USL Report No. 575
1-409-00-00

THE IRREGULAR DISTRIBUTION OF DEEP-OCEAN SEDIMENTS

27 March 1963

by

P. L. Bezrukov
Institute of Oceanology, Academy of Sciences, USSR

Taken from OCEANOLOGY, Vol. 2, Issue 1, 1962
Publication of the Academy of Sciences, USSR, Moscow, USSR

Translation
by
C. N. K. Mooers, Lieutenant, USN

U. S. NAVY UNDERWATER SOUND LABORATORY
FORT TRUMBULL, NEW LONDON, CONNECTICUT

ABSTRACT

This paper is a literal translation of an article by P. L. Bezrukov appearing in Oceanology, Volume 2, Issue 1, 1962. The author reviews the relatively recent discoveries of the irregular distribution of deep ocean sediment chemical and granular composition as well as thickness. The contributing phenomena are identified: complex bathymetry; suspension currents; volcanic, ice, and freshet transport; organic activity; and autogenesis. The increased density of geological observations, an intense study of a limited bottom area, the development of near-bottom current meters, and the creation of improved charting techniques are vigorously indicated as being required for the thorough study of ocean bottom properties.

ADMINISTRATIVE INFORMATION

The translation of this article, which originally appeared in a Russian scientific journal, was requested by Everett H. Scannell, Jr., of USL. The work was accomplished under USL Project No. 1-409-00-00.

While it is doubtful that the article contains the quantitative information which had been hoped for, its qualitative description of deep-ocean sediment distribution is thought to be of interest to those concerned with the study and the relationships of the ocean bottom.

REVIEWED AND APPROVED: 27 March 1963

J. W. Horton

J. Warren Horton
Technical Director

B. H. Andrews

B. H. Andrews, Captain, USN
Commanding Officer ~~and~~ Director

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

THE IRREGULAR DISTRIBUTION OF DEEP-OCEAN SEDIMENTS

INTRODUCTION

In the general arena of geology and oceanography, the contrast between the sediments of the deep ocean and those of shelves, continental slopes, and bordering seas was recognized long ago as being the immense area available for an exceptionally uniform lithological composition. Determinations substantiate that the most widely distributed types of pelagic sediments (globigerina and red clay) occupy an extraordinarily large area of the open ocean, measuring many millions of square kilometers. The remoteness of extensive regions of the ocean from the continents, from which terrigenous materials originate, permits the supposition that the influence of individual terrigenous minerals has been erased from pelagic sediments. Concerning the uniform condition of abyssal pelagic sediments, it may be said that, except beneath frontal zones and sharply defined currents, the physical, chemical, and biological characteristics of ocean surface water change very gradually over comparatively large distances. On a level with these important general considerations, it is sometimes stated that in abyssal parts of oceans, at depths greater than 4000 meters, hydrodynamic conditions are practically uniform, and that because of this, sediment formations here flow uniformly, depending on sea-bottom relief.

In fact, as shown by extensive material gathered in a series of oceanographic expeditions made chiefly in post-war years, the distribution of abyssal, oceanic sediments, in the majority of cases, is immeasurably more complicated. Therefore, earlier presentations of this question should be altered by the very frequently encountered intermittence and mosaic qualities in later observations of abyssal sediment distribution. In other words, the uniform accumulation of deep sediments should be considered as only a special case, quite different from the most extensive case of oceanic sedimentation. Similar inferences have come from a group of investigators in recent times. Of a number of foreign scientists, it is reasonable to mention Heezen and Menard (references 33 and 39) before all others. We have recently turned our attention to the irregular distribution of sediments in the trenches of the Pacific Ocean, resulting in the analysis of geomorphological data by G. B. Udintsev (reference 22). From this developed the basis of these presentations and the initiation of the present article.

It is necessary to emphasize that, when speaking of the irregularity (mosaic quality) of abyssal sedimentary distribution, it is useful to consider the distribution of sediments in the ocean as random, which is quite opposed to being always fully orderly. As a result of being influenced by a series of factors to be spoken of below, areas of homogeneous sediments are found, by detailed examination, to be in very many cases of a quite different order than had previously been supposed, that is, on a much smaller scale.

According to our opinion, the formal point of view about a consistent, uniform distribution of oceanic sediments was based upon a lack of factual data and, in a certain measure, depended upon remnants of a long-abandoned supposition that the relief of the bottom of deep ocean basins had a flat character. In the past few decades, as a result of broad application of the echo-sounding method to the measurement of depth, and especially with the introduction to practical oceanographic research of the high-precision, ultrasonic echo sounder, it has become well known that the relief beneath the ocean possesses very great complexity. And if the density of spot measurements of depth is what we depend upon to judge the relief below, then at this time it has been increased a thousand times (if not more), and the quantity of points determining the composition of abyssal sediments has been increased in the same period perhaps as much as several times (ten times); yet, for the huge space of the oceans, we have extremely few points (quite often there is only one point in many tens or hundreds of thousands of square kilometers). Even more scanty for the time being are data on the thickness of ocean sediments, though comparatively recent measurements have been made by seismoacoustic methods.

All the foregoing reasons appear to account for the steadfastness of the old contentions about the uniform, consistent composition of pelagic sediments. In their place, a thorough description will reflect an understanding of the ocean's natural appearance, andwill exert an influence on the planning of future investigations of deep ocean sediments. According to established tradition, the spatial changes of abyssal sediments are always significantly less than those of sediments in shallow water, or those of the hydrographical and biological characteristics typical of surface water. The conclusion is then made that, in complex oceanographic expeditions, geological stations may be occupied relatively rarely. However, it is known that many important details of sediment distribution inevitably escape attention by such a spacing of stations.

The influences on the distribution of abyssal sediments beneath the deep ocean will be examined from the beginning. The question is divided into two parts: spatial sediment distribution and vertical sediment zonification. It is not possible to touch upon the influence of proximity to land and of climatological factors here.

OCEAN BOTTOM RELIEF AND THE INTERMITTENCE IN SPATIAL DISTRIBUTION OF ABYSSAL SEDIMENTS

As is well known, ocean basins are primarily divided into large ocean deeps and rises by submarine banks and mountain ridges.

Oceanic mountain ridges and banks occupy, approximately, from one-fifth to one-third of the ocean area. In all oceans there is a huge middle ridge and a complex system of transverse and oblique ridges. Many ridges stretch for thousands of miles, and a few for more than 10, 000 miles; most have a breadth of many hundreds of miles and a height of several kilometers. As a rule, oceanic mountain ridges possess a most complicated relief, abounding in exposed hard rocks. They best present an especially illuminating example of the intermittent sedimentary cover on the ocean bottom.

