XXIII.—ON THE NOMENCLATURE, ORIGIN, AND DISTRIBUTION OF DEEP-SEA DEPOSITS.

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[A paper read before the Royal Society of Edinburgh.]

The sea is unquestionably the most powerful dynamic agent on the surface of the globe, and its effects are deeply imprinted on the external crust of our planet; but among the sedimentary deposits which are attributed to its action, and among the effects which it has wrought on the surface features of the earth, the attention of geologists has, till within quite recent times, been principally directed to the phenomena which take place in the immediate vicinity of the land. It is incontestable that the action of the sea along coast and in shallow water has played the largest part in the formation and accumulation of those marine sediments which, so far as we can observe, form the principal strata of the solid crust of the globe; and it has been from an attentive study of the phenomena which take place along the shores of modern seas that we have been able to reconstruct in some degree the conditions under which the marine deposits of ancient times were laid down.

Attention has been paid only in a very limited degree to deposits of the same order, and, for the greater part, of the same origin, which differ from the sands and gravels of the shores and shallow waters only by a lesser size of the grains, and by the fact that they are laid down at a greater distance from the land and in deeper water. And still less attention has been paid to those true deep-sea deposits which are only known through systematic submarine investigations. One might well ask what deposits are now taking place, or have in past ages taken place, at the bottom of the great oceans at points far removed from land, and in regions where the erosive and transporting action of water has little or no influence. Without denying that the action of the tidal waves can, under certain special conditions, exert an erosive and transporting power at great depths in the ocean, especially on submerged peaks and barriers, it is none the less certain that these are exceptional cases, and that the action of waves is almost exclusively confined to the coasts of emerged land. There are in the Pacific immense stretches of thousands of miles where we do not encounter any land, and in the Atlantic we have similar conditions. What takes place in these vast regions where the waves exercise no mechanical action on any solid object? We are about to answer this question by reference to the facts which an examination of deep-sea sediments has furnished.

A study of the sediments recently collected in the deep sea shows that their nature and mode of formation, as well as their geographical and bathymetrical distribution, permit deductions to be made which have a great and increasing importance from a geological point of view. In making known the composition of these deposits and their distribution, the first outlines of a geological map of the bottom of the ocean will be sketched.

This is not the place to give a detailed history of the various contributions to our knowledge of the terrigenous deposits in deep water near land, or of those true deep-sea deposits far removed from land, which may be said to form the special subject of this communication. From the time of the first expeditions undertaken with a view of ascertaining the depth of the ocean, small quantities of mud have been collected by the sounding lead and briefly described. We may recall in this connection the experiments of Ross and the observations of Hooker and Maury.

These investigations, made with more or less imperfect appliances, immediately fixed the attention, without, however, giving sufficient information on which to establish any general conclusions as to the nature of the deposits or their distribution in the depths of the sea.

When systematic soundings were undertaken with a view of establishing telegraphic communication between Europe and America, the attention of many distinguished men was directed to the importance, in a biological and geological sense, of the specimens of mud brought up from great depths. The observations of Wallich, Huxley, Agassiz, Baily, Pourtalès, Carpenter, Thomson, and many others, while not neglecting mineralogical and chemical composition, deal with this only in a subordinate manner. The small quantities of each specimen at their command, and the limited areas from which they were collected, did not permit the establishment of any general laws as to their composition or geographical and bathymetrical distribution. These early researches, however, directed attention to the geological importance of deep-sea deposits, and prepared the way for the expeditions organized with the special object of a scientific exploration of the great ocean basins.

The expedition of the Challenger takes the first rank in these investigations. During that expedition a large amount of material was collected and brought to England for fuller study under the charge of Mr. Murray, who has in several preliminary papers pointed out the composition and varieties of deposits which are now forming over the floor of the great oceans. In order to arrive at results as general as possible, it was resolved to investigate the subject from the biological, mineralogical, and chemical points of view, and M. Renard was associated with Mr. Murray in the work. In addition to the valuable collections and observations made by the Challenger, we have had for examination material collected by other British ships, such as the Porcupine, Bulldog, Valorous, Nassau, Swallow, Dove; and, through Professor Mohn, by the Norwegian North Atlantic expedition. Again, through the liberality of the United States Coast Survey and Mr. Agassiz, the material amassed in the splendid series of soundings taken by the American ships Tuscarora, Blake, and Gettysburg, were placed in our hands. The results at which we have arrived may therefore be said to have been derived from a study of all the important available material.

The work connected with the examination and description of these large collections is not yet completed, but it is sufficiently advanced to permit some general conclusions to be drawn which appear to be of considerable importance. In addition to descriptions and results, we shall briefly state the methods we have adopted in the study. All the details of our research will be given in the report on the deep-sea deposits in the Challenger series, which will be accompanied by charts indicating the distribution, plates showing the principal types of deposits as seen by the microscope, and numerous analyses giving the chemical composition and its relation to the mineralogical composition. The description of each sediment will be accompanied by an enumeration of the organisms dredged with the sample, so as to furnish all the biological and mineralogical information which we possess on deep-sea deposits, and finally, we shall endeavor to establish general conclusions which can only be indicated at present.

Before entering on the subject, we believe it right to point out the difficulties which necessarily accompany such a research as the one now under consideration, difficulties which arise often in part from the small quantity of the substance at our disposal, but also from the very nature of the deposit. Since we have endeavored to determine, with great exactitude, the composition of the deposit at any given point, we have, whenever possible, taken the sample collected in the sounding-tube. That procured by the trawl or dredge, although usually much larger, is not considered so satisfactory on account of the washing and sorting to which the deposit has been subjected while being hauled through a great depth of water. We have, however, always examined carefully the contents of these instruments, although we do not think the material gives such a just idea of the deposit as the sample collected by the sounding-tube. The material collected by the last-named instrument has been taken as the basis of our investigations, although the small quantity often gives to it an inherent difficulty. It was the small quantity of substance collected by the sounding-tube in early expeditions which prevented the first observers from arriving at any definite results, but when such small samples are supplemented by occasional large hauls from the dredge or trawl, they become much more valuable and indicative of the nature of the deposit as a whole. Not only the scantiness of the material, but the small size of the grains, which in most instances make up deep-sea deposits, render the determinations difficult. In spite of the improvements recently effected in the microscopical examination of minerals, it is impossible to apply all the optical resources of the instrument to the determination of the species of extremely fine, loose, and fractured particles. Again, the examination of these deposits is rendered difficult by the presence of a large quantity of amorphous mineral matter, and of shells, skeletons, and minute particles of organic origin. It is also to be observed that we have not to deal with pure and unaltered mineral fragments, but with particles upon which the chemical action of the sea has wrought great changes, and more or less destroyed their distinctive characters.

What still further complicates these researches is the endeavor to discover the origin of the heterogeneous materials which make up the deposits. These have been subjected to the influence of a great number of agents, of some of which our knowledge is to a great extent still in its infancy. We must take into account a large number of agents and processes, such as ocean currents; the distribution of temperature in the water at the surface and at the bottom; the distribution of organisms as dependent on temperature and specific gravity of the water; the influence of aerial currents; the carrying power of rivers; the limit of transport by waves; the eruptions of aerial and submarine volcanoes; the effect of glaciers in transporting mineral particles, and, when melting, influencing the specific gravity of the water, which in turn affects the animal and plant life of the surface. It is necessary to study the chemical reactions which take place in great depths; in short, to call to our aid all the assistance which the physical and biological sciences can furnish. It will thus be understood that the task, like all first attempts in a new field, is one of exceptional difficulty, and demands continued effort to carry it to a successful issue.

In presenting a short résumé of our methods, of the nomenclature we have adopted, and of the investigation into the origin of the deposit in the deep sea and deeper parts of the littoral zones, we offer it as a sketch of our research, prepared to modify the arrangements in any way which an intelligent criticism may suggest.

Before proceeding to a description of methods and of the varieties of deposits, with their distribution in modern ocean, we will briefly enumerate the materials which our examination has shown to take part in the formation of these deposits, state the origin of the material, and the agent concerned in their deposition, distribution, and modification.

