, and the Marianas Trench is the deepest of the deeps. Sediments of all sorts cover the deep-sea floor. Muds of various colors, calcareous and siliceous oozes, and red clays are the dominant types of sediments found. Sedimentation takes place at rates which vary from place to place and which are dependent upon the type of sediments being deposited. These sediments are transported to the sea by streams, wind, animals, and ice, and when they get to the ocean floor, turbidity currents and eddy currents along with submarine landslides transport them further.

Environmental conditions of the deep-sea are varied. Light is absent, the pressure is tremendous--seven tons per square inch at 30,000 feet--, the tempera ture is almost at a freezing point all the time, the oxygen content is low, and the salinity is great, yet, life does exist at these depths and under these conditions. The food supply for this life is limited, but it is sufficient, even at places where life is very abundant. All kinds of life is present: crinoids, echinoderms, asteroids, sponges, holothurians, coelenterares, molluscs, crustaceans, cephalopods, ophiurans, polychaetes, anemones, bivalves, gastropods, ascidians, hydroids, echiuroids, and even fishes.

The deep-sea environment is being studied intensly at the present time, and as soon as more data is gathered, one will be able to draw more definite conclusions about it and its life.

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