ADDRESS

AT THE OPENING OF THE SESSION, 1881-82.

NOVEMBER 4TH, 1881.

BY THE PRESIDENT,

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ON DEEP-SEA INVESTIGATION.

It has now for so many years been the custom for the President of this Association to open the Session with a communication dealing with some subject likely to be of interest to the members, that I need not apologise for following an example of such long standing. Last year my immediate predecessor was able to seize on a convenient opportunity for dealing with a subject of supreme interest to us all, viz., the origin and development of ourselves, and thus, through his able treatment, the Association possesses a history of itself such as few societies can boast of. No similar opportunity presents itself to-day, and I must accordingly fall back on one of the many topics which may be presumed to connect themselves more or less with geology.

The recent issue of three volumes of the long-promised Challenger Reports, being the first instalments of the fourteen or fifteen quartos which are to form the complete work, has served to direct renewed attention to the subject of deep-sea investigation. Besides the hydrographical, physical, and chemical details, the zoological reports will include about fifty distinct memoirs; yet, in spite of this enormous amount of work, it may be interesting for some of you to know that a few classes of creatures are still unappropriated.

It might perhaps be deemed somewhat premature to go into these questions until *all* the Reports had been published, but we must remember that over five years have elapsed since the return of the Challenger, and that during the interval important preliminary reports have been issued and discussed. Moreover, the results of the United States coast survey under A. Agassiz, in the Caribbean Sea and Gulf of Mexico, are being rapidly brought out, whilst during the same interval the Norwegian North Atlantic expedition has contributed additional information, being a portion of the results of cruises during three years in succession.

On referring to our own "Proceedings," you will find that at the meeting in December, 1874, Dr. Carpenter delivered a lecture "On the Conditions which determine the presence or absence of Animal Life on the Deep-Sea bottom." The lecturer began by observing that it would be unnecessary for him to point out to the members of the Association "that the foundation of the whole of geological science—that is, the interpretation of the phenomena presented to us in the study of the earth's crust—must be based upon the study of the changes at present going on upon the surface of the earth, including, of course, the depths of the sea."*

Without pledging ourselves to a too strict uniformitarianism, and with due reservation of all our rights to be guided by such evidence as shall from time to time fall under our notice, we cannot but give a general assent to the doctrine thus enunciated, though possibly, in the sequel, we may arrive at the conclusion that many of the phenomena of deep-sea investigation throw but little light upon the questions ordinarily presented to the geologist. Indeed, as regards the formation of deposits analogous to those of the several geological epochs, there is more perhaps to be learnt from such a work as that by Delesse, entitled "Lithologie du Fond des Mers," of which we have a useful abstract by Lebour in our "Proceedings," having special reference to the British seas.† Nevertheless the discoveries of the last twenty-five years in the depths of the ocean have opened out to us all a new world, besides serving to correct some errors, which stood in the way of the geologist, as well as of every other student of nature, past or present.

In dealing with these discoveries, the great difficulty has been to select from the large amount of published matter such portions as might seem to be of especial interest to you. In order to facilitate reference, the subject has been divided into four sections, any one of which would by itself form the text for an evening's discourse.

SECTION I. gives an exceedingly brief sketch of the history of deep-sea exploration.

SECTION II. deals with hydrography and physical conditions.

* "Proc. Geol. Assoc.," vol. iv., p. 176.

† Vol. iv., p. 158.

SECTION III. with the nature and occurrence of deep-sea deposits.

SECTION IV. with life on the deep-sea bottom.

I. *History of Deep-sea Exploration.*—To submarine telegraphy we owe the first systematic attempts at deep-sea sounding, which had been rendered practicable by a recent American invention. In 1857 Commander Dayman was engaged in the survey of the Atlantic for the purposes of the cable, and this, if we except the work of the Americans on board the Dolphin and the Arctic, may be regarded as the commencement of accurate ocean hydrography; whilst Dr. Wallich in the Bulldog, three years later, may be justly deemed the "pioneer"* of deep-sea zoology.

In those days there were two errors that had to be especially combated. One was that below a certain depth the great mass of ocean water had a uniform temperature of 39° F.—the point of maximum density of fresh water;—and it is curious to note that even so recently as 1868 no less a person than Sir Wyville Thomson observed in a letter to Dr. Carpenter "that the temperature of deep water seems to be constant for all latitudes at 39° F."†

But the notion that the zero of animal life was reached at a depth of 300 fathoms was an error of far more consequence to geologists. This idea is commented on, and its origin explained, by Dr. Carpenter in the lecture previously mentioned, wherein he concludes that Forbes' dictum is in the main true for the Mediterranean, which also further differs from the ocean in having a uniform temperature of 54·7° F. for all depths below 100 fathoms. Yet the depths of the Mediterranean are not wholly destitute of life, for after the Sardinian cable had been fished up for repairs from 1,200 fathoms in 1860, Prof. Fleeming Jenkin in the following year determined an adherent coral to be a variety of the well-known deep-water species, *Caryophyllia borealis.* This Sir Wyville Thomson considers to have been the first absolute proof of life at great depths, though perhaps the thirteen historic star-fish of Dr. Wallich clinging convulsively to the sounding-line might also put in a claim to this distinction.‡

Every now and then, in similar fashion, a witness had risen up

* Moseley, Lecture at Royal Institution, March, 1880.

† "Depths of the Sea," 1st edition, p. 52.

‡ The substance of the facts relating to this interesting capture was communicated to the Editors of the "Annals and Magazine of Natural History," and published by them in December, 1860.

from the deep to testify against the prevailing doctrines. Yet the orthodox clung to their faith as tightly as did the star-fish to the line, and the revelations of Wallich seemed in danger of being set aside, though there had not been wanting dissentients even before the days of deep-sea soundings. Amongst the most distinguished of these was Prof. Lovén, who, at a meeting of the British Association in 1844, observed, " As to the point where animal life ceases, it must be somewhere, but with us (*i.e.*, in Scandinavia) it is unknown." Nineteen years afterwards he was able to refer to the results of the Swedish Spitzbergen expedition of 1861, where dredging had been carried on with success in 1,200 fathoms.* Shortly afterwards Prof. Sars, in 1864 and 1868, obtained important results off the Lofoten Islands, though not below 450 fathoms. To the well-known work of Count Pourtalès on the other side of the Atlantic in 1868, it is hardly necessary to refer.

This brings us down to the work of the Lightning and the Porcupine from 1868 to 1870, when, as regards the seas adjacent to the British Islands, and even in those more remote, Dr. Carpenter, Sir Wyville Thomson, and Dr. Gwyn Jeffreys succeeded in convincing every one of the existence of life at great depths. Nor should I forget to mention that in this latter year one of our own members, Captain Marshall Hall, along with Mr. Saville Kent, did some good zoological work in the yacht Norna, off the coast of Portugal. The crowning point of these most interesting and plucky cruises may be said to have been reached when the dredge was hauled up from a depth of 2,435 fathoms in the Bay of Biscay with good examples of the five invertebrate sub-kingdoms. This victory over difficulties previously insuperable was gained at a station about as far to the west of the Land's End as London is to the east of it, just at the foot of the great submarine slope which constitutes the eastern boundary wall of the old continent.†

* On this occasion the Swedish naturalist expressed an opinion that wherever the bottom is suitable " a fauna of the same general character extends from pole to pole through all degrees of latitude." " Depths of the Sea," p. 269.

† A little to the south of the parallel of Ushant.

The dredge bag contained 1½ cwt. of " very characteristic grey chalk-mud—mostly as an amorphous paste, with but a small proportion of the fresh shells of *Globigerina* and *Orbulina.*" " Depths of the Sea," 1st edition, p. 96.

It is interesting to remember that this feat was performed in time for the veteran Sir Charles Lyell to quote the results in the latest editions of the " Principles of Geology." 11th edition, 1872; 12th edition, 1875.

II. *Hydrography and Physical Conditions.*—Having thus briefly alluded to the events which led to the memorable voyage of the Challenger, I will now proceed to consider some of the general results obtained under the above headings by the various expeditions.

The average depth of the ocean is calculated by Dr. Carpenter, as the results of the investigations of the Challenger, at 2½ miles, or about 12,000 feet.* The narrow zones of shallow water which usually margin the ocean along the coasts of continents and continental islands, such, for instance, as that portion of the Atlantic within the 100 fathom plateau, are not to be accounted as belonging to the ocean in a hydrographical sense. The true border of the ocean is the edge of the great submarine slope which conducts with a gradient not exceeding those on some of our railways to the vast abyssal plains. These plains are on the whole pretty level, but with a bulge here and a depression there, ranging from about 1,700 fathoms to 4,640 fathoms.†