MATERIALS.—The materials which unite to form the deposits which we have to describe may be divided into two groups, viewed in relation to their origin, viz, mineral and organic.

The mineral particles carried into the ocean have a different form and size, according to the agents which have been concerned in their transport. Generally speaking, their size diminishes with distance from the coast, but here we limit our remarks to the mineralogical character of the particles. We find isolated fragments of rocks and minerals coming from crystalline and schisto-crystalline series, and from the clastic and sedimentary formations; according to the nature of the nearest coasts they belong to granite, diorite, diabase, porphyry, &c.; crystalline schists, ancient limestones, and sedimentary rocks of all geological ages, with the minerals which come from their disintegration, such as quartz, monoclinic and triclinic feldspars, hornblende, augite, rhombic pyroxene, olivine, muscovite, biotite, titanic and magnetic iron, tourmaline, garnet, epidote, and other secondary minerals. The trituration and decomposition of these rocks and minerals give rise to materials more or less amorphous and without distinctive characters, but the origin of which is indicated by association with the rocks and minerals just mentioned.

Although the *débris* of continental land to which we have just referred plays the most important *rôle* in the immediate vicinity of shores, yet our researches show beyond doubt that when we pass out towards the central parts of the great ocean basins, the *débris* of continental rocks gradually disappears from the deposits, and its place is taken by materials derived from modern volcanic rocks, such as basalts, trachytes, augite-andesites, and vitreous varieties of these lithological families, for instance, pumice, and loose, incoherent, volcanic particles of recent eruptions, with their characteristic minerals. All these mineral substances being usually extremely fine or areolar in structure, are easily attacked by the sea water at the place where they are deposited. This chemical action brings about an alteration of the minerals and vitreous fragments, which soon passes into complete decomposition, and in special circumstances gives rise to the formation of secondary products. In some places the bottom of the sea is covered with deposits due to this chemical action, principal among which is clayey matter, associated with which there are often concretions composed of manganese and iron. In other regions the reactions which result in the formation of argillaceous matter from volcanic products give rise also to the formation of zeolites.

Among other products arising from chemical action, probably combined with the activity of organic matter, may be mentioned the formation of glauconite and phosphatic nodules, with, in some rare and doubtful examples, the deposition of silica. The decomposition of the tissues, shells, and skeletons of organisms adds small quantities of iron, fluorine, and phosphoric acid to the inorganic constituents of the deep-sea deposits.

Finally, we must mention extra-terrestrial substances in the form of cosmic dust.

We now pass to the consideration of the *rôle* played by organisms in the formation of marine deposits. Organisms living at the surface of the ocean, along the coasts, and at the bottom of the sea are continually extracting the lime, magnesia, and silica held in solution in sea water. The shells and skeletons of these, after the death of the animals and plants, accumulate at the bottom and give rise to calcareous and siliceous deposits. The calcareous deposits are made up of the remains of coccospheres, rhabdospheres, pelagic and deep-sea Foraminifera, pelagic and deep-sea Mollusks, Corals, Alcyonarians, Polyzoa, Echinoderms, Annelids, Fish, and other organisms. The siliceous deposits are formed principally of frustules of Diatoms, skeletons of Radiolarians, and spicules of Sponges.

While the minute pelagic and deep-sea organisms above mentioned play by far the most important part in the formation of deep-sea deposits, the influence of vertebrates is recognizable only in a very slight degree in some special regions by the presence of large numbers of sharks' teeth and the ear bones and a few other bones of whales. The otoliths of fish are usually present in the deposits, but, with the exception of two vertebræ and a scapula, no other bones of fish have been detected in the large amount of material we have examined.

AGENTS.—Having passed in review the various materials which go to the formation of deposits in the deep water immediately surrounding the land and in the truly oceanic areas, attention must now be directed to the agents which are concerned in the transport and distribution of these, and to the sphere of their action. The relations existing between the organic and inorganic elements of deposits to which we have just referred, and the laws which determine their distribution, will be pointed out at the same time.

The fluids which envelop the solid crust of the globe are incessantly at work disintegrating the materials of the land, which, becoming loose and transportable, are carried away, sometimes by the atmosphere, sometimes by water, to lower regions, and are eventually borne to the ocean in the form of solid particles or as matter in solution. The atmosphere, when agitated, after having broken up the solid rock, transports the particles from the continents, and in some regions carries them far out to sea, where they form an appreciable portion of the deposit, as, for instance, off the west coast of North Africa and the southwest coast of Australia. Again, in time of volcanic eruptions, the dust and scoria which are shot into the air are carried immense distances by winds and atmospheric currents, and no small portion eventually falls into the sea.

Water is, however, the most powerful agent concerned in the formation and distribution of marine sediments. Running water corrodes the surface of the land and carries the triturated fragments down into the ocean. The waters of the ocean, in form of waves and tides, attack the coast and distribute the débris at a lower level. Independently of the action of the waves, there exists along most coasts currents, more or less constant, which have an effect in removing sand, gravel, and pebbles farther from their origin. Generally, terrestrial matters appear to be distributed by these means to a distance of one or two hundred miles from the coast. Waves and currents probably have no erosive or transporting power at depths greater than 200 or 300 fathoms, and even at such depths it is necessary that there should be some local and special conditions in order that the agitated water may produce any mechanical effect. However, it is not improbable that, by a peculiar configuration of the bottom and ridges among oceanic islands, the deposit on a ridge may be disturbed by the tidal wave even at 1,000 fathoms; and this may be the cause of the hard ground sometimes met with in such positions. By observations off the coast of France it has been shown that fine mud is at times disturbed at a depth of 150 fathoms; but while admitting that this is the case on exposed coasts, the majority of observations indicate that beyond 100 fathoms it is an oscillation of the water, rather than a movement capable of exerting any geological action, which concerns us in this connection.

Although the great oceanic currents have no direct influence upon the bottom, yet they have a very important indirect effect upon deposits, because the organisms which live in the warm equatorial currents form a very large part of the sediment being deposited there, and this in consequence differs greatly from the deposits forming in regions where the surface water is colder. In the same way a high or low specific gravity of the surface water has an important bearing on the animal and vegetable life of the ocean, and this in its turn affects the character of the deposits.

The thermometric observations of the Challenger show that a slow movement of cold water must take place in all the greater depths of the ocean from the poles, but particularly from the southern pole, towards the equator. It could be shown from many lines of argument that this extremely slow massive movement of the water can have no direct influence on the distribution of marine sediments.

Glaciers, which eventually became icebergs that are carried far out to sea by currents, transport detrital matter from the land to the ocean, and thus modify in the Arctic and Antarctic regions the deposits taking place in the regions affected by them. The detritus from icebergs in the Atlantic can be traced as far south as latitude 36° off the American coast, and in the southern hemisphere as far north as latitude 40°.

The fact that sea water retains fine matter in suspension for a much shorter time than fresh water should be referred to here as having an important influence in limiting the distribution of fine argillaceous and other materials borne down to the sea by rivers, thus giving a distinctive character to deposits forming near land.

We have pointed out the influence of the temperature and salinity upon the distribution of the surface organisms whose skeletons form a large part of some oceanic deposits, and may state also that the bathymetrical distribution of calcareous organisms is influenced by the chemical action of sea water. We will return to these influences presently when describing the distribution of the various kinds of deposits and their reciprocal relations, especially in those regions of the deep sea far removed from the mechanical action of rivers, waves, and superficial currents. The action of life as a geological agent has been indicated under the heading Materials.

METHODS.—We give here an example showing the order followed in describing the deposits examined:

Station 338; latitude 21° 15′ S., longitude 14° 2′ W.; March 21, 1876; surface temperature, 76°.5; bottom temperature, 36°.5; depth, 1,990 fathoms.

Globigerina ooze, white, with slightly rosy tinge when wet; granular, homogeneous, and very slightly coherent when dry; resembles chalk.