Exposed hard rocks are often associated with the sharply peaked, abruptly sloped submarine mountains that crown oceanic ridges and banks, and also with the cleavages in their slope, such as longitudinal and transverse valleys and other depressions. This applies as equally to volcanic ridges as to those of folded origin. Volcanic ridges have a particularly broad dissemination in the oceans. The relative height of subsurface mountains and volcanoes is measured in many hundreds of meters and a few in kilometers. On transverse echo-sounding profiles across the most significant ridges, it is often seen that there are many tens of mountains of such relative heights, not considering the fact that the majority are depicted as shallow hills (Fig. 1). Depth oscillations are at great inclinations, often extending from 20 to 30 degrees; it is common to encounter almost vertical projections. On the more gently sloped terraced steps of ridges and mountains and of shallow ridges and banks, there is a smooth relief or a crowning coral structure;

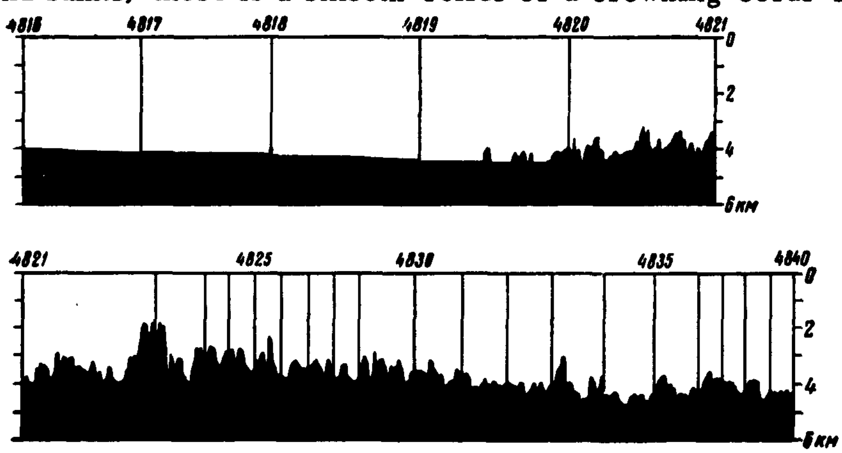


Fig. 1

Arabian-Indian Ridge and Adjacent Part of Arabian Basin (according to material of the 33rd cruise of the R/V VITYAZ). Transverse Meridional Profile from Station 4816 to Station 4840 at 63° Long. (Correlation of scales 1:37.)

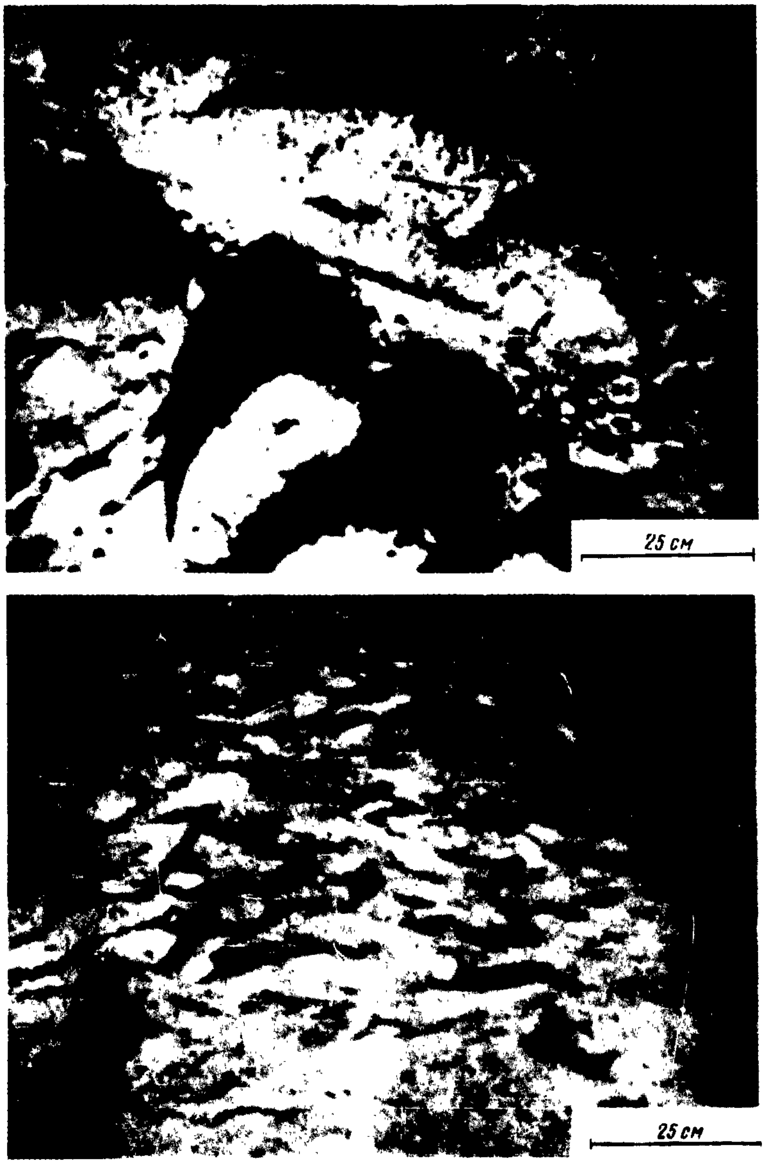
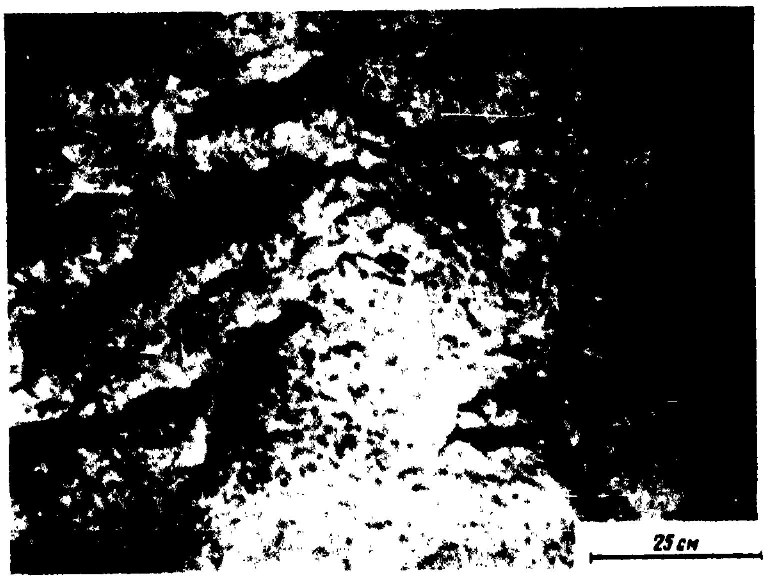


Fig. 2

(I, II, III, and IV) - Photographs of the Bottom at Station 3844 in Fiji Sea at Depth of 2400 meters. (Photographs were taken at distances of a few decameters by H. L. Senkevich.)


25 см


25 см

those which originate just beneath the surface are quite rare. It is to be noted that the sharply broken relief of submerged ridges is far more typical.

Flat-crested mountains (guyots), which rise over many oceanic banks and mountain formations, seem to be surfaces that are devoid of modern sediments; on a few flat-crested mountains and other rises in the Pacific and Atlantic Oceans, there have been encountered quite ancient sediments, up to and including Tertiary and Upper Cretaceous Ages. Also, the steep slopes of flat-crested mountains always abound with deposits of hard rocks.

