

ART. VIII.—*The Origin and Peopling of the Deep Sea*; by
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THE ocean covers two-thirds of the earth's surface. Five continents and numberless islands rise out of it and divide the ocean into separate parts, but nowhere is there to be found a barrier which can permanently prevent the intermingling of the waters. The ever-moving and restlessly intermingling sea water shows therefore a very marked uniformity in its chemical composition. At Pole as at Equator, in the upper surface as in the depth of the sea, the salt content amounts to about 3.5 per cent and the proportion of chloride, sulphate and carbonate remains on an average the same in brackish bays or at the mouths of great rivers.

It is known that the astronomical position of the earth with relation to the sun causes marked climatic zones which are arranged in almost parallel girdles perpendicular to the earth's axis, and we notice on the mainland a steady decrease of organic life the farther we proceed from the warm equatorial region toward the cold polar circle.

The surface of the sea is also girt about with climatic zones, which, corresponding to the continental temperature belts, reach from one coast to the other. In the equatorial region, the water has a warmth of 30° C.; toward the poles its temperature sinks, and since salt water first freezes at -2.5° C., the polar shores are laved by very cold water. One would then believe that hand in hand with this decrease in temperature a diminishing of the organic life in the sea would be noted, but quite the opposite is the case. In the polar seas, the plankton net is filled with a veritable jelly of floating plants and animals which serve as food for the numberless fish swarms and the giant whales, and if the naturalist has drawn the dragnet over the sea bottom, it is filled with a vast multitude of echinoderms, mollusks and crabs.

In order to understand this striking fact, we must keep clearly in mind that almost all sea animals belong to cold-blooded forms whose own warmth changes as the temperature of their surroundings changes. *Pecten islandicus* thrives as well in a sea temperature of zero centigrade as does *Pecten jacobæus* in 10° C., or as the tropical *Pecten sanguinolentus* in the water of the coral seas with a temperature of 25° C. Consequently, the absolute degree of temperature is of no influence on the richness in forms of the sea fauna.

We know that the climate of a continent undergoes very

* Translated from the German (*Naturwissenschaftliche Wochenschrift*, 1904) by Clara Mae LeVene, Peabody Museum, Yale University.

noticeable changes in the same geographical latitude if the land is raised into mountains. Kilimanjaro lies in the tropical zone and still its peak is covered with eternal snow and "polar" glaciers.

Just as the climate of the continent with increasing topographical altitude becomes more like polar climate, so we notice in the sea with increasing depth a constant lowering of temperature. Even at 120 meters* the daily and yearly fluctuations of the warmth of the water cease as a rule, and under the surface water, with a warmth of 30° C. in the equatorial region, we find even at 200 meters a temperature of 12° C. and at 1200 meters one of 5° C. From here to the bottom reigns an unvarying temperature of zero to 5° C., which in the southern Atlantic sinks even to -2° C.

But while on the land the colder regions occupy only scanty space, the contrary condition rules in the sea bottom. For even in the equatorial regions, the warm water is restricted to very narrow zones parallel to the coasts and the whole expanse of the true deep sea bottom is covered with ice-cold water. A gigantic but immeasurably slow stream of cold south polar water flows toward the equatorial region in the depths and projects the thermal characteristics of the southern ice seas to the deep sea bottom.

By examination of a world chart, we do not get the correct impression of the relation of the sea to the continents, because the border region of the continental mass is washed over by the sea, and consequently around almost all coasts extends a broad shallow-water zone, whose depth very slowly sinks to 200 to 300 meters. The whole North sea, the Irish sea and the ocean for 300 kilometers west of Ireland belong to this so-called continental shelf, and not until beyond them does the sea bottom sink suddenly to 4000 meters.

But even if we consider the continental shelf as the submerged edges of the continents, still half the earth's surface belongs to the area of the deep sea, with an average depth of 4000 meters and a maximum depth of 8 to 10 kilometers. This vast region, embracing half of the globe, is so significant in the natural history of the earth to-day that one can well understand the important rôle it has also played in the geologic past. But in order to discern the past history of the deep sea, we must point out still another important characteristic of the present deep sea.