I. Carbonate of calcium, 90.38 per cent., consists of pelagic Foraminifera (80 per cent.); coccoliths and rhabdoliths (9 per cent.); Miliolas, Discorbinas, and other Foraminifera, Ostracode valves, fragments of Echini spines, and one or two small fragments of Pteropods (1.38 per cent.).

II. Residue, 9.62 per cent., reddish brown, consists of—

1. Minerals [1.62] m. di. 0.45^{mm}, fragments of feldspar, hornblende, magnetite, magnetic spherules, a few small grains of manganese, and pumice.

2. Siliceous organisms [1.00], Radiolarians, spicules of Sponges, and imperfect casts of Foraminifera.

3. Fine washings [7.00], argillaceous matter with small mineral particles and fragments of pumice and siliceous organisms.

The description of the deposits has been made upon this plan, which was adopted after many trials and much consideration. This is not the place to give the reasons which have guided us in adopting this mode of description, or to give in detail the methods that we have systematically employed for all the sediments which we are engaged in describing. These will be fully given in the introduction to our Challenger report. We limit ourselves here to explaining the meanings and arrangement of terms and abbreviations, so that the method may be understood and made available for others.

The description commences by indicating the kind of deposit (red clay, blue mud, Globigerina ooze, &c.), with the microscopic characters of the deposit, when wet or dry.

We have always endeavored to give a complete chemical analysis of the deposit, but when it was impossible to do this we have always determined the amount of carbonate of calcium. This determination was generally made by estimating the carbonic acid. We usually took a gram of a mean sample of the substance for this purpose, using weak and cold hydrochloric acid. However, as the deposits often contain carbonates of magnesia and iron as well, the results calculated by associating the carbonic acid with the lime are not perfectly exact, but these carbonates of magnesia and iron are almost always in a very small proportion, and the process is, we think, sufficiently accurate, for, owing to the sorting of the elements which goes on during collection and carriage, no two samples from the same station give exactly the same percentage. The number which follows the words "carbonate of calcium" indicates the percentage of $CaCO_3$; we then give the general designations of the principal calcareous organisms in the deposit.

The part insoluble in the hydrochloric acid, after the determination of the carbonic acid, is designated in our descriptions "residue." The number placed after this word indicates its percentage in the deposit; then follow the color and principal physical properties. This residue is washed and submitted to decantations, which separate the several constituents according to their density; these form three groups, (1) minerals, (2) siliceous organisms, (3) fine washings.

1. MINERALS.—The number within brackets indicates the percentage of particular minerals and fragments of rocks. This number is the result of an approximate evaluation, of which we will give the basis in our report. As it is important to determine the dimensions of the grains of minerals which constitute the deposit, we give, after the contraction *m. di.*, their mean diameter in millimeters. We give next the form of the grains, if they are rounded or angular, &c.; then the enumeration of the species of minerals and rocks. In this enumeration we have placed the minerals in the order of the importance of the *rôle* which they play in the deposit. The specific determinations have been made with the mineralogical microscope in parallel or convergent polarized light.

2. SILICEOUS ORGANISMS.—The number between brackets indicates the percentage of siliceous organic remains; we obtain it in the same manner as that placed after the word "minerals." The siliceous organisms and their fragments are examined with the microscope and determined. We have also placed under this heading the Glauconitic casts of the Foraminifera and other calcareous organisms.

3. FINE WASHINGS.—We designate by this name the particles which, resting in suspension, pass with the first decantation. They are about 0.04^{mm} or less in diameter. We have been unable to arrange this microscopic matter under the category of minerals, for, owing to its minute and fragmentary nature, it is impossible to determine the species. We have always found that the fine washings increase in quantity as the deposit passes to a clay, and it is from this point of view that the subdivision has its *raison d'être*. We often designate the lightest particles by the name argillaceous matter, but usually there are associated with this very small particles of indeterminable minerals and fragments of siliceous organisms. The number within brackets which follows the words "fine washings" is obtained in the same manner as those placed after "minerals" and "siliceous organisms."

These few words will suffice to render the descriptions intelligible. Greater details will be given, as already stated in the Challenger report.

It may be added that in the majority of cases we have solidified the sediments and formed them into thin slides for microscopic examination, and that at all times the examination by transmitted light has been carried on at the same time as the examination by reflected light. Each description is followed by notes upon the dredging or sounding, upon the animals collected, and a discussion of the analysis whenever a complete analysis has been made, which is always the case with typical samples of the deposits.

KINDS OF DEPOSITS.—We now proceed to the description of the various types of deposits into which it is proposed to divide the marine formations that are now taking place in the deeper water of the various oceans and seas. We will speak first of those which are met with in the deeper water of inland seas, and around the coasts of continents and islands, and afterwards of those which are found in the abysmal regions of the great oceans. Those coast formations which are being laid down on the shores, or in very shallow water, and which have been somewhat carefully described previous to the recent deep-sea explorations, are here neglected.

A study of the collections made by the Challenger and other expeditions shows—

(1.) That in the deeper water around continents and islands which are neither of volcanic nor coral origin, the sediments are essentially composed of a mixture of sandy and amorphous matter, with a few remains of surface organisms, to which we give the name of muds, and which may be distinguished microscopically by their color. We distinguish them by the names blue, red, and green muds.

(2.) Around volcanic islands the deposits are chiefly composed of mineral fragments derived from the decomposition of volcanic rocks. These, according to the size of the grains, are called volcanic muds or sands.

(3.) Near coral islands and along shores fringed by coral reefs the deposits are calcareous, derived chiefly from the disintegration of the neighboring reefs, but they receive large additions from shells and skeletons of pelagic organism, as well as from animals living at the bottom. These are named, according to circumstances, coral or coralline muds and sands.

Let us now see what are the chief characteristics of each of these deposits.

Blue mud is the most extensive deposit now forming around the great continents and continental islands and in all inclosed or partially inclosed seas. It is characterized by the slaty color which passes in most cases into a thin layer of a reddish color at the upper surface. These deposits are colored blue by organic matter in a state of decomposition and frequently give off an odor of sulphureted hydrogen. When dried a blue mud is grayish in color and rarely or never has the plasticity and compactness of a true clay. It is finely granular and occasionally contains fragments of rocks 2^{cm} in diameter; generally, however, the minerals, which are derived from the continents and are found mixed up with the muddy matter in these deposits, have a diameter of 0.5^{mm} and less. Quartz particles, often rounded, play the principal part; next come mica, feldspar, augite, hornblende, and all the mineral species which come from the disintegration of the neighboring lands, or the lands traversed by rivers which enter the sea near the place where the specimens have been collected. These minerals make up the principal and characteristic portion of blue muds, sometimes forming 80 per cent. of the whole deposit. Glauconite, though generally present, is never abundant in blue muds. The remains of calcareous organisms are at times quite absent, but occasionally they form over 50 per cent. The latter is the case when the specimen is taken at a considerable distance from the coast and at a moderate depth. These calcareous fragments consist of bottom-living and pelagic Foraminifera, Mollusks, Polyzoa, Serpulæ, Echinoderms, Alcyonarian-spicules, Corals, &c. The remains of Diatoms and Radiolarians are usually present. Generally speaking, as we approach the shore the pelagic organisms disappear, and, on the contrary, as we proceed seawards, the size of the mineral grains diminishes, and the remains of shore and coast organisms give place to pelagic ones, till finally a blue mud passes into a true deep-sea deposit. In those regions of the ocean affected with floating ice the color of these deposits becomes gray rather than blue at great distances from land, and is further modified by the presence of a greater or less abundance of glaciated blocks and fragments of quartz.