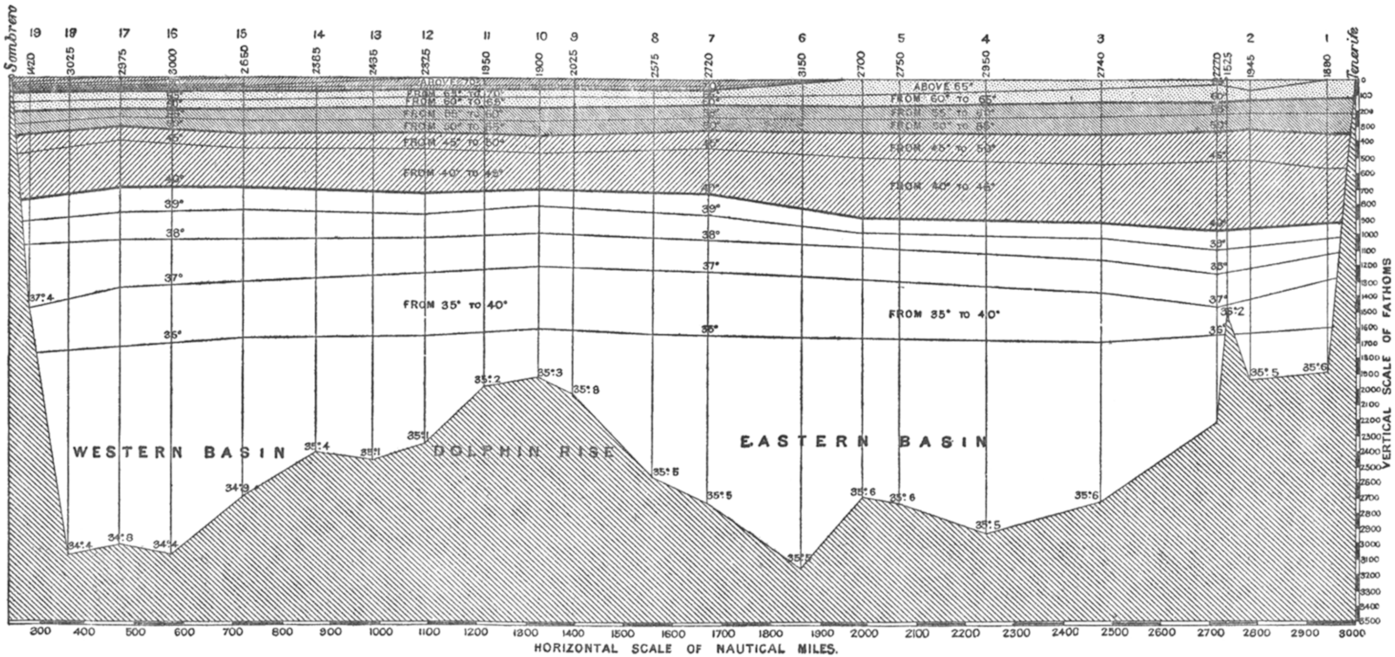
The section of the North Atlantic between the Canaries and the West Indies (Fig. 1) may be regarded in some respects as an average specimen of an ocean-bed contour. In this case the bulge in the middle forms part of the Dolphin ridge, but there is no very marked depression, the maximum depth shown in the section being 3,150 fathoms. Owing to the difference between the vertical and horizontal scales, the steepness of the sides is tremendously exaggerated. This section is, however, defective in one respect, viz., that, being drawn between two islands, it does not show that peculiarity of a submerged shallow plateau which is so characteristic of the edge of the great continents. This feature is better seen in Fig. 2 (New York to Bermuda), where the difference between an island slope and a continental slope is at once perceived, in the fact that the edge of the latter is submerged. Moreover, it so happens that the steepest slope known is at Bermuda, where there is an inclination of nearly twenty degrees from the edge of the reef to 2,000 fathoms.‡ For the reasons above detailed, Dr. Carpenter declares that the term "basin," as applied to the

* "Proc. Roy. Inst.," vol. ix., part 3, p. 268. See also "Nineteenth Century" for 1880.

† The deepest sounding of the Challenger was in 4,475 fathoms. Dr. Gwyn Jeffreys seems to be of a different opinion on the question of these moderate slopes. See his Address to the Hertfordshire Field Club, 1880. "Trans.," vol. i., part 5, p. 173, *et seq.*

‡ Moseley, *loc. cit.* on the authority of Capt. Tizard.

Fig. 1.—Canaries to West Indies. Challenger Hydrographic Reports.



oceans, is a misleading one, a truer representation of an oceanic depression being that of a "tea-tray."

Some of the leading results of deep-sea sounding may be gathered from the map showing the distribution of deposits on the deep-sea bed (Fig. 3, page 257). The deep basins are laid down from the chart at the end of Mr. Moseley's "Notes by a Naturalist on the Challenger." As a general result, it is evident that the Pacific is deeper than the Atlantic, whilst the great Southern Ocean, or subantarctic water-belt, shallows materially towards the south. The greatest depths of the Pacific, as well as the widest areas of deep water, incline towards the Asiatic side. They also lie almost wholly north of the equator, and the same may be said of the Atlantic, from which it follows that the northern hemisphere contains not only the greatest area above sea-level, but also the greatest area below the 3,000 fathom level, and must consequently present a much greater amount of rugosity than the southern hemisphere.

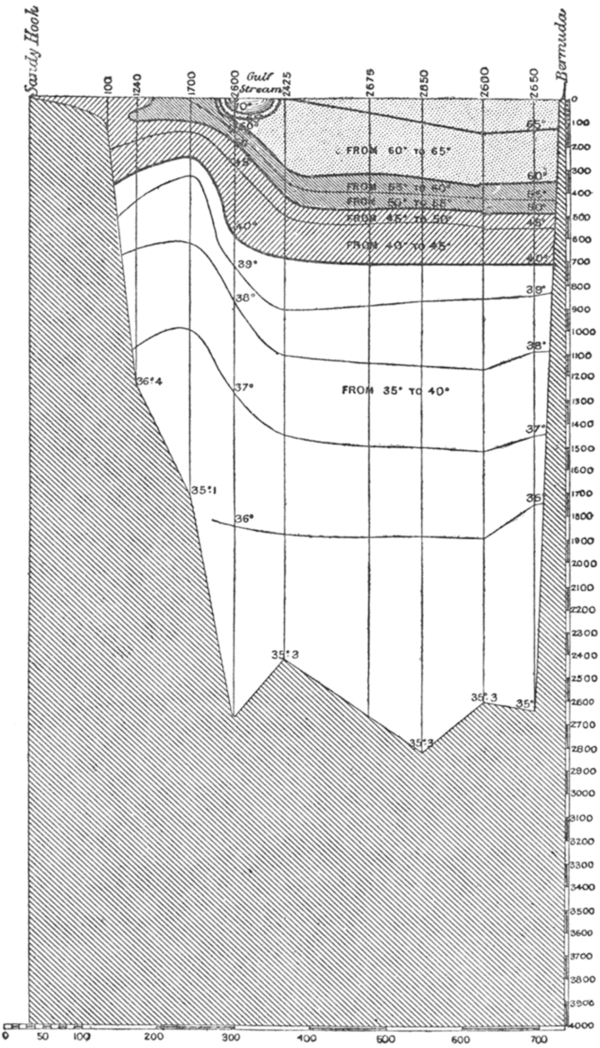
There is another fact in connection with extreme depths to which I may draw attention : it is perhaps a mere coincidence, but still a curious one. The deep sounding of 3,875 fathoms (23,250 ft.) in the Atlantic, off St. Thomas, is so close to the American side as to be regarded in relation to the New World, and accordingly we find this depth approximates in vertical range to the loftier peaks of the Andes.* On the other hand, the deep sounding off the Kurile Islands, in the N.W. Pacific, of 4,655 fathoms (27,930 ft.), is equally connected with the eastern margin of the Old World, whose loftiest summit, Mount Everest, is about 29,000 feet.

The subject of ocean currents is only indirectly connected with the deep-sea, as these appear to be mainly superficial. But, since the Florida current, or American Gulf Stream, figures so conspicuously in all speculations as to the past and present climate of these islands, it is only right to draw your attention to a section of the volume of this famous body of water before it begins to split up. On consulting Fig. 2, you will perceive that it is tolerably superficial, extending no more than 100 fathoms below the surface, with a breadth of 60 miles.† Its temperature is about 10° F.

* Chimborazo, 21,424 ft.

† Captain Tizard speaks of the American Gulf Stream running at a rate of three miles an hour for a width of 15 miles, and thus discharging 108 cubic miles per day of heated water into the North Atlantic. "Challenger Hydrographic Reports," No. 7, p. 12. He would thus seem to limit the central portion of the current to a breadth considerably less than that assigned, in the text, to the entire stream.

Fig. 2.—New York to Bermuda. Challenger Hydrographic Reports.



higher than the water in which it floats, except on the side where it meets the Labrador current, and there the contrast is extreme. It is for you to judge whether the American Gulf Stream, such as you see it in Fig. 2, is capable of performing the feats attributed to it, or whether, on the other hand, the so-called Gulf Stream on this side of the Atlantic is not the result of a series of complex causes, of which the original Florida current is only one amongst many.*

The temperature of the deep-sea is perhaps more widely known than any other of the physical conditions of the ocean. The sections in Figs. 1 and 2 for the most part speak for themselves. And if we took a *longitudinal* section from the equator to the poles, we should see the several zones of temperature cropping out as we receded from the equator, until at last the temperature of the bottom at the equator is about the temperature of the surface in polar waters.

Such are the facts; but what is the explanation? When Dr. Carpenter gave to the Association the lecture to which I have so often referred, he regarded the phenomenon as due to a slow and imperceptible underflow of cold, dense water from *both* poles, meeting at the equator, and slowly welling up, to be returned north and south in a warm surface overflow equally slow and imperceptible. The force which set this machinery in motion was difference of specific gravity.

The investigations of the Challenger, made subsequently, seem to have demonstrated that there is no such underflow of cold water from the Arctic Ocean which anywhere approaches the equator, but that the sources of cold water at the bottom of the equatorial seas are wholly from the Antarctic or Southern Ocean. To make this clear, it would be necessary to exhibit an enlargement of the map showing the deep basins of the Atlantic.†

However, the leading facts may be thus stated. You remember that the Atlantic is divided by its median bulge, known in different

* The fact is that when people on this side of the Atlantic speak of the "Gulf Stream" they usually mean the mass of warm oceanic water which impinges on the N.W. coasts of the Old Continent, and sends off its streams into the western portion of the palæarctic seas. It is not at all intended to underrate the importance of these currents, which even bring West Indian fruits to the shores of the Varanger Fjord; nay, it is the very magnitude of the results which renders it doubtful how far the original Florida current, such as we now know it to be, is to have the sole credit of heating the north-west seas of the Old World.