Waves and currents were produced by passing or periodical winds and set in motion only the upper water strata. In a depth of 1000 meters, even the Gulf Stream is scarcely noticeable and farther down all measurable water movements cease.

*For the sake of simplicity the figures are given in round numbers.

Only imperceptibly slow diffusion streams constantly mix the waters.

Just as the sun's heat can only warm the upper water strata, so the sunlight, even in clear water, penetrates only to a depth of about 400 meters. Photographic plates which were exposed at such a depth at Nice show no influence of light. Only the delicate shimmer of phosphorescent animals lights the dark abyss. The consumption of carbon dioxide, so important for the life of plants, is only possible in sunlight; therefore we need not wonder that the deep sea harbors no single plant and that with their absence fail also the plant-eating animals.

To sum up the characteristics of the abyssal region so far noted,—a uniformly low temperature, quiet water of normal salinity disturbed by no noticeable movement, no light and no plant life: these are the bionomically important characteristics of the deep sea.

These conditions of existence are, moreover, very constant over vast areas and cause the world-wide distribution of most of the deep-sea dwellers. The fauna of the deep sea is undoubtedly poorer than that of the shallower parts of the sea, but if we consider that all light-hungry and plant-eating animals are lacking there as well as all inhabitants of the moving and warm sea water, we are still astonished at the animal world of the abyss. For each dragnet brings up deep sea animals and even the small bottom samples of the sounding apparatus have afforded traces of organic life at the maximum depth of more than 8000 meters.

Ten years ago, Sir John Murray gathered the results of the earlier deep sea expeditions and thereby showed that

down to 200	meters	about 4200	kinds of	bottom-dwelling	animals exist
down to 2000	“	“	600	“	“
at 4000	“	“	400	“	“
below 5000	“	“	150	“	“

rare or very frail. Some are blind, others distinguished by telescopic eyes or wonderful concave mirror-like sight organs. Many live on decaying deep sea ooze and have therefore lost their organs for the mastication of food, others are robbers with strongly developed jaws. Many forms show wonderful contrivances for the care of the young, while others seem to multiply with extraordinary rapidity; but almost all are provided with phosphorescent light organs which unite with their gay, soft radiance, that in some cases can be photographed after capture, to transform the dark depths into a magic garden.

If we inquire into the conditions of existence of this animal world so rich in forms, a peculiar problem arises: we know that organic life is only maintained by the constant introduction of inorganic elements into the cycle of life and that the force which in great measure is able to maintain life is the carbon dioxide consumption by the plants. Only when sunlight falls on brightly colored plant parts are carbonic acid and water separated into their elements and from these the complex protoplasmic molecule built up. Where sunlight and green plants are wanting, there can no new life arise and no organic life be maintained. So the animal life in the deep sea of to-day could not be maintained if a stream of cold south polar water did not pour oxygen and food down into the abyssal depths.

The deep sea resembles, speaking in terms of national ecology, a purely industrial state without agriculture dependent for its existence upon lands pursuing agriculture and stock-raising. Hence it follows as a necessary consequence that the fauna of the deep sea cannot have originated there, but must have wandered down into the dark depths from the sunlit strata rich in plants.

As soon as we have made clear this indisputable fact, a very significant geological problem confronts us. We ask, When did the deep sea become peopled? and when did the deep sea basin originate?

To be able to solve these questions, we must describe in few words the character of the sediments of the present deep sea, for only by knowing these well is it possible to examine an old rock as to the history of its origin.

All deposits of the coast region and the shallow continental shelf had their origin on the mainland of the continental areas. The boulders on the rocky shore, the sand of the dune regions, and the blue or green ooze of the shallow sea are either washed from the strand by the sea waves or borne into the ocean by rivers. The mighty delta masses of the Nile, Ganges or Mississippi bear witness to the vast quantities of continental muds that are carried into the sea.