Green muds and sands.—As regards their origin, composition, and distribution near the shores of continental land, these muds and sands resemble the blue muds. They are largely composed of argillaceous matter and mineral particles of the same size and nature as in the blue muds. Their chief characteristic is the presence of a considerable quantity of glauconitic grains, either isolated or united into concretions. In the latter case the grains are cemented together by a brown argillaceous matter, and include, besides quartz, feldspar, phosphate of lime, and other minerals, more or less altered. The Foraminifera and fragments of Echinoderms and other organisms in these muds are frequently filled with glauconitic substance, and beautiful casts of these organisms remain after treatment with weak acid. At times there are few calcareous organisms in these deposits, and at other times the remains of diatoms and radiolarians are abundant. When these muds are dried they become earthy and of a gray-green color. They frequently give out a sulphureted hydrogen odor. The green color appears sometimes to be due to the presence of organic matter, probably of vegetable origin, and to the reduction of peroxide of iron to protoxide under its influence. The green sands differ from the muds only in the comparative absence of the argillaceous and other amorphous matter, and by the more important part played by the grains of glauconite, which chiefly give the green color to these sands.

Red muds.—In some localities, as for instance off the Brazilian coast of America, the deposits differ from blue muds by the large quantity of ochreous matter brought down by the rivers and deposited along the coast. The ferruginous particles when mixed up with the argillaceous matter give the whole deposit a reddish color. These deposits, rich in iron in the state of limonite, do not appear to contain any traces of glauconite, and have relatively few remains of siliceous organisms.

Volcanic muds and sands.—The muds and sands around volcanic islands are black or gray; when dried they are rarely coherent. The mineral particles are generally fragmentary, and consist of lapilli of the basic and acid series of modern volcanic rocks, which are scoriaceous or compact vitreous or crystalline, and usually present traces of alteration. The minerals are sometimes isolated, sometimes surrounded by their matrix, and consist principally of plagioclases, sanadin, amphibole, pyroxene, biotite, olivine, and magnetic iron; the size of the particles diminishes with distance from the shore, but the mean diameter is generally 0.5^{mm}. Glauconite does not appear to be present in these deposits, and quartz is also very rare or absent. The fragments of shells and rocks are frequently covered with a coating of peroxide of manganese. Shells of calcareous organisms are often present in great abundance, and render the deposit of a lighter color. The remains of Diatoms and Radiolarians are usually present.

Coral muds.—These muds frequently contain as much as 95 per cent. of carbonate of lime, which consist of fragments of Corals, calcareous Algæ, Foraminifera, Serpulæ, Mollusks, and remains of other lime-secreting organisms. There is a large amount of amorphous calcareous matter, which gives the deposit a sticky and chalky character. The particles may be of all sizes, according to the distance from the reefs, the mean diameter being 1 to 2^{mm}, but occasionally there are large blocks of coral and large calcareous concretions; the particles are white and red. Remains of siliceous organisms seldom make up over 2 or 3 per cent. of a typical coral mud. The residue consists usually of a small amount of argillaceous matter, with a few fragments of feldspar and other volcanic minerals; but off barrier and fringing reefs facing continents we may have a great variety of rocks and minerals. Beyond a depth of 1,000 fathoms off coral islands the *débris* of the reefs begins to diminish and the remains of pelagic organisms to increase; the deposit becomes more argillaceous, of a reddish or rose color, and gradually passes into a Globigerina ooze or red clay. Coral sands contain much less amorphous matter than coral muds, but in other respects they are similar, the sands being usually found nearer the reefs and in shallower water than the muds, except inside lagoons. In some regions the remains of calcareous algæ predominate, and in those cases the name coralline mud or sand is employed to point out the distinction.

Such is a rapid view of the deposits found in the deeper waters of the littoral zones, where the débris from the neighboring land plays the most important part in the formation of muds and sands.

When, however, we pass beyond a distance of about 200 miles from land, we find that the deposits are characterized by the great abundance of fragmentary volcanic materials which have usually undergone great alteration, and by the enormous abundance of the shells and skeletons of minute pelagic organisms which have fallen to the bottom from the surface waters. These true deep-sea deposits may be divided into those in which the organic elements predominate, and those in which the mineral constituents play the chief part. We shall commence with the former.

GLOBIGERINA OOZE.—We designate by this name all those truly pelagic deposits containing over 40 per cent. of carbonate of lime, which consists principally of the dead shells of pelagic *Foraminifera*, *Globigerina*, *Orbulina*, *Pulvinulina*, *Pullenia*, *Sphæroidina*, &c. In some localities this deposit contains 95 per cent. of carbonate of lime. The color is milky white, yellow, brown, or rose, the varieties of color depending principally on the relative abundance in the deposit of the oxides of iron and manganese. This ooze is fine grained; in the tropics some of the Foraminifera shells are microscopic. When dried it is pulverulent. Analyses show that the sediment contains, in addition to carbonate of lime, phosphate and sulphate of lime, carbonate or magnesia, oxides of iron and manganese, and argillaceous matters. The residue is of a reddish brown tinge. Lapilli, pumice, and glassy fragments often altered into palagonite, seem always to be present, and are frequently very abundant. The mineral particles are generally angular, and rarely exceed 0.08^{mm} in diameter; monoclinic and triclinic feldspars, augite, olivine, hornblende, and magnetite are the most frequent. When quartz is present it is in the form of minute, rounded, probably wind-borne grains, often partially covered with oxide of iron. More rarely we have white and black mica, bronzite, actinolite, chromite, glauconite, and cosmic dust. Siliceous organisms are probably never absent, sometimes forming 20 per cent. of the deposit, at other times only recognizable after careful microscopic examination. In some regions the frustules of Diatoms predominate, in others the skeletons of Radiolarians.

The fine washings, viewed with the microscope, are not homogeneous. The greater part consists of argillaceous matter colored by the oxides of manganese. Mixed with this, we distinguish fragments of minerals with a diameter less than 0.05^{mm}, and minute particles of pumice can nearly always be detected. Fragments of Radiolarians, Diatoms, and siliceous spicules can always be recognized, and are sometimes very abundant.

PTEROPOD OOZE.—This deposit differs in no way from a Globigerina ooze except in the presence of a greater number and variety of pelagic organisms, and especially in the presence of Pteropod and Heteropod shells, such as *Diacria*, *Atlanta*, *Styliola*, *Carinaria*, &c. The shells of the more delicate species of pelagic Foraminifera and young shells are also more abundant in these deposits than in a Globigerina ooze. It must be remembered that the name "Pteropod ooze" is not intended to indicate that the deposit is chiefly composed of the shells of these mollusks, but as their presence in a deposit is characteristic and has an important bearing on geographical and bathymetrical distribution, we think it desirable to emphasize the presence of these shells in any great abundance. It may here be pointed out that there is a very considerable difference between a Globigerina ooze or a Pteropod ooze situated near continental shores and deposits bearing the same names situated towards the centers of oceanic areas, both with respect to mineral particles and remains of organisms.

DIATOM OOZE.—This ooze is of a pale straw color, and is composed principally of the frustules of Diatoms. When dry it is a dirty white siliceous flour, soft to the touch, taking the impression of the fingers, and contains gritty particles which can be recognized by the touch. It contains on an average about 25 per cent. of carbonate of lime, which exists in the deposit in the form of small Globigerina shells, fragments of Echinoderms and other organisms. The residue is pale white and slightly plastic; minerals and fragments of rocks are in some cases abundant; these are volcanic, or, more frequently, fragments and minerals coming from continental rocks and transported by glaciers. The fine washings consist essentially of praticles of Diatoms along with argillaceous and other amorphous matter. We estimate that the frustules of Diatoms and skeletons of siliceous organisms make up more than 50 per cent. of this deposit.

RADIOLARIAN OOZE.—It was stated when describing a Globigerina ooze that Radiolarians were seldom, if ever, completely absent from marine deposits. In some regions they make up a considerable portion of a Globigerina ooze, and are also found in Diatom ooze and in the terrigenous deposits of the deeper water surrounding the land. In some regions of the Pacific, however, the skeletons of these organisms make up the principal part of the deposits, and to these we have given the name "Radiolarian ooze." The color is reddish or deep brown, due to the presence of the oxides of iron and manganese. The mineral particles consist of fragments of pumice, lapilli, and volcanic minerals, rarely exceeding 0.07^{mm} in diameter. There is not a trace of carbonate of lime in the form of shells in some samples of Radiolarian ooze, but other specimens contain 20 per cent. of carbonate of lime, derived from the shells of pelagic Foraminifera. The clayey matter and mineral particles in this ooze are the same as those found in the red clays, which we will now proceed to describe.