From a number of submarine oceanic ridges subjected in the past few years to quite detailed investigations, a composite of mountain rocks and ancient sediments was revealed by the help of bottom scoops, trawls, and dredges in the Atlantic Ocean on the Middle Atlantic Ridge and Bermuda Rise (references 29 and 35); in the Indian Ocean on the African-Indian and Central Indian Ridges (references 40 and 49); and in the Pacific Ocean on the Hawaiian Ridge, Central-Pacific Oceanic Mountains (reference 31), Fanning and Nasca Ridges (references 18 and 45), and Eastern-Pacific Oceanic Rises. Additionally, other submarine ridges have been encountered in all oceans.

However, the taking of hard rock fragments from the bottom does not constitute a unique, authentic proof of the presence of bare sections on the summits and slopes of submarine ridges and mountains. From echogram records, which register sharp contrasts of relief, very steep slopes, and sharp oscillations from powerful upward-reflecting layers, ordinarily no doubt remains as to the extraordinarily broad development of indigenous rocks and ancient sediments on the bottom.

In connection with these proofs, the majority of the bare sections on oceanic ridges and banks have quite diverse outlines and dimensions, and the distribution of sediments on them bear an exceptionally complex, intermittent character. Gently sloped mountains, foothills, and depressions between them are advantageous for deposition, so sediments frequently, and obviously, change their thickness in very short distances.

Good confirmation of the intermittent sedimentation on submarine ridges and mountains is given by a series of consecutive bottom photographs taken with underwater cameras suspended from drifting ships. Such labors have been undertaken in many oceanographic expeditions; in particular, on a few cruises of the R/V VITYAZ in the Pacific and Indian Oceans (references 4 and 9). In a series of photographs, taken at intervals of a few minutes (the time interval depending upon whether the magnitude of drift corresponds to distances of a few meters or to several decameters), there is distinctly and repeatedly seen an alteration in the spotty distribution of the rocky bottom and of the sediment-covered sections (Fig. 2). The mosaic quality of sediment distribution was more than once confirmed by repeated hauls of bottom samplers. Areas of bare sections may be very distinct and from a few square meters to tens and hundreds of square kilometers.

If it is accepted, with apparent high probability, that deposits of rocks, partly in large aggregates, are found on the majority of individual mountains, then, on diametrical sections across such enormous ridges as the African-Indian (pictured in Fig. 1), these aggregates would be measured in many tens and, along the longitudinal axis, in thousands and tens of thousands.

From all reports, it is not difficult to see that, if collections of separate assays of sediments and hard rocks only are considered, and if the data about the relief of the bottom are not taken into account, it is impossible to acquire even an approximate notion about the character of sediment distribution in regions of submarine ridges by the frequency of geological stations which are ordinarily taken on an oceanographic expedition. In order to determine the true picture of sediment accumulation on sharply broken ridges, very detailed investigations are required.

By assigning a speed of deposition or absolute mass to individual assays of sediments, ridges with broken relief (for example, the Middle-Atlantic Ridge) yield quite random charts.

The measuring of the thickness of sediments by seismoacoustic methods will be discussed. If these measurements are conducted in the region of submarine ridges at intervals of a few miles, charts of the distribution of sediment thickness are shown to be distorted, (without mentioning that which makes the transformation of collected data into such terms so extremely difficult).

Reasons for the uneven distribution of sediments over submarine ridges are quite obvious. The continuously intermittent overflow of water currents above sedimentary material on the contrasts of relief, and the depressions in between, inevitably promote the origination of landslides on steep slopes, similar to the suspension (turbidity) flows to be talked about below. In particular, as an indication of the intensive movement of water in the region of submarine ridges and mountains, distinct examples of the laws of ripples formed by bottom currents are repeatedly found in bottom photographs at depths of 2500 to 3500 meters.

If the broad dissemination of bare parts on surfaces of oceanic ridges has been presented with sufficient evidence, we will show the apparent scale of the previously underestimated, complicated business that exists in the deep ocean basins, which may be viewed as the principal regions of oceanic sedimentation.

As already noted, until a few decades ago it had been acceptable to think that there is always a smooth process of sedimentation in the oceanic deeps. Such an opinion allowed one to suppose that hard rocks are rarely encountered, except when individual mountains arose from the even surface of the bottom.

With the introduction of modern echo sounders to practical investigations, there has been manifested an exceptional average variety of small bottom-relief forms in oceanic deeps. It is now sufficiently well known that in deep basins there are encountered: first of all, extensive expanses of the bottom with very complex, hilly, and even mountainous volcanic or tectonic relief; secondly, undulating plains; and thirdly, limited accumulated abyssal plains, with an angle of incline ordinarily less than 1:1000. The varieties of bottom texture of deep oceanic basins are aggregate proof that in many of them there are numerous large-scale mountain masses, linear zones of tectonic break-up, mountainous projections, submarine hills, and other categories of bottom-relief forms.

In connection with this, two questions naturally arise: What relative areas of deep-water parts of oceans are occupied with these basins versus those of different characteristic relief, and what is there to be said about the spatial distribution of sediments on the rough bottom relief of deep basins?

The answer to the first question is given by results of many oceanographic expeditions conducted in recent years in the Pacific, Atlantic, and Indian Oceans. In the majority of deep water basins, a complex irregular relief prevails. The unlimited abyssal hills and mountains are sometimes located on a wavy-plain background. The accumulated plains do not now occupy a relatively large area of the ocean bottom; they basically gravitate to its borders and to the foothills of large submarine rises and island foundations.

In the Pacific Ocean, according to calculations of Menard, hilly bottoms with an average relief amplitude of several hundred meters occupy nearly 90 percent of the area, the flat bottom along edges of continents are found in all of 2 percent, and the accumulated shelves surrounding underwater mountains and islands in 8 percent (reference 39).

By the calculations of the same author, in the Pacific Ocean there are not less than 10, 000 submarine volcanoes more than one kilometer in height; most of these are found on the borders of deep-water trenches (reference 40). Although the deductions of Menard are based especially on material from American expeditions, enveloping great distances in their investigations yet not covering all areas of the Pacific Ocean, the reduction of these collections has shown that the bottom areas with irregular relief certainly have a strong influence. Material taken by the expedition on R/V VITYAZ during the

International Geophysical Year similarly shows that a complex irregular relief predominates (references 10, 11, and 24) in deep trenches of the northern and western parts of the Pacific Ocean. Data from expeditions on the ship OB, which has examined the southern parts of the oceans, are included.