† "Challenger Hydrographic Reports," No. 7. Plate vi.

parts as the Dolphin ridge, the Connecting ridge, and the Challenger ridge, into an east and west basin of over 2,000 fathoms. Well, the western basin is nipped in two by a cross ridge, starting from the coast of South America, somewhat to the north of the mouth of the Amazon. Thus there are three basins, or "tea-trays," as Dr. Carpenter would prefer to call them. Of these the south-western one has a bottom temperature much below that of the others; under the equator the bottom temperature of this basin is below 32° F. in some places. In the north-west basin, even at the enormous depth of 3,875 fathoms, the bottom temperature is uniform at about 34·5° F., whilst the eastern basin has a uniform bottom temperature about half a degree higher.

Submarine ridges are the chief agents in keeping out the very cold polar waters, and thus the Icelandic ridge of about 500 fathoms, which bars the ice-cold bottom waters of the Norwegian Sea from the North Atlantic, is perhaps a principal agent in keeping up the temperature of the eastern basin, for the Lightning Channel is too narrow, and, on the whole, too shallow, to admit the passage of any important body of ice-cold water from the Norwegian Sea.*

The composition of sea-water cannot be altogether overlooked. The very deepest portion of the ocean contains abundance of oxygen, and according to the determinations of Mr. Buchanan quite enough and to spare for the little life there is there. As regards organic matter, the same chemist found traces, but only slight traces of its presence, and in this way he disposed of *Bathybius*, that all-pervading *moner*, which was supposed to line the floor of the ocean with its sheets of protoplasm. Silicic acid has also been found by Tornöe in the waters of the Norwegian Sea, but only to the extent of some fractions of a milligramme per litre.†

The much-vexed question of free carbonic acid still remains. You are aware that, besides common salt, there are very appreciable amounts of magnesia and lime in sea-water, chiefly in combination with chlorine, bromine, or sulphuric acid. There is also some carbonic acid, and the determination of this, both as to quantity and status, was an important item in the Challenger laboratory work.

There had always been a difficulty about disengaging carbonic

* Mr. Buchanan is of opinion that the temperature of the lower layers in the Pacific is, to a certain extent, influenced by northern waters.—"Journal Chem. Soc.," 1878.

† This agrees with Thorpe and Morton's determinations of silicic acid in the waters of the Irish Sea.—Tornöe, "Chemistry of the Norwegian North Atlantic Expedition."

acid gas from sea-water—a difficulty easily explained by the light of subsequent discovery. The whole story forms one of the most curious episodes in the history of chemical analysis, if the results detailed by Herr Tornöe are to be relied on.* Mr. Buchanan, acting upon the ideas of Jacobsen, and strengthened by his own experiments, had concluded that the unwillingness of sea-water to part with its carbonic acid on boiling, was principally due to the sulphates, which he was therefore in the habit of precipitating with chloride of barium. In this way he found about 50 milligrammes of carbonic acid per litre in Atlantic surface water.† The Pacific water was found to contain less. The difference between the carbonic acid found on the surface and at the bottom was not great.‡ Mr. Buchanan made a number of experiments to detect the presence of carbonates in sea-water, with the general result that carbonates are never present except in small quantities, and in many samples they were absent altogether. The inference, therefore, to be drawn from these experiments was to the effect that the carbonic acid found was, for the most part, uncombined.

This large amount of free carbonic acid, under the influence of powerful pressure at great depths, was supposed by Sir Wyville Thomson to be one of the principal agents in removing the *Globigerina*-shells from the "red clay" areas. Herr Tornöe, on the other hand, declares that there is no uncombined carbonic acid in sea-water, and he fortifies his position with two most important facts. In the first place, he finds that the reaction of sea-water is alkaline, whereupon Prof. Duncan, in a letter to "Nature," exclaims—"What a comfort for *Globigerinæ* and coral reefs!" Secondly, it turns out that protracted boiling with evaporation decomposes simple carbonates in the presence of soluble salts of magnesia; this is owing to the unstable character of carbonate of magnesia.§ Finally, Herr Tornöe concludes, as the result of many

* Tornöe, *op. cit.*

† "Proc. Roy. Soc.," vol. xxiv., p. 604.

‡ On the whole, there was less carbonic acid in warm than in cold water. An average of results gave 45 milligrammes per litre for ocean water. Jacobsen, in the North Sea, had an average of 88·6 m. per litre, but he experimented on green water, Buchanan on blue water. In the Antarctic Ocean, where such green water sometimes occurs, carbonic acid is present in marked excess. In lat. 65-42 S., for instance, occurred the maximum in bottom water, viz., 83 m. (depth 1,675 fathoms). Of the surface water the actual maximum—96 m. per litre—occurred between the New Hebrides and Fiji.—"Journal Chem. Soc.," 1878, p. 460 *et seq.*

§ On boiling a solution of carbonate of soda and sulphate of magnesia with due precautions, the whole of the carbonic acid is expelled.—Tornöe, *op. cit.*, p. 39.

determinations, that the waters of the Norwegian Atlantic contain 53 milligrammes per litre of carbonic acid as carbonate, and 44 milligrammes per litre of carbonic acid as bicarbonate. How far these results will bear investigation remain to be seen.

III. *Nature and Occurrence of Deep-sea Deposits.*—To us, as geologists, this is perhaps the most important part of deep-sea investigation; and, since much of the material is organic, it involves also a partial consideration of the fauna of the pelagic surface and of intermediate depths.

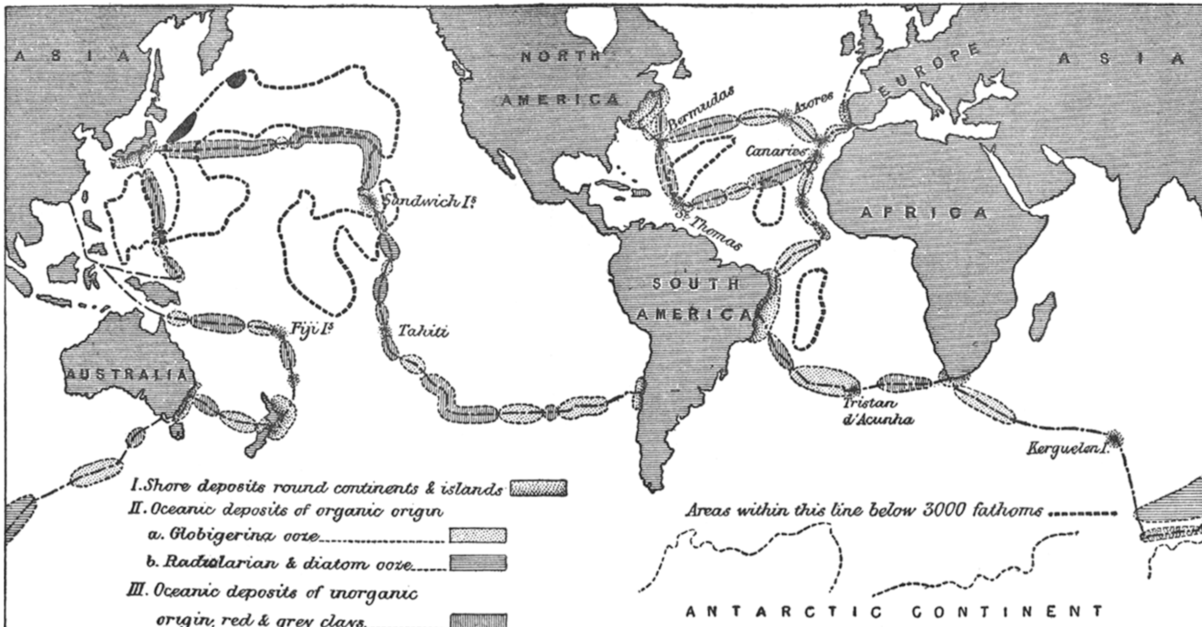
Mr. Murray* has classified the deposits met with during the Challenger voyage under the head of *Shore deposits*, *Globigerina-ooze*, *Radiolarian and Diatomaceous ooze*, and *Red Clays*. To these may be added the *Biloculina*-ooze of the deeper parts of the Norwegian Sea. The accompanying map (Fig. 3) shows the distribution of these deposits as far as the track of the Challenger to Valparaiso in 1875. It accompanies Mr. Murray's preliminary report.

1. As regards the *shore deposits*, we may, on the present occasion, neglect all but the green and blue muds met with near the margin of the continents and larger islands. The deep-sea itself is affected by the mechanical degradation of the land for short distances, and floating ice occasionally gives both the coarser and finer materials a passage out to sea to within about 40° of the equator in some latitudes. Even the finer materials derived from the wear of the coast, or brought to sea by rivers, are deposited almost entirely within two hundred miles of land.† In depths from 50 to 700 fathoms these shore deposits are often of a green colour from the presence of glauconite; below 700 fathoms they are usually blue. About 150 miles from the shores of a continent the mud loses its blue colour and becomes reddish or brown; also, instead of the particles of mica and rounded pieces of quartz found nearer the land, pumice and volcanic minerals are more noticeable.

These green and blue muds have been found to prevail in all the enclosed seas visited by the Challenger, as the Arafura, Banda, Celebes, and China Seas, likewise in the inland sea of Japan. In all these cases the carbonate-of-lime organisms would appear to be removed from the sea-bottoms at a less depth than on open coasts by 400 or 500 fathoms.