RED CLAY.—Of all the deep-sea deposits this is one which is distributed over the largest areas of the modern oceans. It might be said that it exists everywhere in the abysmal regions of the ocean basins, for the residue in the organic deposits, which has been described under the name Globigerina, Pteropod, and Radiolarian ooze, is nothing else than the red clay. However, this deposit only appears in its characteristic form in those areas where the terrigenous minerals and calcareous and siliceous organisms disappear to a greater or less extent from the bottom. It is in the central regions of the Pacific that we meet with the typical examples. Like other marine deposits this one passes literally, according to position and depth, into the adjacent kind of deep-sea ooze or mud.

The argillaceous matters are of a more or less deep brown tint from the presence of the oxides of iron and manganese. In the typical examples no mineralogical species can be distinguished by the naked eye, for the grains are exceedingly fine and of nearly uniform dimensions, rarely exceeding 0.05^{mm} in diameter. It is plastic and greasy to the touch; when dried it coagulates into lumps so coherent that considerable force must be employed to break them. It gives the brilliant streak of clay, and breaks down in water. The pyrognostic properties show that we are not dealing with a pure clay, for it fuses easily before the blow-pipe into a magnetic bead.

Under the term "red clay" are comprised three deposits in which the characters of clay are not well pronounced, but which are mainly composed of minute particles of pumice and other volcanic material which, owing to their relatively recent deposition, have not undergone great alterations. If we calculate the analyses of red clay, it will be seen, moreover, that the silicate of alumina present as clay ($2\ SiO_2, Al_2O_3 + 2\ H_2O$) comprises only a relatively small portion of the sediment; the calculation shows always an excess of free silica, which is attributed chiefly to the presence of siliceous organisms.

Microscopic examination shows that a red clay consists of argillaceous matter, minute mineral particles, and fragments of siliceous organisms; in a word, it is in all respects identical with the residue of the organic oozes. The mineral particles are, for the greater part, of volcanic origin, except in those cases where continental matters are transported by floating ice, or where the sand of deserts has been carried to great distances by winds. These volcanic minerals are the same constituent minerals of modern eruptive rocks enumerated in the description of volcanic muds and sands. In the great majority of cases they are accompanied by fragments of lapilla, and of pumice more or less altered. Vitreous volcanic matters belonging to the acid and basic series of rocks predominate in the regions where the red clay has its greatest development, and it will be seen presently that the most characteristic decompositions which there take place are associated with pyroxenic lavas.

Associated with the red clay are almost always found concretions and microscopic particles of the oxides of iron and manganese, to which the deposit owes its color. Again, in the typical examples of the deposit zeolites in the form of crystals and crystalline spherules are present, along with metallic globules and silicates, which are regarded as of cosmic origin. Calcareous organisms are so generally absent in the red clay that they cannot be regarded as characteristic. When present they are chiefly the shells of pelagic Foraminifera, and are usually met with in great numbers in the surface layers of the deposit, to which they give a lighter color. On the other hand, the remains of Diatoms, Radiolarians, and Sponge-spicules are generally present, and are sometimes very abundant. The ear-bones of various cetaceans, as well as the remains of other cetacean bones, and the teeth of sharks, are, in some of the typical samples far removed from the continents, exceedingly abundant, and are often deeply impregnated with or imbedded in thick coatings of oxides of iron and manganese. The remains of these vertebrates have seldom been dredged in the organic oozes, and still more rarely in the terrigenous deposits.

The fine washings, as examined with a power of 450 diameters, are composed of an amorphous matter, fragments of minerals, the remains of siliceous organisms, and coloring substances. What we call amorphous matter may be considered as properly the argillaceous matter, and presents characters essentially vague. It appears as a gelatinous substance, without definite contours, generally colorless, perfectly isotropic, and forms the base which agglutinates the other particles of the washings. As these physical properties are very indefinite, it is difficult to estimate even approximately the quantity present in a deposit. However, it augments in proportion as the deposit becomes more clayey, but we think that only a small quantity of this substance is necessary to give a clayey character to a deposit. Irregular fragments of minerals, small pieces of vitreous rocks, and remains of siliceous organisms predominate in this fundamental base. These particles probably make up about 50 per cent. of the whole mass of the fine washings, and this large percentage of foreign substances must necessarily mask the character of the clayey matter in which they are imbedded. The mineral particles are seldom larger than 0.01^{mm} in diameter, but descend from this size to the merest points. It is impossible, on account of their minuteness, to say to what mineral species they belong; their optical reactions are insensible, their outlines too irregular, and all special coloration has disappeared. All that can be reasonably said is that these minute mineral particles probably belong to the same species as the larger particles in the same deposit, such as feldspar, hornblende, magnetite, &c. In the case of pumice and siliceous organisms the fragments can, owing to their structure, be recognized when of a much less size than in the case of the above minerals.

It can be made out by means of the microscope that the coloring substances are hydrated oxides of iron and manganese. The former is scattered through the mass in a state of very fine division; in some points, however, it is more localized, the argillaceous matter here appearing with a browner tinge, but these spots are noticed gradually to disappear in the surrounding mass. The coloration given by the manganese is much more distinct. There are small, rounded brownish spots with a diameter of less than 0.01^{mm}, which disappear under the action of hydrochloric acid with disengagement of chlorine. These small round concretions, which are probably a mixture of the oxides of iron and manganese, will be described with more detail in the Challenger report.

The following table shows the nomenclature we have adopted:

TERRIGENOUS DEPOSITS.	Shore formations, Blue mud, Green mud and sand, Red mud,	Found in inland seas and along the shores of continents.
	Coral mud and sand, Coralline mud and sand, Volcanic mud and sand,	Found about oceanic islands and along the shores of continents.
PELAGIC DEPOSITS.	Red clay, Globigerina ooze, Pteropod ooze, Diatom ooze, Radiolarian ooze,	Found in the abysmal regions of the ocean basins.

GEOGRAPHICAL AND BATHYMETRICAL DISTRIBUTION.—In the preceding pages we have confined our remarks essentially to the lithological nature of the deep-sea deposits, including in this term the dead shells and skeletons of organisms. From this point of view it has been possible to define the sediments and to give them distinctive names. We now proceed to consider their geographical and bathymetrical distribution, and the relations which exist between the mineralogical and organic composition and the different areas of the ocean in which they are formed.

A cursory glance at the geographical distribution shows that the deposits which we have designated muds and sands are situated, at various depths, at no great distance from the land, while the organic oozes and red clays occupy the abysmal regions of the ocean basins far from land. Leaving out of view the coral and volcanic muds and sands which are found principally around oceanic islands, we notice that our blue muds, green muds and sands, red muds, together with all the coast and shore formations, are situated along the margins of the continents and in inclosed and partially inclosed seas. The chief characteristic of these deposits is the presence in them of continental *débris*. The blue muds are found in all the deeper parts of the regions just indicated, and especially near the embouchures of rivers. Red muds do not differ much from blue muds except in color, due to the presence of ferruginous matter in great abundance, and we find them under the same conditions as the blue muds. The green muds and sands occupy, as a rule, portions of the coast where detrital matter from rivers is not, apparently, accumulating at a rapid rate, viz, on such places as the Angulhas Bank, off the east coast of Australia, off the coast of Spain, and at various points along the coast of America.