In the Indian Ocean, abyssal accumulated plains occupy several large areas; also, the ocean has significant regions of sharply irregular bottom relief. In the north, according to data taken on the 31st and 33rd Cruises of the R/V VITYAZ, accumulated plains are distributed on the bottom of the African deeps and Bengal Gulf and on an adjacent part of the Indian-Australian Basin to approximately 7 degrees south latitude (reference 4); to the west and east, they extend in a more or less broad strip from along the continental slopes of Africa (and Madagascar) to Australia; and, on the south, from data of expeditions in the ship OB (references 7 and 16), they generate a comparatively narrow (nearly 300 miles) strip of foothills on the continental slope of Antarctica. The largest parts of the extensive Indian-Australian, Central-Indian, African-Australian, and other basins of the Indian Ocean present regions with complex irregularities of volcanoes and places of tectonic relief. The total number of submarine volcanoes in the Indian Ocean has not been calculated, but undoubtedly there are many thousands.

In the Atlantic Ocean, abyssal accumulated plains have a very large development. However, judging by the data of detailed works produced by the Lamont Geological Observatory, reflected in the lucid physiographic chart created by Heezen and Thorp, they occupy not less than one-fifth of that ocean's area. A large part of the bottom surfaces of the deep-water Atlantic basins is in the province of abyssal hills of volcanic origin, with an average relief amplitude of several hundred meters, and is not smoothed-out sedimentation.

Moreover, the principal "dismembering" over most of the oceanic deep-water basins is characteristically of volcanic relief, so that figuratively speaking, vast structures of oceanic beds possess traits of a "lunar landscape."

On the second of the previously established questions (about the influence of deep-water basin relief on the distribution of sediments), the answers are given by geomorphological findings (echo-sounding profiles), by findings of deposited indigenous rocks and ancient sediments in the limits of these depths, by results of seismoacoustic investigations, and also by some other observations.

Studies of echo-sounding profiles of deep oceanic depths with complex relief bring one to the conclusion that rock deposits should have a very broad dissemination on the bottom of these basins. Concerning this, there is evidence not only of sharp and partial contrasts of relief, but also of significantly steep, complex slopes (from a few degrees up to 20 to 30 degrees and more). As a prime example, we cite the characteristic profiles of the bottom of Central-Indian and Indian-Australian Basins, taken from material of the 33rd Cruise of the R/V VITYAZ (Fig. 3). Analogous illustrations may be found in the works of many investigators who have studied the bottom relief of the Atlantic (reference 35), of the Pacific (references 10, 11, 24, and 27), and of the Indian (reference 7) Oceans.

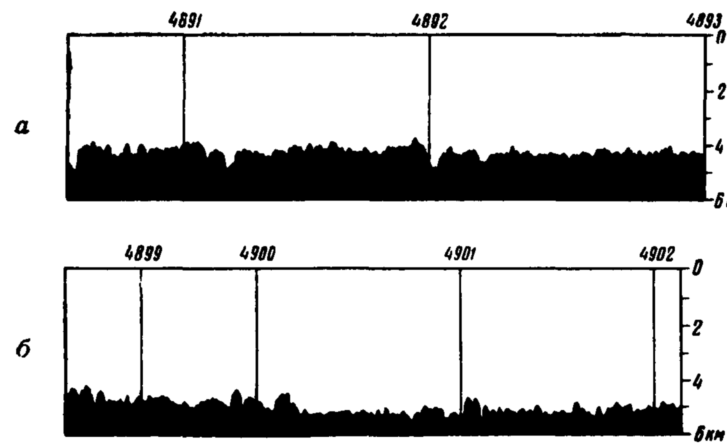


Fig. 3

Examples of Bottom Profiles. (Correlation of scales 1:37.)

A. Central-Indian Basin (from Station 4891 to 4893) at 72° E. Long.

B. Indian-Australian Basin (from Station 4899 to 4902) at 83° E. Long.

Factual information about the location of hard rock deposits in deep oceanic basins with complex relief has been obtained by many oceanographic expeditions; such knowledge is increased each year. On the 33rd Cruise of R/V VITYAZ, not only were a large number of pieces and blocks of indigenous volcanic rocks discovered at the bottom of the Indian-Australian Basins, but peculiar brick-colored sediments, consisting of chalky, acute-angled fragments of basalt contained in a semi-liquid silt were also found at one station. Such sediments may be viewed as the result of submarine landslides on steep slopes.

Together with what has been shown to be the characteristic condition of sediment deposits in the region of submarine ridges, separate probes always, to a certain measure, add to the immensely complex and random but true picture of the distribution of the exposed area on the bottom. The area of each hard rock deposit is ordinarily many times less than the adjacent regions of the bottom covered by sediments. Because of this, a coring apparatus always has far more chance of exactly cutting into sediments; this ordinarily creates a false impression about the continuity of sediment cover in deep basins and obstructs many investigators from mentioning the finding of separate rock deposits on the bottom. But even if the dimensions of the majority of abyssal hills are of small stature in terms of sharply irregular relief, the general plan of sediment distribution and thickness is seen to be extraordinarily complex.

The volcanic relief on the ocean bottom makes it impossible to regard every place as very ancient.* If for individual regions of the oceans, it is proven that they originated even in the Limestone (Mesozoic) Time (for example, by light chalky sediments in abraded surfaces of guyots in the region of the Central Pacific Ocean Mountains (reference 30)), for many other regions, there is evidence of an intensive display of submarine volcanism in Tertiary, Quarternary, or preceding ages from even earlier periods of the Earth's history. An example of youthful volcanic relief is given in the southern part of the Indian Ocean; there is submarine volcanic activity on an extensive space of the bottom, judging from the broad dissemination of volcanic materials in sediments and the almost, or wholly unmasked deposits of rocks found lying on the bottom. Because of this, and also considering the very low rate of sedimentation in central parts of the oceans, we have all the basis for supposing that there is in such regions, an especially large distribution of volcanic rock deposits, which are almost, or completely uncovered by modern sediments.

In many oceanic regions, there is paleontological evidence of Pleistocene and Tertiary Age sediment dissemination. Many examples may be found in the work of Riedel (references 44 and 50), Ericson (reference 29), and a series of other investigators. In some cases where modern sediments are absent, it is possible to judge by one of the lithological signs (for example, the sighting of very dense, crumbled clay). The presence of barren parts in deep ocean basins has not once been verified by means of bottom photographs.

Measuring the thickness of oceanic sediments by seismoacoustic methods does not contradict this summary of data. Results of these measurements show that, on the fringes of oceans (on accumulated plains), the thickness of slightly dense sediments sometimes attains 2.5 kilometers and more (reference 17), and that in central regions, it ordinarily averages all of 200 to 400 meters, and occasionally attains 1 to 1.5 kilometers (references 8, 12, 34, and 43). Moreover, the thickness of sediments is commensurate with amplitude of bottom relief oscillation at oceanic depths. Individual measurements show complete absence of sediments.

*The growth of relief, and not that of the oceanic deeps themselves, is discussed in this article.

There is basis to think that rocks of the "second layer" (possessing a speed of sound propagation on the order of 2.1 to 5.5 kilometers/second) lying under less dense sediments were produced, as suggested by their mass, in the same manner as normal sediment accumulation which has suffered consolidation (references 8 and 32); their true thickness may be 1.5 to 2.5 times larger. However, with the increase of sediment lens thickness between separate rises, the unevenness of sedimentation only grows.