* "Proc. Roy. Soc.," vol. xxiv., p. 518.
† Murray, "Proc. Roy. Soc. Ed.," 1876-7, p. 53.

FIG. 3.—SKETCH-MAP SHOWING THE TRACK OF THE CHALLENGER AS FAR AS VALPARAISO IN 1875, WITH THE NATURE OF THE DEPOSITS AS DEDUCED FROM THE SOUNDINGS.



[Based upon Mr. Murray's map, "Proc. Roy. Soc.," vol. xxiv., pl. 20.]

The dark spots within the 3000 fathom line, in the north-west Pacific, indicate the deep soundings of the Tuscarora.

Perhaps the most interesting feature in connection with these shore deposits is the abundance of glauconite or other green silicate, which occurs both as grains and as casts of the interiors of calcareous organisms whose tests have disappeared. The phenomenon is mainly confined to depths less than 700 fathoms. Below this depth both glauconite grains and casts are but sparingly distributed. Glauconite was more especially noticed off the coast of Portugal, and in the Indian section of the Southern Ocean off the Crozets, in grey mud at 600 fathoms, where the casts were of a pale straw-colour, unaccompanied by any grains ; and again off the east coast of Australia, in 400 fathoms, when the casts were dark green, pale green, and dirty white. In some cases the smaller chambers of the foraminifera were green, whilst the larger ones were white or grey-coloured.

If time permitted, I might attempt to establish some connection between these green silicates, which go under the general term of glauconite, and the red clays of the deeper parts of the ocean. Their composition is probably not very different. The cretaceous glauconite is, for the most part, a hydrous silicate of ferric oxide, with a considerable amount of alumina, and very much smaller quantities of magnesia and potash. The great peculiarity is that a ferric silicate, or one where the ferric oxide predominates, should be green, and not red. Allusion has been made to this circumstance by Prof. Morris in the notes to his lecture on the "Geology of Croydon."* The ultimate source both of glauconite and of red clay must be sought mainly in the products of decomposition of the varieties of pumice. As an exceptional instance of the occurrence of foraminiferal casts in red silicate (?), I will mention one in the S.E. Pacific, at a depth of 1,450 fathoms, on a bottom of *Globigerina*-ooze of a red colour, containing much pumice.† In this case the red substance had coated as well as filled the shell, thus affording an external and an internal cast connected by pillars representing the foramina. As a rule it should be noted that the casts of foraminifera occur very sparingly in *Globigerina*-ooze ; the purest samples contain none.

2. This brings us to the consideration of the *Globigerina-ooze,* which is not met with south of 50° S., nor possibly much beyond lat. 60° N., but within these limits is, after the deep-sea clays, the most abundant of the oceanic deposits. It may be as well to bear in

* Pnblished by F. Baldiston, "Chronicle" Office, Croydon.

† Lat. 18° 30' S., long. 173° 52' E.

mind that *Globigerina*-ooze, Radiolarian-ooze, and "red clays" all more or less commingle, or rather their constituents do. Nothing can bring out this fact more clearly than the 20 analyses of bottom samples from the section between the Canaries and the West Indies (see Fig. 1) given in the Appendix to Thomson's "Atlantic."* Under these circumstances it will be necessary to bear in mind that the sharp divisions shown on the general chart (Fig. 3) are merely adopted for the sake of contrast. Some of the intermediate varieties marked as "red clay," for instance, contain almost as much carbonate of lime as the adjacent *Globigerina*-ooze. On the other hand, however deep the deposit, or however red the clay, *Globigerinæ*, generally speaking, are found all over the bottom of the ocean; indeed, on only one or two occasions did Mr. Murray fail to detect some variety of pelagic foraminifera.†

As regards the materials composing the *Globigerina*-ooze, they are pretty well known. In the first place, it consists largely of the dead shells of *Globigerina*, *Orbulina*, and *Pulvinulina*, &c.‡

There is a vast difference between the highly ornamented shell of the foraminifer, whilst it floats on the warm and sunlit surface of the ocean, and the dead shells which are brought up from beneath. Another beautiful pelagic species has been called *Hastingerina Murrayi*;§ the shell is very delicate, and has only once been noted from the bottom. In a specimen obtained from the surface, "the sarcode of the animal was thrown out into bubble-like extensions between the spines of the shell, and over these expansions of the sarcode and along the spines, the pseudopodia moved freely and rapidly"‖—a charming picture of a pelagic foraminifer in a playful mood!

In the early days of deep-sea investigation, there was a general impression that *Globigerina* and its allies lived on the bottom. That was also the period when Atlantic mud was described as modern chalk. It is now stated by Sir Wyville Thomson,¶ by Prof. Huxley,** and by Mr. Murray,†† that these organisms live only on

* Vol. ii., p. 369.

† They appear to be quite absent in the Arafura Sea.—Murray, "Proc. Roy. Soc.," vol. xxiv., p. 523.

‡ For drawings of these forms see "Challenger in the Atlantic," vol. i., pp. 211, 214, 218.

§ *Op. cit.*, vol. ii., p. 294.

‖ Murray, "Proc. Roy. Soc.," vol. xxiv., p. 524, pls. 22 and 23.

¶ "Preface to Atlantic," vol. i., p. 12.

** Speech at Edinburgh after the return of the Challenger, reprinted in "Nature."

†† *Loc. cit.*, p. 535.

the surface and sub-surface waters of the ocean. Prof. Huxley says that when they die "their skeletons are rained down in one continual shower, falling through a mile or a couple of miles of sea-water."

When Sir Wyville Thomson, some years ago, first announced his change of opinion on this subject, such a piece of backsliding was very grievous to his late colleague in the Porcupine, Dr. Carpenter, who suggested that the *Globigerinæ* are pelagic in the earlier stage of their lives, and that, in consequence of the increasing thickness of their calcareous shells, they sink to the bottom, and there continue to live and probably to multiply.* Dr. Carpenter gave some excellent reasons for showing that the facts observed by the Challenger might bear a different interpretation, and he also dwelt especially on the difficulty of explaining the absence of *Globigerina*-ooze in certain areas of no excessive depth, such as the cold bottom between the Shetlands and the Faröes, on the hypothesis now adopted by Thomson.

It must be admitted that the disappearance of *Globigerina*-shells from the bottom of certain areas, whose surface waters are said to contain them in abundance, has not yet met with a satisfactory explanation. Still, is it right that, because we cannot explain certain phenomena, we should neglect such a piece of evidence as that of Mr. Murray? who says, "No living specimen of a *Globigerina*, an *Orbulina*, a *Pulvinulina*, or of the new genera found on the surface, which undoubtedly came from the bottom, has yet been met with."† This was written when the voyage of the Challenger was approaching its termination. More recently Mr. Brady, after examining all the Challenger collections bearing on this point, is said to have concluded that the main components of the mud are organisms which *do live* at the bottom.

There certainly does seem, as pointed out by Mr. Moseley, a curious connection between life at the surface and at the bottom, but a mere inference drawn from this connection can hardly outweigh the direct statements of Mr. Murray. At any rate, the court must adjourn the case for further evidence.

With regard to the rest of the calcareous elements of *Globigerina*-ooze, much of it consists of "coccoliths" and "rhabdoliths." Sir Wyville Thomson has concluded that "coccoliths" are the separated

* "Nature," Feb. 11, 1875.

† *Loc. cit.*, p. 535.

elements of a peculiar calcareous armature, which covers certain spherical bodies—the "coccospheres" of Dr. Wallich. "Rhabdoliths" are the like elements of the armature of extremely beautiful little bodies—the "rhabdospheres" of Mr. Murray. From the drawings* on the wall you may perceive what these curious things are like: the spheres themselves are infinitesimally small, and the disconnected plates of their outsides must be proportionally smaller. No one appears to know much about the organic position of these things. The botanist and zoologist would seem to regard them with equal suspicion. It has been suggested that they are in some way connected with the Algæ; but whatever they are, they secrete a large quantity of carbonate of lime, and that circumstance entitles them to our notice when considering the deep-sea deposits, whose inorganic constituents and chemical composition will presently claim our attention.

The *Globigerina*-ooze, owing to admixture with organic silica in the form of Radiolaria and Diatoms, with "red clay" elements, and, where near the land, with rock débris, is far from being a pure calcareous formation. The best samples noted by the Challenger were in parts of the Southern Ocean off the Cape of Good Hope, where there is a wonderfully pure deposit in the neighbourhood of Prince Edward Island and the Crozets, consisting almost entirely of *Globigerina bulloides*, and containing possibly as much as 98 per cent. of carbonate of lime.† There are of course many gradations between a sample like this and an average specimen of what was called "modern chalk," such as that selected from the Atlantic mud for purposes of comparison with the white chalk of the south coast, and which happened to contain about 60 per cent. of carbonate of lime.‡

An inspection of the accompanying table,§ which shows the total amount of earthy carbonates in twenty samples from the bottom—in the typical section across the Atlantic (see Fig. 1), will place the leading facts of the case before us in a very instructive manner:—

* For a drawing of Coccosphere see "Depths of the Sea," page 414; for drawings of Rhabdospheres see "Atlantic," vol. i., pp. 221, 222.

† "Atlantic," vol. i., pp. 219 and 228.

‡ "Depths of the Sea," p. 469.

§ Drawn up from data supplied in the appendix to the "Atlantic."

Carbonates in 20 samples of deposit between the Canaries and the West Indies. See Fig. 1. Page 250.