Let us cast a glance at the region occupied by terrigenous deposits, in which we include all truly littoral formations. This region extends from high-water mark down, it may be, to a depth of over 4 miles, and in a horizontal direction from 60 to perhaps 300 miles seawards, and includes, in the view we take, all inland seas, such as the North Sea, Norwegian Sea, Mediterranean Sea, Red Sea, China Sea, Japan Sea, Caribbean Sea, and many others. It is the region of change and of variety with respect to light, temperature, motion, and biological conditions. In the surface waters the temperature ranges from 80° F. in the tropics to 28° F. in the polar regions. Below the surface down to the nearly ice-cold water found at the lower limits of the region in the deep sea there is in the tropics an equally great range of temperature. Plants and animals are abundant near the shore, and animals extend in relatively great abundance down to the lower limits of this region, which is now covered with these terrigenous deposits. The specific gravity of the water varies much, owing to mixture with river water or great local evaporation, and this variation in its turn affects the fauna and flora. In the terrigenous region tides and currents produce their maximum effect, and these influences can in some instances be traced to a depth of 300 fathoms, or nearly 2,000 feet. The upper or continental margin of the region is clearly defined by the high-water mark of the coast-line, which is constantly changing through breaker action, elevation, and subsidence. The lower or abysmal margin is less clearly marked out. It passes in most cases insensibly into the abysmal region, but may be regarded as ending when the mineral particles from the neighboring continents begin to disappear from the deposits, which then pass into an organic ooze or a red clay.

Contrast with these those conditions which prevail in the abysmal region in which occur the organic oozes and red clay, the distribution of which will presently be considered. This area comprises vast undulating plains from 2 to 5 miles beneath the surface of the sea, the average being about 3 miles, here and there interrupted by huge volcanic cones (the oceanic islands). No sunlight ever reaches these deep, cold tracts. The range of temperature over them is not more than 7°, viz, from 31° to 38° F., and is apparently constant throughout the whole year in each locality. Plant life is absent, and, although animals belonging to all the great types are present, there is no great variety of form or abundance of individuals. Change of any kind is exceedingly slow.

What is the distribution of deposits in this abysmal region of the earth's surface? In the tropical and temperate zones of the great oceans, which occupy about 110° of latitude between the two polar zones, at depths where the action of the waves is not felt, and at points to which the terrigenous materials do not extend, there are now forming vast accumulations of Globigerina and other Pelagic Foraminifera, coccoliths, rhabdoliths, shells of pelagic Mollusks, and remains of other organisms. These deposits may perhaps be called the sediments of median depths and of warmer zones, because they diminish in great depths and tend to disappear towards the poles. This fact is evidently in relation with the surface temperature of the ocean, and shows that pelagic Foraminifera and Mollusks live in the superficial waters of the sea, whence their dead shells fall into the bottom. Globigerina ooze is not found in inclosed seas nor in polar latitudes. In the southern hemisphere it has not been met with beyond the fiftieth parallel. In the Atlantic it is deposited upon the bottom at a very high latitude below the warm waters of the Gulf Stream, and is not observed under the cold descending polar current which runs south in the same latitude. These facts are readily explained if we admit that this ooze is formed chiefly by the shells of surface organisms which require an elevated temperature and a wide expanse of sea. But as long as the conditions of the surface are the same we would expect the deposits at the bottom also to remain the same. In showing that such is not the case we are led to take into account an agent which is in direct correlation with the depth. We may regard it as established that the majority of the calcareous organisms which make up the Globigerina and Pteropod oozes live in the surface waters, and we may also take for granted that there is always a specific identity between the calcareous organisms which live at the surface and the shells of these pelagic creatures found at the bottom. This observation will permit us to place in relation the organic deposits and those which are directly or indirectly the result of the chemical activity of the ocean. Globigerina ooze is found in the tropical zone at depths which do not exceed 2,400 fathoms, but when depths of 3,000 fathoms are explored in this zone of the Atlantic and Pacific there is found an argillaceous deposit without, in many instances, any trace of calcareous organisms. When we descend from the "submarine plateaus" to depths which exceed 2,250 fathoms the Globigerina ooze gradually disappears, passing into a grayish marl, and finally is wholly replaced by an argillaceous material, which covers the bottom at all depths greater than 2,900 fathoms.

The transition between the calcareous formations and the argillaceous ones takes place by almost insensible degrees. The thinner and more delicate shells disappear first. The thicker and larger shells lose little by little the sharpness of their contour and appear to undergo a profound alteration. They assume a brownish color, and break up in proportion as the calcareous constituent disappears. The red clay predominates more and more as the calcareous element diminishes in the deposit.

If we now recollect that the most important elements of the organic deposits have descended from the superficial waters, and that the variations in contour of the bottom of the sea cannot of themselves prevent the *débris* of animals and plants from accumulating upon the bottom, their absence in the red clay areas can only be explained by a decomposition under the action of a cause which we must seek to discover.

Pteropod ooze, it will be remembered, is a calcareous organic deposit, in which the remains of Pteropods and other pelagic Mollusca are present, though they do not always form a preponderating constituent, and it has been found that their presence is in correlation with the bathymetrical distribution.

In studying the nature of the calcareous elements which are deposited in the pelagic areas it has been noticed that, like the shells of the Foraminifera, those of the Thecosomatous Pteropoda, which live everywhere in the superficial waters, especially in the tropics, become fewer in number as the depth from which the sediments are derived increases. We have just observed that the shells of Foraminifera disappear gradually as we descend along a series of soundings from a point where the Globigerina ooze has abundance of carbonate of lime towards deeper regions; but we notice also that when the sounding-rod brings up a graduated series of sediments from a declivity descending into deep water, among the calcareous shells, those of the Pteropods and Heteropods disappear first in proportion as the depth increases. At depths less than 1,400 fathoms in the tropics a Pteropod ooze is found with abundant remains of Heteropods and Pteropods; deeper soundings then give a Globigerina ooze without these molluscan remains; and in the still greater depths, as before mentioned, there is a red clay in which calcareous organisms are nearly if not quite absent.

In this manner, then, it is shown that the remains of calcareous organisms are completely eliminated in the greatest depths of the ocean. For if such be not the case why do we find all these shells at the bottom of the shallower depths and not at all in the greater depths, although they are equally abundant on the surface at both places? There is reason to think that this solution of calcareous shells is due to the presence of carbonic acid throughout all depths of ocean water. It is well known that this substance dissolved in water is an energetic solvent of calcareous matter. The investigations of Buchanan and Dittmar have shown that carbonic acid exists in a free state in sea water, and, in the second place, Dittmar's analyses show that deep-sea water contains more lime than surface water. This is a confirmation of the theory which regards carbonic acid as the agent concerned in the total or partial solution of the surface shells before or immediately after they reach the bottom of the ocean, and is likewise in relation with the fact that in high latitudes, where fewer calcareous organisms are found at the surface, their remains are removed at lesser depths than where these organisms are in greater abundance. It is not improbable that sea water itself may have some effect in the solution of carbonate of lime, and, further, that the immense pressure to which water is subjected in great depths may have an influence on its chemical activity. We await the result of further researches on this point, which have been undertaken in connection with the Challenger reports.

We are aware that objections have been raised to the explanation here advanced on account of the alkalinity of sea water, but we may remark that alkalinity presents no difficulty which need be here considered (Dittmar, "Phys. Chem. Chall. Exp.," part 1, 1884).

This interpretation permits us to explain how the remains of Diatoms and Radiolarians (surface organisms like the Foraminifera) are found in greater abundance in the red clay than in a Globigerina ooze. The action which suffices to dissolve the calcareous matter has little or no effect upon the silica, and so the siliceous shells accumulate. Nor is this view of the case opposed to the distribution of the Pteropod ooze. At first we should expect that the Foraminifera shells, being smaller, would disappear from a deposit before the Pteropod shells; but if we remember that the latter are very thin and delicate, and, for the quantity of carbonate of lime present, offer a larger surface to the action of the solvent than the thicker, though smaller, Globigerina shells, we shall see the explanation of this apparent anomaly.