As far as the determination of sediment thickness with seismoacoustic methods is concerned, there are very few separate measurements (as individual corings) in conditions of complex relief; this does not eliminate possibilities of making full resolution (sometimes repeatedly) of sediments between neighboring points of observation. Moreover, results of seismoacoustic investigations fully suggest and, in some cases, confirm the intermittence of sedimentation in deep oceanic basins. Additionally, seismoacoustic investigations ordinarily determine average sediment thickness, but modern thin-layered sediments may not be observed.

The seriousness of well-established interruptions in the sediment cover of the ocean bottom may be acquired from the analysis of new information about the speed of deep currents. Such facts are given by instruments measuring currents at automatic buoy stations and also by observation of neutral floats (references 20 and 46). By the labors of the R/V VITYAZ in the Pacific and Indian Oceans with instrumented measurements at a series of buoy stations, it was established that, even in depths of from 2000 to 5000 meters, currents not uncommonly exist at speeds of 10 to 25 cm/sec. Similar results were obtained by the use of neutrally buoyant floats on English and American expeditions; in some cases, the speed of currents at depths of 4000 meters has attained 42 cm/sec (reference 47).

These data disproved opinions of those investigators who had considered that, at the greatest depths of the oceans (greater than 4000 meters), hydrodynamic conditions are practically stationary and that sediments cloak the uneven bottom (reference 13). In reality, such cloaking deposits appear most limited, and processes that wash away and horizontally transfer sedimentary materials occur on a large scale at the extreme depths of the ocean, promoting the appearance and preservation of exposed parts on steep and projecting portions of the bottom. In essence, it is being said that it is impossible to explain the formation of flat abyssal accumulated plains without proving that there exists a horizontal transfer of materials in water layers (independent of whether the transfer be associated with slow, constant velocity currents or rapid, episodic suspension currents). Abyssal plains are distributed at the great oceanic depths, partly in deep oceanic troughs having depths up to 10 or 11 kilometers.

It should be noted that steep, deep troughs are also found to contain an extraordinarily complex, intermittent distribution of sediments. Here there are abundant deposits of hard rocks as well as ancient sediments. However, we have repeatedly reviewed that question (references 1 and 25), so we will not pause on it here.

Bringing this to a summary, we inevitably arrive at the fact that there are unlimited collections of hard indigenous rocks on the ocean bottom, not only in regions of underwater ridges, but also in great depths, where there are ancient and modern sediments as well. The most essential trait is the unevenness of oceanic sedimentation. Reasons for it lie in the morphology, in the tectonic structure of the bottom, in the especially deep circulating oceanic waters, and in the small and changing speeds of sedimentation.

VERTICAL ZONIFICATION OF SEDIMENTATION

The vertical zonification of sedimentation expresses itself in regular changes in the composition of sediments measured at great depths of the ocean and is independent of the distance from continents and from their influence on the processes of sedimentation (references 2, 6, and 13). Below, some questions of the vertical zonification of deep sediment distribution will be briefly examined.

Above all, the granulated condition of the sediments changes with oscillations. It varies with changing hydrodynamic conditions; over bottom rises and craters, currents are found to be in more mobile conditions than over lower portions. Accordingly, sediments on bottom projections, as a rule, possess more coarsely granulated conditions than those in the depressions between them; this has been repeatedly noted by many investigators. In the regions of steep slopes, where the most complex divisions of the crater ordinarily appear, and sometimes landslides, the changing granulated composition of the sediments has a particularly capricious character.

As a result, it should be emphasized that a correlation between ocean depth and the granulated composition of sediments does not exist. Sediments of one measurable fraction may be encountered, depending upon hydrodynamic conditions, at quite varied depths.

On the surface of oceanic ridges with strongly irregular relief oscillation, there are produced sharply and repeatedly changing sediment granulations. In tropical and sub-tropical zones of the oceans, where there is an extraordinarily broad dissemination of foraminiferal (globigerina) sediments in regions of submarine ridges and hills, any significant depth oscillations originate changes in the granulated conditions, ranging from foraminiferal sands to lime silts. Former foraminifera shells have been found in fragmented states. Similar changes of foraminiferal sediment granulations have been repeatedly noted, and particularly distinctly, in the Indian Ocean (reference 3).

In regions of deep oceanic basins, the granulated conditions of sediments also make a transition from rises (abyssal hills) to depressions, but thinner, clayey sediments predominate here, and these changes are ordinarily expressed to a less abrupt degree. It should be noted that, for the present, there is very little detailed analysis of data concerning changes in the granulated condition of sediments on steep abyssal hills.

The material composition of sediments also undergoes serious changes with depth oscillations; in contrast to granulations, the changing material composition is very often related to depth.

The relationship of calcium carbonate to the changing contents of deep sediments will be viewed first. As was first established by Murray and Renard (reference 42), and later verified by many other investigators, in the interval of depths from 4000 to 5000 or 5500 meters, with which the latest data agree, and most sharply from 4300 to 4800 meters (references 3 and 15), the carbonated foraminiferal silts almost everywhere change to sedimentation without carbonation. In the central oceanic regions, the deep water has red clays, radiolarians, and spots of diatomaceous silt; in its bordering parts, particularly in deep troughs, there are primarily terrigenous muds. In regions of moderate width near the edges, the distribution of carbonated sediments rises, in spots, to depths of 3500 meters.

The regular fall in sediment carbonation as an indication of depth interval is related to the distribution of pelagic foraminifera lime shells on ocean bottoms and to the calcium carbonate deficiency in cold, deep water. At the critical depths of 4500 to 4700 meters, there are frequently found obvious traces of planktonic foraminifera disintegration.

In regions of submarine oceanic ridges, over which the depth does not basically exceed 4000 to 4500 meters, the changing carbonation of sediments is not closely related to the vertical, as a rule. But, in transition to the great depths (greater than 4000 to 4500 meters) which are predominant in oceanic deeps, these changes are very substantially reflected in the material composition of the sediments.

The above explains the following circumstance. If oceanic basins with sharply irregular relief have an average depth at their boundaries of 4000 to 5000 meters, then, in complex ways, on any number of large abyssal hills (from a few hundred meters to a kilometer and more in height), there ought to occur changes in the carbonated sediments (sometimes in large divisions of from 90 to 95 percent or more but, on the average, of 7 to 10 percent in each 100 meters of vertical). Materials, collected in the Indian Ocean by R/V VITYAZ, confirm this description. In many extremities of the Indian-Australian and Central-Indian Basins, depth intervals are marked on submarine hills and mountains by very sharp variations in the carbonation of sediments.