1.	1,890 fathoms	Gl.	$CaCO_3$.	50·00	$MgCO_3$.	1·32
2.	1,945 ,,	Gl.	,,	64·55	,,	1·17
3.	2,740 ,,	R.	,,	56·39	,,	0·98
4.	2,950 ,,	R.	,,	4·11	,,	1·20
5.	2,750 ,,	R.	,,	16·42	,,	2·70
6.	3,150 ,,	R.	,,	3·11	,,	1·90
7.	2,720 ,,	R.	,,	13·30	,,	1·31
8.	2,575 ,,	R.	,,	51·16	,,	1·93
9.	2,025 ,,	Gl.	,,	43·93	,,	1·94
10.	1,900 ,,	Gl.	,,	74·50	,,	1·27
11.	1,950 ,,	Gl.	,,	79·17	,,	1·40
12.	2,325 ,,	Gl.	,,	67·60	,,	2·58
13.	2,435 ,,	R.	,,	52·22	,,	0·76
14.	2,385 ,,	R.	,,	58·40	,,	0·68
15.	2,650 ,,	R.	,,	17·58	,,	1·41
16.	3,000 ,,	R.	,,	1·49	,,	3·10
17.	2,975 ,,	R.	,,	3·50	,,	2·14
18.	3,025 ,,	R.	,,	2·44	,,	3·48
19.	1,420 ,,	Gl.	,,	80.69	,,	0.68
20.*	450 ,,	Pt.	,,	84.27	,,	1.28

Gl. Globigerina-ooze. R. Red clay. Pt. Pteropod-ooze.

In this table only two varieties of deposit are noted, if we except the Pteropod-ooze of the last station, occurring in water of very moderate depth, and close to the shore. On studying the table you will perceive that some portions of the bottom marked "red clay," such for instance as No. 3, at a depth of 2,740 fathoms, contain nearly as much carbonate of lime as the *Globigerina*-ooze to the eastward. Again (presuming that there is no mistake), the station immediately to the westward, practically at the same depth, contains less than 6 per cent. However, you may learn, by comparing the depths with the total amounts of carbonate of lime, that, as a rule, below 2,200 fathoms there is a very material decrease, though affected by some curious irregularities. The purest sample of *Globigerina*-ooze in this traverse contains rather less than 81 per cent. of carbonate of lime; at a less depth, where the pteropod shells are not removed, the percentage is slightly greater.

In his work on the "Atlantic"† Sir Wyville Thomson thus

* Too near the shore to be shown in the section.

† Vol. i., p. 225.

classifies the deposits of the type section (Fig. 1), starting from the Canaries:—

About 80 miles of volcanic mud and sand.—Shore deposits.
„ 350 „ *Globigerina*-ooze.
„ 1,050 „ Red clay.
„ 330 „ *Globigerina*-ooze.
„ 850 „ Red clay.
„ 40 „ *Globigerina*-ooze.

He is careful to point out that these deposits shade into one another, and do not occur in nature, as they are shown for the sake of contrast on maps and diagrams. The *Globigerina*-ooze, for instance, passes gradually into the "red clay" of the greater depths in the form of a deposit to which he gives the name of "grey ooze."

At a depth of 3,150 fathoms the central axis of the eastern basin, or "tea-tray," of the Atlantic is reached. Here the deposit at the bottom is described as "red clay," containing much amorphous matter, and very many small mineral particles, a few broken pieces of pelagic foraminifera and a few manganese grains.* Next comes the Dolphin rise, and with the shallower water the *Globigerina*-ooze is again in the ascendant, though it is easy to perceive from Mr. Murray's report that in this region it is largely contaminated with mineral particles, the colour being often red or rosy, in part from the presence of iron or manganese. This may serve to explain the very high percentages of carbonate of lime in Nos. 13 and 14 (see table of carbonates), marked as "red clay," which, from their chemical composition, should rather be referred to *Globigerina*-ooze.

The axis of the western basin is reached at about 3,000 fathoms, where the carbonates are at a minimum—only 1·5 per cent. of carbonate of lime, but with twice that amount of carbonate of magnesia. It would seem indeed that the agencies which serve to remove carbonate of lime are not unfavourable to the increase of carbonate of magnesia. At this station (No. 16 of the table) a small piece of a shell and a portion of a siliceous spine were the only organic fragments visible, though the mud was full of the cases of a tube-building annelid, formed out of the gritty matter, which occurs sparingly in the clay.

Quitting now the type section along which, in the spirit at least,

* Murray, *vol cit.* p. 476.

we have been walking at the bottom of the sea, let us trace the distribution of *Globigerina*-ooze upon the chart (Fig. 3, p. 257), taking note occasionally of anything remarkable. In those portions of the Atlantic traversed by the Challenger, the deposits classed under this head range in depth from 780 fathoms to 2,675 fathoms. In the Pacific the range is much greater, extending from 275 fathoms to 2,925 fathoms. We can neglect the upward limit, since this is largely affected by the extent to which the deposit may be masked by shore débris. The lower limit is of more importance. I have already pointed out that about 2,200 fathoms may be accepted; yet the limit is extremely capricious, and the cause of the disappearance of the carbonate of lime is still, as far as I know, a matter for conjecture.

By the aid of Mr. Murray's chart, you may perceive those regions where the *Globigerina*-ooze is developed. Here is the traverse we have just made from the Canaries to the West Indies. The great yellow patch between the two reds is the *Globigerina*-ooze of the Dolphin rise, corresponding to the hump at the bottom in Fig. 1.

The north-west basin of the Atlantic is mainly occupied by "red clay," except round Bermuda, where the more purely pelagic matter is masked by coral mud and its concomitants. On the other hand, the shore deposits of the adjacent coasts of North America serve equally to mask the pelagic matter in those depths, where *Globigerina*-ooze might be expected to occur. In addition to this, there is the confusion produced by icebergs, which occasionally drop a few hundred-weight of syenite in a single block, besides other contributions to the deep-sea bottom.*

In fact, though marked as "red clay," there is a fair amount of carbonate of lime in parts of the north-west basin. This is well brought out by reference to the deposit at the very deepest spot yet found in the Atlantic (3,875 fathoms), just north of St. Thomas. It is classed "red clay," but is in reality a bluish grey mud, only red on the top. The chief point of interest however is, that it contains "a good many broken pieces of pelagic foraminifera: pteropods and heteropods; along with a few coccoliths and rhab-

* Sounding of 7th May, 1873, in 1,340 fathoms. Lat. 41° 15′ N., long. 66° 48′ W.—A blue mud composed of:—amorphous matter, an immense number of particles and pebbles, pelagic foraminifera and coccoliths and a few diatoms. Proc. Roy. Soc., vol. xxiv., p. 481.

doliths. The lower layers appear to contain more carbonate of lime than the upper ones." Thus even at the greatest depth known in the Atlantic our old friends have not deserted us, whilst you remember that at far less depths in the typical section (Fig. 1) scarcely a trace of a carbonate-of-lime organism was found. Hence we must conclude *that depth alone, without reference to other considerations, does not always determine the non-appearance of calcareous matter.*

On recrossing the Atlantic, *Globigerina*-ooze again predominates on the plateau whence spring the Azores. In a sounding here at 1,260 fathoms (lat. 38½ N.), besides the usual things, there occurred otoliths of fish, *Cypridina*-valves, urchin-spines, and *Biloculina.* I mention the latter especially, because the remains of this foraminifer take the place of *Globigerina* in the Norwegian Sea at suitable depths and under bottom water colder than ice. This *Biloculina*-ooze, according to Sars, contains a larger proportion of lime than the other.

Next come the shore deposits round the Azores, but when we get clear of these, *Globigerina*-ooze again prevails as far as Madeira, and at depths that surprise us. Here is a sounding in 2,675 fathoms, where the deposit is described as a white *Globigerina*-ooze, "containing much amorphous calcareous matter, many pelagic foraminifera and their broken parts, coccoliths and rhabdoliths, a good many mineral particles, coarse and fine pumice, quartz, mica, a few radiolarians."

Let us now shift the scene to the Pacific, where the depths are greater, and the "red clay" area very extensive, especially towards the north-west. Nevertheless, at a point almost on the meridian of the Sandwich Islands, and a little north of the equator, is a patch of *Globigerina*-ooze, well within the great Radiolarian tract presently to be mentioned. This patch has a maximum depth of 2,925 fathoms, a point at which, on our type section (Fig. 1), almost every trace of lime has vanished. "The carbonate of lime organisms were the most abundant in the lower layers. The upper brown layer had carbonate of lime and siliceous organisms in nearly equal proportions, but more clayey matter and manganese grains than the one underneath."*

* Murray, *loc. cit.*, p. 510.

Thus we perceive that there are deposits containing something like 50 per cent. of carbonate of lime at depths exceeding by hundreds of fathoms those in other parts of the Pacific marked as Red clay. For instance, the S.E. portion of the Pacific is comparatively shallow, though very free from islands, and *Globigerina*-ooze prevails to a considerable extent ; yet an area within this ooze region W.S.W. of Valparaiso, at the moderate depth of 2,270 fathoms, is marked as "red clay," where most of the carbonate of lime has disappeared.

These results make the question of the disappearance of lime very difficult to explain. Should the observations of Herr Tornöe be applicable to all parts of the ocean, the theory of free carbonic acid, never adopted by Mr. Murray, must be abandoned, except in those cases where there may be occasional emanations of carbonic acid through the floor of the ocean itself. There remains the alleged increase in the power for dissolving carbonate of lime possessed by water under greatly augmented pressure, as suggested by Dr. Carpenter from the results of Sorby's observations.* This, and other modes of explanation, have doubtless received the attention of Messrs. Murray and Rénard, whose work, we hope, will shortly be in the hands of the public.