But the salty sea water has the peculiar property of clarifying muddy river water in a short time and of precipitating all ooze to the bottom. In this way all the river mud is deposited in the shallow sea region and no fragment of quartz reaches the abyss.

Sir John Murray, after the completion of the Challenger expedition, examined all the known samples of deep-sea bottom and showed that in these depths sediments of a very peculiar character exist. The mightiest rôle in their composition is played by the floating organisms of the sea. The chalky shells of frail *Globigerina* cement together the main mass of the so-called *Globigerina* ooze, which covers about half of the entire deep sea bottom. This cream-yellow when fresh, soft, liquid lime-ooze is connected with the continental muds of the coast zones by transition stages, and passes, by decrease of its chalk content, into the so-called Red Clay of the deep sea, which covers about one-fourth of the earth's surface. To it are joined isolated areas which are completely strewn over by the delicate microscopic siliceous tests of *Radiolaria*. The Red Clay of the deep sea originates from transformed volcanic ashes and through the solution of organic calcareous skeletons.

With certain exceptions the above named deep sea sediments and other associated deposits of the abyssal regions are distinguished by the following characteristics:

1. They contain neither quartz nor other fragments of continental rocks.
2. They contain no plant residue which is brown or black in color.
3. They are piled in horizontal layers and are spread over marvelous distances.
4. They contain no remains of shallow sea animals or plant-eaters.
5. By very slow and gradual transitions they are connected with the shallow water sediments of another origin.

The geologic examination of the continental masses has given the remarkable result that from the oldest times of earth history to the present day almost every part was repeatedly sea bottom. The present position and limits of the ocean are a transitory appearance, and while it was formerly believed that it was possible to measure and gauge the height of the land by the fixed level of the sea surface, it has been known for twenty-five years that the sea level is variable. Now, if each part of the present dry land was one or more times sea bottom, we must first ask whether we know deposits in the earth crust which by their lithologic and faunal character can be considered as formerly sea bottom.

I have busied myself much with recent deep sea sediments, have studied those of the Challenger expedition, and in my geologic studies have considered again and again whether anywhere a fossil rock possesses abyssal characteristics, and can state that nowhere have I met with a rock either from Paleozoic or Mesozoic deposits that by its structure and nature of deposition corresponds to the present sediments of the deep sea. Even the radiolarian rocks made known through Dr. Rüst's careful studies contain no likeness to the radiolarian ooze of the present deep sea. Their coal wealth, the mass of terrigenous material, and their stratigraphic connection with undoubted littoral sediments make it impossible to see in them the deposits of the deep sea. We are much more reminded of the tripoli of Sicily and the oceanographic conditions in the straits of Messina. Here rushes upward a mighty stream of cold deep sea water, bringing deep sea fishes, crabs and radiolarians to the surface of the sea where they, mingled with the dwellers of the upper water strata, give rise to the richness of the sea fauna here so well known to all zoologists. John Murray attained the same result after he had applied to a number of geologists with the request to send him fossil "deep sea rocks." The microscopic examination showed that only on a few small islands like Malta, Barbados, and Christmas island occurs true Tertiary deep sea ooze, and the local distribution of these unmistakably indicates that local upheavals of former deep sea bottom formed the nuclei of these islands. Although almost the entire areas of the continents of to-day have been wholly or partly and repeatedly overflowed by the ocean since the Cambrian, yet we know here only such deposits as are now forming in the shallow seas or in depths not below 1000 to 2000 meters.

Herewith we confirm by geologic proof a view which has long been asserted on the ground of theoretical speculations and which centers in the statement: the deep sea of to-day has been deep sea for a long period and it has not essentially shifted its place on the earth's sphere since its origin. The deep sea basins appear to us as the original regions of ocean origin, from which the sea periodically transgresses upon the continents, only to flow back again into the gigantic gathering-reservoir.