By the calculations of Kossina (reference 36), the zone of depths from 4000 to 5000 meters occupies 32.4 percent of the bottom in the Atlantic Ocean, 37.7 percent in the Pacific Ocean, and 38.9 percent in the Indian Ocean; the average for all oceans is 36.6 percent. It follows from the above account that in over three-fourths of this area, there are found regions of the bottom with an irregular relief. From this, it is not difficult to see that the sharp variations in carbonated sediments are related to the vertical zonification of their accumulation. These variations occur on a broad expanse of the bottom. If zones of temperate and polar widths are excluded, where carbonated silts have comparatively small development, then, by rough calculation, a sharp variation of carbonated sediments ought to cover approximately 20 to 25 percent of the general area of the deep ocean or more than one-third of the area occupied by foraminiferal (globigerina) sediments. In this case, calculations were not made for the more gradual changes in the carbonation of sediments which are related to the proximity of land and to shifting climatological conditions.

Parallel with variations of the $CaCO_3$ content of sediments, autogenesis changes the content in terrigenous and volcanic materials of silica (composed of radiolarians and diatoms), iron, manganese, and a series of other components; calcium carbonate appears to be diluted by them. Simultaneously, there are similar changes in the speeds of accumulation and the thickness of sediments. It is well known that the average speed of accumulation for foraminiferal silts is a few times greater than the speed for deep water red clays, by the determinations of Hamilton (reference 32), and that carbonated silts are two times thicker than red clays in the eastern parts of the Pacific Ocean.

Moreover, where there is an irregular ocean bottom relief, vertical sediment zonification dictates a sharp spatial change in many characteristic traits of sediments; it appears that it is the second greatest factor in their uneven distribution.

If conditions of abrupt ground relief and vertical zonification are combined with intermittent sedimentation, the unevenness appears still more salient.

DEPOSITS OF SUSPENSION CURRENTS

The third great factor in the uneven distribution of deep-water oceanic sediments appears to be the work of suspension currents.

The currents of turbid waters are called suspension, stirred-up, or turbidity currents; their flow down slopes is related to their increased density, caused by a high content of suspended particles.

Suspension currents and their geological activities (erosion, transport, and accumulation of sediments) are dealt with extensively in the literature. The list recently composed by Kuenen of works on this question includes nearly 400 names and is apparently incomplete. The most detailed summary of modern presentations on the sedimentation roles of suspension currents may be found in the works of Kuenen (reference 37), Heezen (references 33 and 35), Menard (reference 41), and Shepard (reference 48). In a section of a basic article, we would want to turn our attention to only some of the traits of suspension current accumulations.

The formation of suspension currents is related to irregular factors— to landslides and slumping, to the discharge of strong freshets into the sea by rivers, to sediments in shoal water distorted by tsunamic waves and, also, by rough waves sent by hurricanes and sometimes by volcanic eruptions. An especially large significance is given to landslides generated by submarine earthquakes. As the classic example, it is customary to cite the case of the 1929 earthquake in the region of the Grand Banks of Newfoundland, which resulted in a powerful suspension current, and which in turn caused a sequence of ruptures in trans-Atlantic cables (references 28 and 34).

Large masses of sedimentary materials are drawn up in suspension currents, which are later carried away to great distances (many hundreds of miles) to be gradually deposited on the bottom, ordinarily creating layers of related groups of sediments (sand and aleurite (silt)). As a rule, these layers are of irregular thickness (from many centimeters to a meter or more), have characteristically sorted grains in the vertical, and are broadly distributed in oceanic sediments. Because of this, they are not often encountered on the surface of the bottom (such as the accumulated stream on the Grand Banks), but, in sub-bottom horizontal sections, intensified actions of suspension currents in the Pleistocene can be examined.

The greatest incidence of suspension current accumulations is on oceanic fringes, in the regions of abyssal accumulated plains. The circumstance of the existence of narrow valleys and the partial evidence of current formation therein are, in the opinion of a number of investigators (references 26, 35, and 40), an indication that suspension currents play a role in the formation of accumulated plains. Areas of such accumulations are found in the central parts of oceans at the foot of submarine heights and ridges.

It should also be noted that streaks in pelagic sediments of volcanic ashes usually possess vertical sorting, and they are ordinarily easily distinguished by their mineral composition.

By the labors of the R/V VITYAZ in the Indian Ocean on typical suspension current accumulations, a presentation of many layers of micaceous sands and aleurite (silt) was encountered in a full linear series of columns on the accumulated plains of the Somali Basin, the Arabian Sea, the Bay of Bengal, and from the adjacent to the lowest parts of the Indian-Australian Basin, at depths up to 5 kilometers.

By the very nature of suspension currents (episodic, changeability of direction, and speed), their accumulations are distributed very unevenly. This is confirmed in the fact that repeated corings in one and the same station frequently register the unevenness of the individual sediment layers.

Moreover, if the character of the abyssal accumulated plain relief is relatively simple and does not give the clear examples of intermittence and vertical zonification of sedimentation described earlier, the forming and building of the sedimentary thicknesses of these basins show an unevenness of oceanic sedimentation which varies not only in space but in time.

SOME OTHER EXAMPLES OF THE IRREGULAR DISTRIBUTION OF DEEP-WATER SEDIMENTS

From a number of other examples of the unevenness of deep-water sedimentation, it is possible to distinguish the distribution of the products of volcanic activity; the roughly fragmented materials transported by icebergs, ice, and marine plants; and also the deposits of iron manganese nodules. These examples will be discussed briefly.

The source of volcanic products on the bottom seems to be as named—that is, submarine volcanoes. The modern epoch is characterized by a slackening of submarine volcanic activity; in former epochs it was apparently more intense, since there existed large collections of volcanic hearths on the ocean bottom which have now discontinued activity. Because many regions are distant from modern centers of volcanism, their layers of volcanic ashes are often limited in thickness and extent; similar facts are true for deposits of glassy material. The most unevenly distributed products of modern volcanism are pumice pebbles, which are borne by currents to a broad distribution, and which are encountered in deep-water sediments almost everywhere.

Broken fragments of material transported by icebergs and ice are found, as pumice, in sediments of quite diverse types and at a variety of depths, but their distribution is restricted and determined by climatological borders, which frequently suffer displacements. Bottom areas covered by broken fragments of material transported by ice and icebergs constitute nearly 25 percent of the World Ocean.

Iron-manganese nodules represent a fine example of uneven sediment distribution in the deep basins occupied by red clays. Bottom probes, resulting from trawls and photographs of the bottom, show that iron-manganese nodules have been developed on a broad expanse of the ocean bottom and that, at the same time, they have an exceptionally complex, spotty distribution, the reasons for which are a long way from being cleared-up at the present. It is timely to turn our attention to the fact that the most abundant accumulation of nodules is in the parts of the bottom with an irregular relief and a slow rate of sedimentation. An essential role in the spotty distribution of nodules is apparently played by related diagenetic processes.

In conclusion, it is necessary to say that the uneven distribution of deep-water oceanic sediments, caused by the complex submarine relief, the activity of over-the-bottom currents and suspension torrents, and the other factors enumerated above, define the mosaic quality of the ocean bed distribution; the same is true for bottom fauna distribution to which Sokolova (reference 19) recently turned his attention. In particular, suspension currents appear to be one medium by which organic materials enter pelagic sediments.

In their turn, bottom creatures show an influence on some deep-water sediment traits, such as their structural and textural peculiarities, the heterogeneity of which is aggravated by the vital activity of Annelida, for example.