It remains now to point out the area occupied by the red clay. We have seen how it passes at its margins into organic calcareous oozes, found in the lesser depths of the abysmal regions, or into the siliceous organic oozes or terrigenous deposits. In its typical form the red clay occupies a larger area than any of the other true deep-sea deposits, covering the bottom in vast regions of the North and South Pacific, Atlantic, and Indian Oceans. As above remarked, this clay may be said to be universally distributed over the floor of the oceanic basins, but it only appears as a true deposit at points where the siliceous and calcareous organisms do not conceal its proper characters.

Having now indicated its distribution, we must consider the mode of its formation, and give, in addition, a concise description of the minerals and of the organic remains which are commonly associated with it. The origin of these vast deposits of clay is a problem of the highest interest. It was at first supposed that these sediments were composed of microscopic particles arising from the disintegration of the rocks by the rivers and by the waves on the coasts. It was believed that the matters held in suspension were carried far and wide by currents, and gradually fell to the bottom of the sea. But the uniformity of composition presented by these deposits was a great objection to this view. It could be shown, as we have mentioned above, that mineral particles, even of the smallest dimensions, continually set adrift upon disturbed waters, must, owing to a property of sea water, eventually be precipitated at no great distance from land. It has also been supposed that these argillaceous deposits owe their origin to the inorganic residue of the calcareous shells which are dissolved away in deep water, but this view has no foundation in fact. Everything seems to show that the formation of the clay is due to the decomposition of fragmentary volcanic products, whose presence can be detected over the whole floor of the ocean.

These volcanic materials are derived from floating pumice and volcanic ashes, ejected to great distances by terrestrial volcanoes and carried far by the winds. It is also known that beds of lava and of tufa are laid down upon the bottom of the sea. This assemblage of pyrogenic rocks, rich in aluminous silicates, decomposes under the chemical action of the water, and gives rise in the same way as do terrestrial volcanic rocks to argillaceous matters, according to reactions we can always observe on the surface of the globe, and which are too well known to need special mention here.

The detailed microscopic examination of hundreds of soundings has shown that we can always demonstrate in the argillaceous matter the presence of pumice, of lapilli, of silicates, and other volcanic minerals in various stages of decomposition.

As we have shown in another paper,* the deposit most widely distributed over the bed of modern seas is due to the decomposition of the products of the internal activity of the globe; and the final result of the chemical action of sea water is seen in the formation of this argillaceous matter, which is found everywhere in deep-sea deposits, sometimes concealed by the abundance of siliceous or calcareous organisms, sometimes appearing with its own proper characteristics associated with mineral substances, some of which allow us to appreciate the extreme slowness of its formation, or whose presence corroborates the theory advanced to explain its origin.

In the places where this red clay attains its most typical development we may follow, step by step, the transformation of the volcanic fragments into argillaceous matter. It may be said to be the direct product of the decomposition of the basic rocks, represented by volcanic glasses, such as hyalomelan and tachylite. This decomposition, in spite of the temperature approximating to zero (32° F.), gives rise, as an ultimate product, to clearly crystallized minerals, which may be considered the most remarkable products of the chemical action of the sea upon the volcanic matters undergoing decomposition. These microscopic crystals are zeolites lying free in the deposit, and are met with in greatest abundance in the typical red-clay areas of the Central Pacific. They are simple, twinned, or spheroidal groups, which scarcely exceed half a millimeter in diameter. The crystallographic and chemical study of them shows that they must be referred to christianite. It is known how easily the zeolites crystallize in the pores of eruptive rocks in process of decomposition; and the crystals of christianite, which we ob-

* "On Cosmic and Volcanic Dust," Proc. Roy. Soc. Edin., 1883–'84.

serve in considerable quantities in the clay of the center of the Pacific, have been formed at the expense of the decomposing volcanic matters spread out upon the bed of that ocean.

In connection with this formation of zeolites reference may be made to a chemical process whose principal seat is the red-clay areas, and which gives rise to nodules of manganiferous iron. This substance is almost universally distributed in oceanic sediments; yet it is not so much of the areas of its abundance that we intend to speak as to the fact of its occurrence in the red clay, because this association tends to show a common relation of origin. It is exactly in those regions where there is an accumulation of pyroxenic lavas in decomposition, containing silicates with a base of manganese and iron, such, for example, as augite, hornblende, olivine, magnetite, and basic glasses, that manganese nodules occur in greatest numbers. In the regions where the sedimentary action, mechanical and organic, as it were, suspended, and where, as will appear in the sequel, everything shows an extreme slowness of deposition, in these calm waters, favorable to chemical reactions, ferro-manganiferous substances form concretions around organic and inorganic centers.

These concentrations of ferric and manganic oxides, mixed with argillaceous materials whose form and dimensions are extremely variable, belong generally to the earthy variety or wad, but pass sometimes, though rarely, into varieties of hydrated oxide of manganese, with distinct indications of radially fibrous crystallization. The interpretation to which we are led in order to explain this formation of manganese nodules is the same as that which is admitted in explanation of the formation of coatings of this material on the surface of terrestrial rocks. These salts of manganese and iron, dissolved in water by carbonic acid, then precipitated in the form of carbonate of protoxide of iron and manganese, become oxidized, and give rise in the calm and deep oceanic regions to more or less pure ferro-manganiferous concretions. At the same time it must be admitted that rivers may bring to the ocean a contribution of these same substances.

Among the bodies which, in certain regions where red clay predominates, serve as centers for these manganiferous nodules, are the remains of vertebrates. These remains are the hardest parts of the skeleton—tympanic bones of whales, beaks of Ziphius, teeth of sharks; and just as the calcareous shells are eliminated in the depths, so all the remains of the larger vertebrates are absent except the most resistant portions. These bones often serve as a center for the manganese-iron concretions, being frequently surrounded by layers several centimeters in thickness. In the same dredgings in the red-clay areas some sharks' teeth and cetacean ear-bones, some of which belong to extinct species, are surrounded with thick layers of the manganese, and others with merely a slight coating. We will make use of these facts to establish the conclusions which terminate this paper.

In these red clays there occur, in addition, the greatest number of cosmic metallic spherules, or chondres, the nature and character of which we have pointed out elsewhere. We merely innicate their presence here, as we will support our conclusions by a reference to their distribution.

Reviewing, then, the distribution of oceanic deposits, we may summarize thus:

(1) The terrigenous deposits—the blue muds, green muds and sands, red muds, volcanic muds and sands, coral muds and sands—are met with in those regions of the ocean nearest to land. With the exception of the volcanic muds and sands and coral muds and sands around oceanic islands, these deposits are found only lying along the borders of continents and continental islands and in inclosed and partially inclosed seas.

(2) The organic oozes and red clay are confined to the abysmal regions of the ocean basins. A Pteropod ooze is met with in tropical and subtropical regions in depths less than 1,500 fathoms, a Globigerina ooze in the same regions between the depths of 500 and 2,800 fathoms, a Radiolarian ooze in the central portions of the Pacific at depths greater than 2,500 fathoms, a Diatom ooze in the Southern Ocean south of the latitude of 45° south, a red clay anywhere within the latitudes of 45° north and south at depths greater than 2,200 fathoms.

CONCLUSIONS.—All the facts and details enumerated in the foregoing pages point to certain conclusions which are of considerable geological interest, and which appear to be warranted by the present state of our investigations.

We have said that the débris carried away from the land accumulates at the bottom of the sea before reaching the abysmal regions of the ocean. It is only in exceptional cases that the finest terrigenous materials are transported several hundred miles from the shores. In place of layers formed of pebbles and clastic elements with grains of considerable dimensions, which play so large a part in the composition of emerged lands, the great areas of the ocean basins are covered by the microscopic remains of pelagic organisms, or by the deposits coming from the alteration of volcanic products. The distinctive elements that appear in the river and coast sediments are, properly speaking, wanting in the great depths far distant from the coasts. To such a degree is this the case that in a great number of soundings, from the center of the Pacific, for example, we have not been able to distinguish mineral particles on which the mechanical action of water had left its imprint, and quartz is so rare that it may be said to be absent. It is sufficient to indicate these facts in order to make apparent the profound differences which separate the deposits of the abysmal areas of the ocean basins from the series of rocks in the geological formations. As regards the vast deposits of red clay, with its manganese concretions, its zeolites, cosmic dust, and remains of vertebrates, and the organic oozes which are spread out over the bed of the Central Pacific, Atlantic, and Indian Oceans, have they their analogues in the geological series of rocks? If it be proved that in the sedimentary strata the pelagic sediments are not represented, it follows that deep and extended oceans like those of the present day cannot formerly have occupied the areas of the present continents, and, as a corollary, the great lines of the ocean basins and continents must have been marked out from the earliest geological ages. We thus get a new confirmation of the opinion of the permanence of the continental areas.