3. *Radiolarian-ooze.*—The siliceous deposits of organic origin are the result of silica-secreting creatures which abound on the surface waters and apparently also in the deepest waters of all the oceans and seas visited by the Challenger, though more numerous in the Pacific than in the Atlantic. Of these, the radiolarians are the most important and the most widely distributed. You may perceive from the drawings of *Dictyopodium* and *Ziphacantha* what sort of fellows are these siliceous rhizopods.† There are also other siliceous organisms of a very microscopic character, originally called Challengerias. The siliceous tests of these various forms are sufficiently abundant in the Pacific to become characteristic of the deep-sea ooze. About half-way between Japan and New Guinea there is a depth of 4,575 fathoms—the deepest Challenger sounding—with a bottom of ooze, containing chiefly the remains of radiolarians, and diatoms, together with Challengerias, and other deep-sea rhizopods ; in this

* "Proc. Roy. Soc.," 1862-3, p. 538.

† For drawings of these forms see "Atlantic," vol. i., pp. 234, 235.

sounding there was a very small amount of amorphous clayey matter, and no carbonate of lime organisms are expressly mentioned. The other areas characterized by radiolarian ooze are not of excessive depth, ranging from 2,000 to 2,250 fathoms.

As regards the *Diatom-ooze*, time will not permit me to do more than indicate the large region in the Indian section of the Southern Ocean, adjoining the shore deposits off the presumed Antarctic continent. Over the area occupied by the siliceous deposit, the higher fauna was found to consist mainly of forms with but little carbonate of lime entering into the composition of their tests, such as very thin-shelled irregular urchins, &c.* Diatoms are most abundant where the specific gravity of the water is comparatively low, but, like the foraminifera and radiolaria, traces of them exist throughout the greater part of the oceanic deposits.

4. There yet remains the important subject of *Red clay*, conspicuously *the* deep-sea deposit; and with this is associated the well-known phenomenon of the manganese nodules, so abundant in certain portions of the ocean, and not altogether absent from our own shallow seas.

In order to give an idea of the composition of Red clay, I append an analysis of a sample from a sounding in 3,150 fathoms, being No. 6 of our type section (Fig. 1 and table, p. 250) in the deepest part of the eastern basin of the Atlantic.

ANALYSIS OF A RED CLAY FROM 3,150 FATHOMS.

(Dried at 110° C.)

Water and organic matter	10·40
Silica	53·30
Alumina	17·40
Ferric oxide...	11·70
Lime, Magnesia } in combination with Silica ...	1·35
Carbonate of lime	3·10
Carbonate of magnesia	1·90
Sulphate of lime	·85
	100·00

In connection with manganese nodules one of the most interest-

* "Atlantic," vol. ii., p. 339.

ing trawls in the Pacific * occurred in 2,335 fathoms, dark chocolate clay forming the upper two inches of the deposit, and light brown clay with many calcareous organisms the lower five inches. The trawl brought up over a bushel of nodules, some without apparent nucleus, some with a hard cherty yellow mineral in the centre. Besides these were over a hundred shark's teeth, and numerous ear bones of cetacea, on all of which much manganese was deposited. With reference to this trawl, Professor Turner remarks† that the remains of at least forty-five whales were fished up on this occasion, but no bone was identified as belonging to the great sperm whale. The spot where all these things were found is within the Red clay area, and their mode of occurrence appears to throw some light upon its history. On this subject one might dilate at considerable length, but it is time that I should move on to another theme, as I feel that if I were once to get well into the Red clay, I should stick there for the rest of the evening.‡

IV. *Life on the Deep-sea Bottom.*—This, indeed, as Mr. Moseley says, must be a very slow affair. In utter darkness, in water almost as cold and sometimes colder than ice, with a pressure amounting to tons on the square inch, the organic functions must be exceedingly mechanical, and sensation reduced to a minimum.

There are just a few points to be considered before we enter into particulars.

1. In deep water there is no plant life, though the absolute limit of vegetation in the sea may not have been determined with precision. A parasitic fungus is not a plant in an economic sense, and therefore the existence of a lowly organized form infesting

* Lat. 33° 29' S., Long. 133° 22' W.

† "Challenger Reports," vol. ii., p. 39, "Bones of Cetacea."

‡ It is also impossible to pay adequate attention to the subject of the manganese nodules, yet a prevalent misapprehension should be removed, viz., that they are composed of nearly pure peroxide of manganese. Some specimens from the Pacific examined by Professor Church contained either a core of Red Clay or fragment of pumice ; round these the material was deposited in concentric layers. These layers were found to contain 30 per cent. of manganese dioxide, the remainder consisting chiefly of water, ferric oxide, and silica. Church, in "Min. Mag." vol. i., p. 50.

Mr. Buchanan states that the manganese occurs wholly as peroxide, which amounts to about 35 per cent., with some 25 per cent. of ferric oxide, from 15·20 per cent. of insoluble residue, and 8·10 per cent. of water, with variable proportions of alumina and soda. Cobalt, with copper and a little nickel, is present in all of them. "Proc. Roy. Soc.," Edin.

corals—even at 1,000 fathoms—constitutes no exception to the rule. This absence of vegetation bears on the food question: whence do the deep-sea animals obtain their supplies? There used to be a theory which regarded the waters of the ocean as a sort of *soupe maigre*, enriched by lumps of protoplasm. Those were the days of *Bathybius* and the "Urschleim." It seems now to be held that the ultimate sources of food are derived entirely from above. Mr. Moseley calculated that it would take a dead Salpa four days to fall through 2,000 fathoms of water.

If diatoms, coccospheres, and rhabdospheres are so far vegetables as to have the power of decomposing inorganic substances, they must also contribute to set the vital circle in motion. Star-fish, holothurids, &c., doubtless fill their digestive sacks with these, as well as with foraminifera and radiolarians. Thomson gives an account of a holothurid so transparent that when the body cavity was distended with diatom-ooze the animal looked like a thin, transparent bag filled with it.*

2. Life only occurs within moderate distances of the surface, and on the bottom. The intermediate depths, which, according to Sir Wyville Thomson, are the most stale, probably contain hardly any. A. Agassiz considers that certain experiments "appear to prove that the surface fauna of the sea is really limited to a comparatively narrow belt in depth, and that there is no intermediate belt, so to speak, of animal life between those living on the bottom or close to it and the surface pelagic fauna."† It amounts to this, therefore, that, in the ocean, life is restricted to waters near the top, and at or near the bottom.

3. What do we mean by deep-sea now-a-days? Three hundred fathoms was deep water in Forbes' time, and this depth may now, I suppose, be roughly accepted as the upper limit of the deep-sea. A. Agassiz concluded recently, according to Mr. Moseley, that the fauna extending from the shore to 150 fathoms should be termed the littoral fauna; "whilst from the hundred fathom line to the four hundred fathom line extend species which are neither littoral,

* "Atlantic," vol. ii., p. 339. It becomes a singular question how far the juices of such creatures succeed in dissolving silica, which they do not secrete. Fancy an animal having *Dictyopodium* for his dinner and *Ziphacantha* for his dessert.

Quoted by Dr. Gwyn Jeffreys, *loc cit*, p. 182.

nor have the wide geographical distribution belonging to forms found below that depth." Sir Wyville Thomson has told us very lately * that the "abyssal" fauna attains its greatest development in a zone of depth between 600 and 1,200 fathoms. Below that depth, though the character of the fauna may remain the same, yet its abundance is materially diminished.

These views do not seem quite to coincide, but perhaps we may roughly gather, (1) that there is a *littoral fauna*, an *intermediate fauna*, and a *deep-sea fauna*, (2) that the latter extends from 400 fathoms to any known depth, but attains its maximum development between 600 and 1,200 fathoms, whilst below 2,000 fathoms, especially on red clay bottoms, life is very scarce.

Here is a picture, painted by Prof. G. D. Sars† of marine life at depths from 400 to 900 fathoms in the cold water area between Norway and Iceland, where, contrary to expectation, the prevailing low temperature is no hindrance to the development of animal life. "Forests, of a peculiar group of sponges (Cladorhiza) with tree-like branches, deck the bottom for long distances. Various crustacea, amongst them the wonderful object, *Arcturus Baffini*,‡ known from the polar sea, and slow-moving Pycnogonida, some of colossal size, creep along between these sponge branches, and suck out their organic juices ; whilst a whole world of more delicate Polyzoa and Hydrozoa find their abode on the sponges that are dead." The writer then goes on to describe the submarine population in the open spaces between the sponge forests. He speaks of the sea stars (*Astropecten*) and ophiurids, and here again of the swarms of crustaceans. Above all predominate the Umbellularias, "with their delicate straight stems and elegantly curved crowns set full of fringes of polyps." In default of sunlight this glacial aquarium is illuminated, if not warmed, by the phosphorescence of the animals themselves, and especially of *Umbellularia*, which we can almost imagine as playing the part of a submarine gas-lamp, or electric light, if you will, to its more lowly companions.

The Norwegians called this the region of the *Umbellularia*. Upon

* "Challenger Reports." General introduction.

† Norwegian North Sea Expedition—"Nature," March, 1877.

‡ For drawing see "Depths of the Sea," p. 128.

the wall is a drawing of *Umbellularia greenlandica.** The group of which this genus is a member extends to very considerable depths, some species occurring below 2,000 fathoms. It belongs to the division of Alcyonarian polyps called Pennatulids. These, for the most part, says Dr. Kölliker, are very shallow water forms ; moreover, they are more complex in organization than their deep-sea relatives.

Dr. Kölliker further observes that this peculiarity holds good with regard to the other invertebrate groups, viz., that the deep water organisms are the more simply constructed relatives of shallow water forms—*i.e.*, one might almost say, of forms which, under the stimulus of light and more food, have lived faster and become more highly developed. In this way also he arrives at the conclusion that these simple forms are probably the oldest and may be regarded as the last remnants of an almost extinct primary creation.