CONCLUSIONS

Both the composition and thickness of deep-water oceanic sediments sustain gradual changes, which are related to their remoteness from land, and to changes in hydrodynamic conditions; other sediments, which are more sharply changing, are apparently found in comparatively limited distribution.

The complexity of ocean-bed relief, in regions of submarine ridges as well as in deep basins, determines the extraordinarily broad distribution of hard rock deposits (and ancient sediments), which are covered intermittently with modern sediments. With large basin depths, vertical zonification of sediments is called for, which is reflected in the granularity as well as the material composition of the sediments. Regions with irregular relief occupy significantly larger areas on the ocean bed than do accumulated plains; the associated unevenness is observed as one of the most characteristic traits of oceanic sedimentation.

On the fringes of abyssal accumulated plains, there also exists an unevenness of sedimentation, caused principally by the activity of suspension currents.

Volcanism, ice, and freshets which transport fragments of materials; vital activity of bottom organisms; and diagenetic processes on the bottom aggravate the heterogeneity of deep-water sediments.

Evaluating the influence on sedimentation of all the enumerated factors makes it possible to arrive at the conclusion that the spatial variability of deep-water sediments is shown, in the majority of cases, to be significantly more pronounced than variations of hydrological, chemical, and biological characteristics in the surface waters of the ocean; some sediments often substantially change their composition and other properties in the length of several miles and even tens and hundreds of meters. The explanation for this phenomenon can be sought through the planning of expeditionary investigations.

The unevenness of deep-water sedimentation requires further refinement of methods for mapping oceanic sediments; in particular, of methods of representation for hard-rock deposits. It is quite clear that, by marking on charts only those deposits which have been observed by corings, it is impossible, even in the first approximation, to reflect the real, complex map of their placement on the bottom.

For a deeper study of the questions of the unevenness of deep-water sedimentation, it is necessary to establish specialized, greatly detailed geological (also geochemical and geophysical) investigations and to focus on some limited areas (polygons) and their various geomorphological conditions (continental slope, deep water troughs, oceanic hills and ridges, basins with irregular characteristic bottom relief, individual mountains and hills, fracture zones, etc.). For the establishment of these investigations, it is particularly necessary to produce instruments to measure near-bottom currents. In light of all the aforementioned, the problem is presented as one of great urgency for future examination. Experience of systematic findings even on individual lines and polygons of stations (reference 21) confirm that.

New descriptions of uneven, deep-water sedimentation ought to consider, by restoration, the paleographic conditions of ancient seas and oceanic reservoirs. In all cases, it has now become clear, that the former presentation of uniform, monotonous oceanic sedimentation ought to be abandoned.

REFERENCES

1. Bezrukov, P. L., 1955. "Bottom Deposits in the Kurile-Kamchatka Depression," Works in Oceanology, AS USSR, 12.
2. Bezrukov, P. L., 1959. "Some Problems of Zonification of Sedimentation in the World Ocean," Preprints International Oceanographic Congress, Washington.
3. Bezrukov, P. L., 1961. "Investigation of Bottom Sediments in Northern Parts of Indian Ocean," Oceanological Investigations, No. 4.
4. Bezrukov, P. L., 1961. "Investigation of the Indian Ocean on the 33rd Cruise of the R/V VITYAZ," Oceanology, No. 4.
5. Bezrukov, P. L., Udintsev, G. B., 1955. "About the Northern End of the Underwater Hawaiian Ridge," Papers of AS USSR, 103, No. 6.
6. Bezrukov, P. L., Lesetzien, O. P., Petalin, V. P., Skornyakova, N. S., 1961. "Chart of Bottom Sediments of the World Ocean," Modern Sediments of the Oceans and Seas, Works of the Committee on Sediment Distribution.
7. Shivago, O. V., 1960. "Tectonics and Geomorphology of the Bottom of the Southern Part of the Indian Ocean," International Geological Congress, XXI Session, Soviet Geological Papers, Problem 10, Marine Geology.
8. Svereff, S. M., Kovielin, V. M., Udintsev, G. B., 1961. "Thickness of the Ocean Bottom Accumulations," Modern Sediments of the Oceans and Seas, Works of the Committee on Sediment Distribution.
9. Senkevich, N. L., 1960. "A Photocamera for Survey of the Greatest Depths of the Bottom," Works in Oceanology, AS USSR, 44.
10. Senkevich, N. L., 1961. "New Data About the Bottom Relief in the Northeastern Part of the Pacific Ocean," Works in Oceanology, AS USSR, 45.
11. Kanaev, V. F., 1960. "New Data About the Relief of the Western Part of the Pacific Ocean," MGG, Oceanology Investigations, No. 2.
12. Kovelin, V. M., 1961. "Results of Seismo-Acoustic Investigations to the East of Africa in the Region of Zanzibar and in the Central Part of the Indian Ocean," Oceanology, No. 3.
13. Leontev, D. K., 1955. "Geomorphology of the Sea Shores and Bottom," Investigations MGU.
14. Lisitzen, A. P., 1960. "Sediment Formation in Southern Parts of Pacific and Indian Oceans," International Geological Congress, XXI Session, Soviet Geological Papers, Problem 10, Marine Geology.

15. Lisitzen, A. P., 1961. "Processes of Modern Sediment Formation in Southern and Central Parts of Indian Ocean," Modern Sediments of the Oceans and the Seas, Works of the Committee on Sediment Distribution.

16. Lisitzen, A. P., Shivago, A. V., 1958. "Bottom Relief and Sediments of the Southern Part of the Indian Ocean," Extracts of AS USSR, Heart of Geography, No. 2 and No. 3.

17. Neprochnov, U. P., 1961. "Thickness of Sediments in the Basins of the Arabian Sea," Papers of AS USSR, 139, No. 1.

18. Petelin, V. P., 1960. "About the Bottom Sediments of Western Parts of the Pacific Ocean," MGG, Oceanology Investigations, No. 2.

19. Sokolova, M. N., 1960. "About Some of the Special Dissemination of Biological Beds in the Northwestern Part of the Pacific Ocean," Works of the Committee on Sediment Distribution, AS USSR, 34.

20. Sesoev, N. N., 1959. "About Currents in the Oceans," Papers of AS USSR, 125, No. 5.

21. Sesoev, N. N., 1961. "To Study Natural Zones in the Ocean," Papers of AS USSR, 137, No. 3.

22. Udintsev, G. B., 1959. "Investigation of the Bottom Relief of Seas and Oceans," Subtitle - Successes in the Study of Oceanic Depths, Summary of Scientific Achievements in Oceanology, 1.

23. Udintsev, G. B., 1960. "Bottom Relief and Tectonics of the Western Part of the Pacific Ocean," International Geological Congress, XVI Session, Soviet Geological Papers, Problem 10, Marine Geology.

24. Udintsev, G. B., 1960. "About the Bottom Relief of the Western Part of the Pacific Ocean," MGG, Oceanological Investigations, No. 2.