Geologically it can be shown with certainty that former continents have been sea bottom. Thus, we find in Devonian time on both sides of the Atlantic ocean, in North America and Spitzbergen as well as in Scotland and Russia, deposits of great fresh-water basins with a very characteristic fish fauna. In the Carboniferous as well as in the Jurassic and Cretaceous the same land and plant animals lived in North America as in

North Europe. All this points to the conclusion that during these long periods an Atlantic land connection existed between both continents which to-day is in part deep sea bottom. Similar facts force the acceptance of the opinion that the present Indian ocean throughout long periods possessed a land bridge from Africa to India and Australia. Finally, how can we explain the occurrence of entire skeletons of hippopotamus and African elephants in very ancient bone caverns at Palermo except by the conclusion that Sicily was once joined with Africa, although now a deep sea exists between the two shores? For a passive transportation of these gigantic animals is not to be considered.

Aside from a few local exceptions where deep sea bottom has again become land, there are numerous cases in all parts of the earth where we can show that great portions of the firm earth crust through sinking have become changed into sea bottom. In other words, the deep sea has grown at the expense of the shallow sea and the mainland.

The great interest of geologists in the investigation of the deep sea arose when the elder Sars discovered in the Lofotens at a depth of 1000 meters a small sea lily, *Rhizocrinus lofotensis*. The stalked sea lilies up to this time had been held as an entirely extinct group which in the geologic past had possessed a great significance, inhabiting the former seas in hundreds of genera now extinct. Out of the deep sea there was then drawn such an ancient animal still living and at once then arose the hope of obtaining by methodical dredging of the deep sea bottom other animal species also believed to be extinct. It was one of the more important tasks of the Challenger expedition to seek after these very ancient types.

A number of expeditions have now explored the bottom of the deep sea and we know very well the systematic interrelation of the present deep sea fauna and its characteristics acquired by adaptation to the peculiar environmental conditions; and it seems a praiseworthy task to prove the geologic age of this fauna, just as paleontologists do in determining the age of an extinct fauna. It is well known that in each period of the earth's history different sea animals have lived; let us now compare the present deep sea fauna with the chronologically arranged faunas of the past.

To this end we must first point out that not a single animal characteristic of the Paleozoic is found in the present deep sea. The Archæocyathidæ, Tetracoralla, Tabulata, Stromatopora, Spiriferidæ, Graptolithidæ, Cystidea, Blastoidea, Paleocrinoidæ, Orthoceratidæ, and Trilobitæ are completely lacking. We might then perhaps surmise that in general no Paleozoic forms

still live. Therefore we must also point out that in the present shallow sea there actually live a number of uncommonly long enduring Paleozoic genera :

Of brachiopods, *Lingula*, *Rhynchonella*
 Of bivalves, *Arca*, *Avicula*, *Astarte*, *Leda*, *Mytilus*
 Of univalves, *Capulus*, *Pleurotomaria*
 Of cephalopods, *Nautilus*
 Of worms, *Serpula*
 Of starfishes, *Astropecten*.

Limulus, the last representative of Silurian horseshoe crabs, is a coast dweller, and *Ceratodus*, rooted in the Devonian, still lives in Australian rivers.

We must thereto also add a number of forms without skeletons which are phylogenetically very old and which must have had their origin in the pre-Cambrian faunas. *Hydra* and *Amphioxus* as well as the *Asconia* sponges, Planarians and Holothurians are mostly dwellers in very shallow water, and all these forms reach back into the oldest part of the earth's history.

Only the Cambrian genus *Discina*, some Silurian bivalves such as *Arca* and *Nucula*, univalves such as *Dentalium* and the Devonian *Terebratula*, have descended into the deep sea, but it is naturally very easy to suppose that they first began this migration at a later time. Mustering now the remaining animals with skeletons living below 2000 meters and with a clear understanding as to their paleontologic position, there can be no doubt that the oldest genera date from the Triassic and Jurassic periods.

The Euretidae among the hexactinellid siliceous sponges, the turbinolids among the corals, *Pentacrinus* among the crinoids, *Ophioglypha* and *Asterias* among the starfishes, *Echinus* among the sea urchins and *Penæus* among the crabs are forms whose oldest kin belong to the Mesozoic age. Their migration into the deep sea can therefore at best date from the Triassic.