I may mention that *Umbellularia* was once regarded as the living representative of the "lily" encrinite. † But the latter has far nearer relatives ; some of whom we will now proceed to consider.

The Crinoidea form an interesting group in the deep-sea fauna —interesting from its beauty, its comparative rarity, and above all, to palæontologists, from the fact that it has seen better days. I should note, however, at the outset that, though the stalked crinoids occur in deep water, they are also found according to Moseley, in a depth of 40 fathoms. A representative of the genus *Pentacrinus*,‡ of which there is a drawing on the wall, was brought from the West Indies more than a century ago. The first deep-sea Pentacrinite was, I think, dredged by Dr. Gwyn Jeffreys at a depth of 1,095 fathoms off the coast of Portugal, and named by him after Wyville Thomson.

A more singular group of living crinoids—wholly unknown before the days of deep-sea investigation—is that referred by

* For drawing see "Atlantic," vol. i., p. 150. Dr. Kölliker has described several new species, one of which—a very elegant form—he calls *Umbellula Huxleyi*. "Challenger Reports," Zoology, vol. i.

† "Atlantic," vol. i, p. 151.

‡ *Pentacrinus asteria*, L. For drawing see "Depths of the Sea," p. 436.

Thomson to the Apiocrinidæ, of which the well-known pear-encrinite of the Bradford Clay may be taken as the type. Of these new crinoids, *Rhizocrinus loffotensis*, Sars, first dredged off Norway was early found in the British seas at a depth of 530 fathoms (temp. 43·5 F.), and has since been taken elsewhere. There seems to be little doubt, says Sir Wyville Thomson, that *Rhizocrinus* finds its nearest known ally in *Bourgueticrinus*, a very aberrant form from the chalk.*

There is another of these forms, viz., *Bathycrinus*, which is also referred to the Apiocrinidæ on the grounds that "the lower portion of the head consists of a gradually expanding funnel-shaped piece, which seems to be composed of coalesced upper stem-joints."†

A great haul of this sort of crinoids was made by the Challenger, between the coast of Africa and St. Paul's rocks, in 1,850 fathoms (35° F.) on a bottom of *Globigerina*-ooze. Besides a very handsome new *Bathycrinus*, they took a form to which the generic name of *Hyocrinus* was given. This has a striking, though, we are told, superficial resemblance to certain palæozoic genera, one of which, *Periechocrinus*, is placed alongside in the drawing for comparison.‡

Altogether there have been found, according to Sir Wyville Thomson's communication to the Linnæan Society,§ five living species belonging to three genera referable to the Apiocrinidæ; but it remains for the morphologist to determine how far the solid structure of the Jurassic Apiocrinids resembles that of these recent forms.

The Star-fishes and Ophiurids of the deep-sea are also interesting from their partial resemblance to ancient forms. This is especially seen in *Astrogonium, Archaster, Astropecten,* and their allies.‖ At the same time, it must be remembered that there are many genera belonging to other groups which also inhabit the

* For drawing of *Rhizocrinus loffotensis*, Sars, see "Depths of the Sea," p. 451.

† "Depths of the Sea," p. 450; and figure of *Bathycrinus gracilis*, W. T., p. 453.

‡ For drawings of *Hyocrinus*, see "Atlantic," vol. ii., pp. 96, 97.

§ "Journal—Zoology," vol. xiii., p. 47.

‖ "Depths of the Sea," p. 455.

deep-sea. Here is a drawing of *Archaster bifrons*,* showing the tesselated mailing on the disk and massive marginal plates. To this group belongs the well-known *Astropecten rectus*, a cast of which, from the Kelloway Rock of Yorkshire, is exhibited by Dr. Woodward.

Again, if we take the Urchins (Echinoidea) we trace a likeness to some long-lost friends in several of the deep-sea forms. Here is *Salenia*, for instance, not heard of on this side of the equator† since the days of the chalk. A specimen of one of these prizes from the deep is kindly lent for exhibition by the President of the Geological Society.

The chalk genus *Ananchytes* would also seem to have its representatives in the deep waters of the modern ocean. This may be especially noted in an irregular urchin, called *Calymne relicta*, W. T., trawled from 2,650 fathoms off Red clay, between Halifax and Bermuda.‡ It is amongst these irregular urchins that the relation between the modern " abyssal " fauna and the fauna of the later mesozoic beds is most marked ; and it is right to bear in mind that the genera allied to *Infulaster* and *Micraster* are more abundant and bigger in the Southern Ocean than elsewhere.§

But the most wonderful of all these Urchins, allied to Cretaceous forms, is *Asthenosoma*, Grube. The celebrated *Calveria hystrix* belongs to this genus, and it seems almost a pity that the name of the captain should no longer accompany that of the ship (the Porcupine) in connection with this very interesting species. This Urchin‖ has a flexible test, reversed imbrication, and other peculiarities, which closely ally it with the once puzzling genus *Echinothuria*. An allied genus, *Phormosoma*, has been found in 1,525 fathoms off Cape St. Vincent, and in 400 fathoms off the east coast of Australia.

In connection with this subject, I should remind you that Mr.

* For figure see " Depths of the Sea," p. 132.

† Professor Tate found a *Salenia* in the Middle Tertiaries of Australia. " Q. J. G. S.," vol. xxxiii., p. 256.

‡ " Atlantic," vol. i., p. 396.

§ " Atlantic," ii., 332.

‖ For figure of *Asthenosoma* (*Calveria*) *hystrix*, see "Depths of the Sea," p. 156.

Walter Keeping has lately described from the Coral Rag of Calne an urchin which he calls *Pelanechinus,* and which he believes to have had its test flexible, though not to such an extent as in *Asthenosoma.** Similar forms have been traced back as far as the Devonian.

The number of Corals dredged by the Challenger in deep water was comparatively small; "they were mostly simple and solitary, and the greater number belonged to the Turbinolidæ; many of the genera pass back to tertiary, and a few to mesozoic times."† *Caryophyllia borealis* is well known off our own coasts, and the only species, higher than Protozoan, that is common to modern deep-seas and the chalk, would seem to be *C. cylindracea,* Reuss. Prof. Duncan, who was the first to point this out, remarks, at the same time, on the very persistent character and less variable nature of the corals of the deep-sea fauna.‡

Bathyactis symmetrica, Pourtalès, one of the Fungidæ, has probably, the widest range of anything living, as it literally extends all over the world, and through all depths from 30 to 2,900 fathoms.§ In certain places off the British coasts, at depths from 300 to 600 fathoms, the handsome branching coral, *Lophohelia prolifera,* Pallas, forms stony copses covering the bottom for many miles.‖

Mr. Moseley considers that the deep-sea forms of the true corals are not, as a whole, of greater geological antiquity than shallow water forms. Many of the genera have a considerable range in depth, but those which attain extreme depths are *Deltocyathus, Flabellum,* and *Bathyactis.* The annexed abstract from the very complete table given by Mr. Moseley¶ will serve to show the range in depth and time of a few of the genera more especially interesting to the student of palæontology.

* "Q. J. G. S.," vol. 34, p. 924, *Pelanechinus corallinus* (Wright), Keeping—was originally described by Dr. Wright, in 1855, as a *Hemipedina,* from a fragment said to have been obtained in the Coralline Oolite of Malton.

† "Atlantic," ii., p. 346.

‡ "Q. J. G. S.," vol. xxvii., p. 436.

§ For figure of *Fungia symmetrica,* see "Atlantic," vol. ii., p. 149.

‖ "Depths of the Sea," p. 168.

¶ "Challenger Reports," Zoology, vol. ii., p. 132.

	Depth.	Age.	
TURBINOLIDÆ.			
Caryophyllia	shallow water—1500 fms.	Ter.	Sec.
Deltocyathus	150 fms. —2250 fms.	Ter.	
Trochocyathus	100 fms. — 750 fms.	Ter.	Sec.
Sphenotrochus	shallow water— 150 fms.	Ter.	
Flabellum	shallow water—1500 fms.	Ter.	
Parasmilia	50 fms. — 300 fms.		Sec.
OCULINIDÆ.			
Lophohelia	100 fms. —1000 fms.	Ter.	Sec.
ASTRÆIDÆ.			
Astræa	shallow water— 150 fms.	Ter.	Sec.
Cladocora	shallow water— 50 fms.	Ter.	Sec.
FUNGIDÆ.			
Bathyactis	50 fms. —3000 fms.		
EUPSAMMIDÆ.			
Balanophyllia	shallow water— 400 fms.	Ter.	
Dendrophyllia	50 fms. — 750 fms.	Ter.	
Stephanophyllia	100 fms.	Ter.	Sec.

We have a representative of the hydroid corals in the very elegant *Cryptohelia pudica*, Miln. Ed., which occurs all over the world at depths from 350 to 1,500 fathoms. The drawing represents the common skeleton of a highly complex colony.*

The importance of the Sponges is perhaps more considerable. To-night we must confine our attention to the Hexactinellidæ—a group especially dear to the geologist. There are several genera which affect deep water, but I will only mention three.

Off the north-west coast of Scotland *Holtenia*, the sea-nest sponge of the Portuguese shark fishers, is particularly abundant on a bluish-grey calcareous mud containing some sand and a considerable admixture of *Globigerinæ*, and which extends from off the Butt of the Lews to Gibraltar. Along with this is *Hyalonema*, the celebrated glass-rope sponge of the Japanese, which has been the means of deceiving so many collectors. The researches of Professor Sollas and others have made us acquainted with the exquisite internal structure of many of the Hexactinellids, but

* For figure, see "Atlantic," vol. i., p. 272. "It is true that corals, which come within Milne-Edwards' definition of the Rugosa, occur in deep water, but that group needs great modification, and the structural difference between the deep-sea forms and ordinary Caryophyllias is probably of comparatively little zoological importance." Moseley, "Nature," Ap. 15, 1880.

perhaps the most striking of all these pieces of siliceous network is *Euplectella.* I would especially draw attention to *Euplectella suberea,** W. T., a new hexactinellid obtained in 1,090 fathoms off Cape St. Vincent. There is such a strong general resemblance between this form and *Ventriculites simplex,* T. Smith, of the chalk, that I have had drawings of the two placed side by side in order that you may note their resemblances and their differences.