25. Bezrukov, P. L., 1959. "Sediments of Trenches in the Northwestern Pacific," Ecologea Geol. Helv., 51, No. 3.

26. Dietz, R. S., 1953. "Possible Deep-Sea Turbidity Current Channels in the Indian Ocean," Bull. Geol. Soc. America, 64, No. 3.

27. Dietz, R. S., Menard, H. W., Hamilton, E. L., 1954, "Echograms of the Mid-Pacific Expedition," Deep-Sea Res., 1, No. 4.

28. Ericson, D. B., Ewing, M., Heezen, B. C., 1955. "Sediment Deposition in the Atlantic," Geol. Soc. America, Special Paper, 62.

29. Ericson, D. B., Ewing, M., Wollin, G., Heezen, B. C., 1961. "Atlantic Deep-Sea Sediment Cores," Bull. Geol. Soc. America, 2.

30. Hamilton, E. L., 1954. "Upper Cretaceous, Tertiary and Recent Planktonic Foraminifera from Mid-Pacific Flat-Topped Seamounts," J. Paleontol, 27.

31. Hamilton, E. L., 1956. "Sunken Islands of the Mid-Pacific Mountains," Geol. Soc. America, Mem., 64.

32. Hamilton, E. L., 1959. "Thickness and Consolidation of Deep-Sea Sediments," Bull. Geol. Soc. America, 70, No. 11.

33. Heezen, B. C., 1959. "Dynamic Processes of Abyssal Sedimentation: Erosion, Transportation and Redeposition on the Deep-Sea Floor," Geophys. J. Royal Astronomical Soc., 2, No. 2.

34. Heezen, B. C., Ewing, M., 1952. "Turbidity Currents and Submarine Slumps, and the Grand Banks Earthquake," Amer. Sci., 250.

35. Heezen, B. C., Tharp, M., Ewing, M., 1959. "The Floor of the Oceans. Part I," The North Atlantic Geol. Soc. America, Special Paper, 65.

36. Kossina, E., 1921. "Die Tiefen des Weltmeeres, Veroff.," Ints. Meereskunde, N. F. H. 9, B. S. 9.

37. Kuenen, Ph. H., Menard, H. W., 1952. "Turbidity Currents Graded and Non-Graded Deposits," J. Sediment., Petrol., 22, No. 2.

38. Menard, H. W., 1952. "Deep Ripple-Marks in the Sea," J. Sediment. Petrol., 22.

39. Menard, H. W., 1956. "Archipelagic Aprons," Bull. Amer. Assoc. Petrol. Geologists, 40, No. 9.

40. Menard, H. W., 1959. "Geology of the Pacific Sea Floor," Experientia, XV, No. 6.

41. Menard, H. W., 1955. "Deep Channels, Topography and Sediment," Bull. Amer. Assoc. Petrol. Geologists, 39, No. 2.

42. Murray, I., Renard, A., 1891. "Deep-Sea Deposits," Report of the Sci. Res. of the Voyage of H. M. S. Challenger, 1871-1876.

43. Raitt, R., 1956. "Seismic Studies Refraction of the Pacific Ocean Basins," Bull. Geol. Soc. America, 67, No. 12.

44. Riedel, W. R., Bramlette, M. N., 1959. "Tertiary Sediments in the Pacific Ocean Basin," Preprints International Oceanographic Congress, Washington.

45. Ruegg, W., 1960. "An Intra-Pacific Ridge, Its Continuation onto the Peruvian Mainland and Its Bearing on the Hypothetical Pacific Landmass," International Geological Congress, Report of the XXI Session, Part X, "Submarine Geology," Copenhagen.

46. Swallow, I. C., 1957. "Some Further Deep Current Measurements Using Neutrally-Buoyant Floats," Deep-Sea Res., 4, No. 2.

47. Swallow, M., 1961. "Deep Currents in the Open Ocean," Oceanus, VII, No. 3.

48. Shepard, F. R., 1959. "Turbidity Currents and Erosion of the Deep-Sea Floor," Preprints International Oceanographic Congress, Washington.

49. Wiseman, J. D. H., 1937. "Basalts from the Carlsberg Ridge, Indian Ocean," John Murray Expedition, III, No. 1.

50. Wiseman, J. D. H., Riedel, W. R., 1960. "Tertiary Sediments from the Floor of the Indian Ocean," Deep-Sea Res., 7, No. 3.

Navy Underwater Sound Laboratory
Report No. 575
THE IRREGULAR DISTRIBUTION OF DEEP-OCEAN SEDIMENTS, P. L. Bezrukov, Institute of Oceanology, Academy of Sciences, USSR, Translated by C. N. K. Mooers, Lt., USN, from OCEANOLOGY, Vol. 2, Issue 1, 1962. 27 March 1963.
i-ii + 24 pp., figs. UNCLASSIFIED

This paper is a literal translation of an article by P. L. Bezrukov appearing in Oceanology, Volume 2, Issue 1, 1962. The author reviews the relatively recent discoveries of the irregular distribution of deep ocean sediment chemical and granular composition as well as thickness. The contributing phenomena are identified:

1. Ocean bottom—Properties
2. Sediment—Distribution
I. Bezrukov P. L.
II. Mooers, C. N. K., Lt., USN, trans.
III. 1-409-00-00

complex bathymetry; suspension currents; volcanic, ice, and freshet transport; organic activity; and autogenesis. The increased density of geological observations, an intense study of a limited bottom area, the development of near-bottom current meters, and the creation of improved charting techniques are vigorously indicated as being required for the thorough study of ocean bottom properties.

1. Ocean bottom—Properties
2. Sediment—Distribution
I. Bezrukov, P. L.
II. Mooers, C. N. K., Lt., USN, trans.
III. 1-409-00-00

Navy Underwater Sound Laboratory
Report No. 575
THE IRREGULAR DISTRIBUTION OF DEEP-OCEAN SEDIMENTS, P. L. Bezrukov, Institute of Oceanology, Academy of Sciences, USSR, Translated by C. N. K. Mooers, Lt., USN, from OCEANOLOGY, Vol. 2, Issue 1, 1962. 27 March 1963.
i-ii + 24 pp., figs. UNCLASSIFIED

This paper is a literal translation of an article by P. L. Bezrukov appearing in Oceanology, Volume 2, Issue 1, 1962. The author reviews the relatively recent discoveries of the irregular distribution of deep ocean sediment chemical and granular composition as well as thickness. The contributing phenomena are identified:

1. Ocean bottom—Properties
2. Sediment—Distribution
I. Bezrukov, P. L.
II. Mooers, C. N. K., Lt., USN, trans.
III. 1-409-00-00

complex bathymetry; suspension currents; volcanic, ice, and freshet transport; organic activity; and autogenesis. The increased density of geological observations, an intense study of a limited bottom area, the development of near-bottom current meters, and the creation of improved charting techniques are vigorously indicated as being required for the thorough study of ocean bottom properties.

1. Ocean bottom—Properties
2. Sediment—Distribution
I. Bezrukov, P. L.
II. Mooers, C. N. K., Lt., USN, trans.
III. 1-409-00-00