But, without asserting in a positive manner that the terrestrial areas and the areas covered by the waters of the great ocean basins have had their main lines marked out since the commencement of geological history, it is, nevertheless, a fact, proved by the evidence derived from a study of the pelagic sediments, that these areas have a great antiquity. The accumulation of sharks' teeth, of the ear-bones of cetaceans, of manganese concretions, of zeolites, of volcanic material in an advanced state of decomposition, and of cosmic dust, at points far removed from the continents, tend to prove this. There is no reason for supposing that the parts of the ocean where these vertebrate remains are found are more frequented by sharks or cetaceans than other regions where they are never or only rarely dredged from the deposits at the bottom. When we remember, also, that these ear-bones, teeth of sharks, and volcanic fragments are sometimes incrusted with two centimeters of manganese oxide, while others have a mere coating, and that some of the bones and teeth belong to extinct species, we may conclude with great certainty that the clays of these oceanic basins have accumulated with extreme slowness. It is indeed almost beyond question that the red-clay regions of the Central Pacific contain accumulations belonging to geological ages different from our own. The great antiquity of these formations is likewise confirmed in a striking manner by the presence of cosmic fragments, the nature of which we have described ("On Cosmic and Volcanic Dust," Proc. Roy. Soc. Edin.). In order to account for the accumulation of all the substances in such relatively great abundance in the areas where they were dredged, it is necessary to suppose the oceanic basins to have remained the same for a vast period of time.

The sharks' teeth, ear-bones, manganese nodules, altered volcanic fragments, zeolites, and cosmic dust are met with in greatest abundance in the red clays of the Central Pacific, at that point on the earth's surface farthest removed from continental land. They are less abundant in the Radiolarian ooze, are rare in the Globigerina, Diatom, and Pteropod oozes, and they have been dredged only in a few instances in the terrigenous deposits close to the shore. These substances are present in all the deposits, but, owing to the abundance of other matters in the more rapidly forming deposits, their presence is masked, and the chance of dredging them is reduced. We may then regard the greater or less abundance of these materials, which are so characteristic of a true red clay, as being a measure of the relative rate of accumulation of the marine sediments in which they lie. The terrigenous deposits accumulate most rapidly; then follow in order Pteropod ooze, Globigerina ooze, Diatom ooze, Radiolarian ooze, and, slowest of all, red clay.

From the data now advanced it appears possible to deduce other conclusions important from a geological point of view. In the deposits due essentially to the action of the ocean we are at once struck by the great variety of sediments which may accumulate in regions where the external conditions are almost identical. Again, marine faunas and floras, at least those of the surface, differ greatly, both with respect to species and to relative abundance of individuals, in different regions of the ocean; and as their remains determine the character of the deposit in many instances, it is legitimate to conclude that the occurrence of organisms of a different nature in several beds is not an argument against the synchronism of the layers which contain them.

The small extent occupied by littoral formations, especially those of an arenaceous nature, shown by our investigations, and the relatively slow rate at which such deposits are formed along a stable coast, are matters of importance.

In the present state of things there does not appear to be anything to account for the enormous thickness of the clastic sediments making up certain geological formations, unless we consider the exceptional cases of erosion which are brought into play when a coast is undergoing constant elevation or subsidence.

Great movements of the land are doubtless necessary for the formation of thick beds of transported matter like sandstones and conglomerates.

In this connection may be noted the fact that in certain regions of the deep sea no appreciable formation is now taking place; hence the absence in the sedimentary series of a layer representing a definite horizon must not always be interpreted as proof either of the emergence of the bottom of the sea during the corresponding period or of an ulterior erosion. Arenaceous formations of great thickness require seas of no great extent and coasts subject to frequent oscillations, which permit the shores to advance and retire. Along these, through all periods of the earth's history, the great marine sedimentary phenomena have taken place.

The continental geological formations, when compared with marine deposits of modern seas and oceans, present no analogues to the red clays, Radiolarian, Globigerina, Pteropod, and Diatom oozes. On the other hand, the terrigenous deposits of our lakes, shallow seas, inclosed seas, and the shores of the continents reveal the equivalents of our chalks, green sands, sandstones, conglomerates, shales, marls, and other sedimentary formations. Such formation as certain Tertiary deposits of Italy, Radiolarian earth from Barbadoes, and portions of the chalk where Pelagic conditions are indicated must be regarded as having been laid down rather along the border of a continent than in a true oceanic area. On the other hand, the argillaceous and calcareous rocks recently discovered by Dr. Guppy in the upraised coral islands in the Solomon group are nearly identical with the Pteropod and Globigerina oozes of the Pacific.

Regions situated similarly to inclosed and shallow seas and the borders of the present continents appear to have been, throughout all geological ages, the theater of the greatest and most remarkable changes; in short, all, or nearly all, the sedimentary rocks of the continents would seem to have been built up in areas like those now occupied by the terrigenous deposits, which we may designate *the transitional or critical area of the earth's surface.* This area occupies, we estimate, about two-eighths of the earth's surface, while the continental and abysmal areas occupy each about three-eighths.

During each era of the earth's history the borders of some lands have sunk beneath the sea and been covered by marine sediments, while in other parts the terrigenous deposits have been elevated into dry land, and have carried with them a record of the organisms which flourished in the sea of the time. In this transitional area there has been throughout a continuity of geological and biological phenomena.

From these considerations it will be evident that the character of a deposit is determined much more by distance from the shore of a continent than by actual depth, and the same would appear to be the case with respect to the fauna spread over the floor of the present oceans. Dredgings near the shores of continents, in depths of 1,000, 2,000, or 3,000 fathoms, are more productive both in species and individuals than dredgings at similar depths several hundred miles seawards. Again, among the few species dredged in the abysmal areas furthest removed from land the majority show archaic characters, or belong to groups which have a wide distribution *in time* as well as over the floor of the present oceans. Such are the Hexactinellida, Brachiopoda, Stalked Crinoids, and other Echinoderms, &c.

As already mentioned, the transitional area is that which now shows the greatest variety in respect to biological and physical conditions, and in past time it has been subject to the most frequent and the greatest amount of change. The animals now living in this area may be regarded as the greatly modified descendants of those which have lived in similar regions in past geological ages, and some of whose ancestors have been preserved in the sedimentary rocks as fossils. On the other hand, many of the animals dredged in the abysmal regions are most probably also the descendants of animals which lived in the shallower water of former geological periods, but descended into deep water to escape the severe struggle for existence, which must always have obtained in those depths affected by light, heat, motion, and other conditions. Having found existence possible in the less favorable and deeper water, they may be regarded as having slowly spread themselves over the floor of the ocean, but without undergoing great modifications, owing to the extreme uniformity of the conditions and the absence of competition. Or we may suppose that in the depressions which have taken place near coasts some species have been gradually carried down to deep water, have accommodated themselves to the new conditions, and have gradually migrated to the regions far from land. A few species may thus have migrated to the deep sea during each geological period. In this way the origin and distribution of the deep-sea fauna in the present oceans may in some measure be explained. In like manner the pelagic fauna and flora of the ocean are most probably derived originally from the shore and shallow water. During each period of the earth's history a few animals and plants have been carried to sea, and have ultimately adopted a pelagic mode of life.

Without insisting strongly on the correctness of some of these deductions and conclusions, we present them for the consideration of naturalists and geologists as the result of a long, careful, but as yet incomplete investigation.