Before quitting the subject of the sponges I would also remind you that the Hexactinellidæ, though undoubtedly a deep-water group in the present day, have their comparatively shallow water representative in the well-known Venus' Flower-basket (*Eupl. aspergillum*), which occurs as high up as 90 fathoms, in water having a temperature of 70° F., on a soft blue mud at Zebu, in the Philippine Islands.

It would, of course, be utterly hopeless to go through all the classes. There are just two more which have a claim to some notice. We cannot altogether slight the Crustacea, since these are so extremely characteristic of some parts of the deep-sea, and especially of the cold areas, where they frequently attain to a very great size. The macrurous decapods are particularly numerous, whilst the brachyurous decapods appear to be confined almost entirely to comparatively shallow water. There is a large family, having a strong general resemblance to the fossil genus *Eryon.*†

It is well known that in the deep-sea animals, the eyes are frequently atrophied or altogether absent; but in some cases the eyes are very large and clear. This is well shown in the crustacea, and is a good illustration of the opposite action of the same cause, showing how extremes may meet. The following drawings are exhibited in this connection :—

Bathynomus giganteus, Alp. Miln. Ed., one of the largest isopods, with huge facetted eyes, dredged in 1878 from 900 fathoms.

Thaumops pellucida, Von W. S., 84 millimetres long, an amphi-

* For figure of *Euplectella suberea,* see "Atlantic," vol. i., p. 139. For figure of *Ventriculites simplex,* see "Depths of the Sea," p. 483.

† A drawing of a specimen from the Lias of Barrow-on-Soar was exhibited. See also "Geol. Mag.," Dec., 1881, p. 349.

pod trawled in 1873 from 1,090 fathoms off Cape St. Vincent. This has large compound eyes.*

Polycheles (*Willemösia*) *crucifer*, W. T., a macrurous decapod without eyes, dredged in 1873 from 1,000 fathoms off the West Indies. The same genus occurs abundantly in 320 fathoms, near the Fiji Islands, along with the pearly *Nautilus*.†

The Brachiopoda also have especial claims on our notice. This class extends from 5 to 2,900 fathoms, but considerably more than half the species known to exist occur in depths of less than 150 fathoms. *Discina atlantica*, a shell about three millimetres in length, ranges from 600 to 2,425 fathoms, whilst *Lingula* ranges from a depth of a few inches to no more than 60 fathoms. A species of *Terebratula*, having a range from 1,035 to 2,900 fathoms, has been found at six stations on various kinds of ground; it is a good size, outwardly like a *Waldheimia*, and, according to Mr. Davidson, very much resembles a fossil from the Kimmeridge Clay of Switzerland. There is a *Terebratulina* occurring in 390 fathoms, off St. Thomas Island, which the same authority declares to be the finest species of the subgenus, recent or fossil.‡

I am trying to get on, but the Mollusca will have a word, especially the Gasteropoda and Lamellibranchiata. We have the authority of Sir Wyville Thomson that they do not enter largely into the fauna of the deep-sea, and this must be accepted, more especially as regards the vast extent of submarine flats away from the continental margins. In these great plains the Mollusca are for the most part small and stunted; yet nearer shore, even in tolerably deep water, they are sufficiently numerous. A proof of this we have in Dr. Gwyn Jeffreys' celebrated haul off the coast of Portugal in 994 fathoms, when he obtained 185 species of Mollusca (including Pteropods), of which 23 were Pliocene Gasteropods.§ Such an assemblage may have been accidental. Another

* For figure of *Th. pellucida*, see "Phil. Trans.," 1873, pl. 49.

Dr. Woodward informs me that several of these large-eyed amphipods are in the habit of taking up their quarters in the stomachs of Medusæ and pelagic Tunicata. It is a somewhat curious coincidence that these Medusæ are highly phosphorescent, so that the amphipods obtain both light and lodgings for nothing.

† Moseley, "Notes by a Naturalist," p. 297. For figure of *P. crucifer*, see "Atlantic," vol. i., p. 256.

‡ See "Challenger Reports," Zoology, vol. i.

§ "Depths of the Sea," p. 183.

remarkable exception to the rule is the case of a volute allied to *Cymbium*, 6¾in. long and 4in. broad, dredged in 1,600 fathoms off the Crozet Islands.*

Conclusion.—In thus giving a partial and imperfect sketch of the deep-sea fauna, with more especial reference to those groups likely to be of interest to the geologist, there is a possibility of producing an exaggerated impression as to the relative importance of these groups. If the discovery of a few survivors of classes which have been more numerous in former times is to be held conclusive, the stalked Crinoids might claim that they were still living in Jurassic or even older periods. In opposition to them the Ventriculite-like Hexactinellids and the Urchins which resemble the Salenias, the Echinothurias, and the Ananchytidæ of the chalk, would claim that they were living in the Cretaceous period.

It was very natural in the early days of deep-sea dredging, when several of the forms long supposed to be lost kept turning up, to attach an undue importance to their occurrence. The discovery at the same time that there are deposits forming in the Atlantic which have some resemblance to chalk gave additional weight to the zoological evidence in favour of the Cretaceous period. The time for wholly removing what appears to be a misconception on the part of some geologists has not, perhaps, yet arrived. We await the fuller reports of Sir Wyville Thomson and Mr. Murray, though it is pretty clear what are now the opinions of those gentlemen. Sir Wyville Thomson, writing a year ago with reference to the views of Mr. Murray and himself, observes :—" (1) That the chalk of the Cretaceous period was not laid down in what we now consider deep water, and that its fauna, consisting mainly of shallow water forms, merely touches the upper limit of the abyssal fauna. (2) That no beds exist in the series of known sedimentary rocks which correspond in composition and in structure with the beds now in process of formation in the abyssal sea."† This is a pretty strong recantation on the part of the author of the " Continuity of the Chalk," but Sir Wyville has seen a little more of the world since those days.

Another point of considerable importance to geologists should also be urged. Since some species and many genera range at pre-

* Gwyn Jeffreys, *loc. cit.*, p. 180.

† " Nature," Nov. 11, 1880.

sent almost from the shore to vast depths, many forms now restricted to deep water may formerly have lived in less depths, and most probably did so. Hence no absolute conclusions of any value can be drawn as to the depths at which a deposit was formed "until the reign of reef coral and plant life is reached."* For instance, it would be useless to urge that *Pentacrinus* is necessarily a deep-sea form, and hence that the Lias was deposited in deep water, for if *Pentacrinus* now ranges from abyssal depths up to 40 fathoms, and from cold to very warm water, its range as to temperature and depth in the past can in no wise be limited.

At first sight such a conclusion is rather discouraging, but we may fairly believe that the general facies of a fossil fauna will still have its bathymetrical value, though no one would be justified in appealing to the evidence of a limited number of forms. In this way a truly littoral fauna will always carry its mark with it, and the original divisions of Forbes for water of moderate depth will probably be true both for the past and the present.

It follows, therefore, that the power of adaptation which probably all groups of invertebrate animals possess, whereby many modern shore genera, and even species, are enabled to exist at great depths, renders it difficult to use the zoological evidence in deep-sea investigations for estimating the depth at which a given formation may have been laid down. Similarly the lithologists have, as you know, arrived at the conclusion that the beds now forming under the deep-sea correspond to none of the known sedimentary rocks.

But if the immediate advantages to geological science are, perhaps, not so great as was at one time hoped and believed; if hardly a single *species* has yet been found, excluding the Protozoa, of more than Pliocene age, notwithstanding the representatives of old and curious groups; if not a single animal has yet been brought to light which can supply the missing link between any of the great zoological classes; † and if modern deep-sea deposits are unlike anything in the known sedimentary rocks, are we to suppose that deep-sea investigation has no geological import? Certainly not.

Besides the hydrographical, physical, and chemical results which

* Moseley, in "Nature," *loc. cit.*

† Moseley, *loc. cit.*, p. 571.

have been added to the store of human knowledge, an acquaintance with the deep-sea fauna will always have its value. That fauna has a certain relation to the existing shore fauna, as previously noted, but there are other elements of older date, as we have also seen. Why should it not be regarded as a vast colony or back settlement which has from time to time throughout the geological ages received the surplus population of the happier shallows—those shallows where sea and air unite, under the stimulating effects of warmth and the solar rays, in offering a congenial cradle to life? This would at once explain its genetic relations to the past and to the present, without the necessity for supposing that existing deep-sea conditions are representative of any particular epoch of the earth's history.

In thus changing or enlarging their habitat, some groups—the macrurous decapods, for instance—rather flourish in the deep-sea, whilst their more sagacious relatives, the brachyura, take care to remain above. It is evident from the monotonous character of the deep-sea fauna generally, and from the comparative simplicity of several of its groups, that uniformity of conditions, a constant low temperature, and absence of solar light has, on the whole, a conservative effect on the tendencies to structural change inherent in all organisms. We thus have a zoological assemblage to which more than one age of the earth has contributed its quota, an assemblage hitherto safe in the cold, dark depths of the once mysterious ocean, but which the persevering curiosity of man is by degrees dragging forth from its hiding-place.