Very close is the relationship of the present deep sea fauna to the animal world of the Jurassic and Cretaceous periods. The German Valdivia expedition found the nearest kin of the upper Jurassic *Eryon* in the characteristic deep sea crabs *Pentacheles*, *Willemæsia* and *Polychæles*, and A. Agassiz has shown that most of the deep sea urchins are related to Cretaceous genera.

The deep sea corals belong almost entirely to Cretaceous genera. It is further noteworthy that typical Tertiary forms are very rare in the deep sea. The migration must therefore in general have ceased in the Tertiary.

Were the present deep sea fauna laid before a paleontologist "without designation of locality," he would on the basis of

the more fundamental relationships have to consider it as Mesozoic and would refer the majority of the forms to Cretaceous and Jurassic genera and others to genera of the Triassic. The few Paleozoic genera occurring at all water depths would thereby gain no significance because all specific forms of Paleozoic time are wanting in the deep sea, whereas, on the other hand, many representatives of the same are found living in the present shallow sea.

General considerations as to the life habitats of the deep sea have led us to the conviction that its fauna must have migrated from the shallow sea; the comparison of the deep sea fauna with the fossil faunas has shown us that it has a Mesozoic character; therefrom the conclusion necessarily follows that the peopling of the deep sea can be traced at the earliest to the Triassic.

The deep sea basins represent the greatest inequalities of the earth's crust. While the average height of the mainland amounts to only 700 meters, the average depth of the oceans is 3500 meters, but the average depth of the deep sea basins amounts to about 5000 meters. It is only the Tibetan highland that rises to this amount above the mainland, while one-half of the entire earth's surface is depressed below this level.

In different periods of the earth's history great land areas have sunk beneath the surface of the sea to be united to the deep sea; into the new depressions the water flowed and left the former shallow sea regions. Since the Jurassic, North America and Europe have in this way gained land, and even in Asia we see the land growing at the expense of the shallow sea. The intensive development of mammals, birds and insects since the Eocene seems to stand in the closest causal connection thereto.

The fact, recurring in all great sea basins, that the greatest depths occur nearest the coasts, can be explained only by the assumption that these deep channels represent local exaggerated deepening of a general deepening process.

From the study of newer and older mountains it is now seen that hand in hand with the elevation of the mountain chains extensive depressions have occurred. The Alpine folding continues into the depressed plain of Lombardy just as the chains of the Himalayas are connected with the Bengal depression and the South American Cordillera finds in the bottom of the Pacific ocean its downward-directed compensation. With the elevation of the Black Forest and Vosges the plain of the Rhine valley sank into the depths, and the sinking of the Dead Sea corresponds to the elevation of the Lebanon.

We must also expect the beginnings of those immense depression areas to be connected with the powerful processes

manifested in mountain-building, and have to examine as well whether in the earth's history there is discernible an increased folding of the crust at the end of the Paleozoic..

Everyone who is at all familiar with the events of that epoch knows that at no other period did there arise anything equalling the extent and grandeur of the mountain ranges of the time between the Carboniferous and Triassic periods. A gigantic range of mountain folds can be traced from Ireland through all of France to the banks of the Rhone; a second range extended from the Rhine northeast through Germany to the Carpathians. The eastern Alps were mountain land and in Switzerland as well are to be seen undoubted traces of a former mountain range. In the same epoch arose the Urals and simultaneously the Appalachians were thrust together in North America. In the Sudan there probably arose a mountain fold with great granite stocks at the termination of the Paleozoic and in South America the Permian age of extensive mountain folding was definitely established! Even in eastern Asia keen scientific explorers have been able to trace a Permian period of folding from China to Japan and through the interior of India to Sumatra.

But where are to be sought the complementary movements of this same time directed toward the center of the earth?

An answer to these questions is not difficult to find. For if the present deep sea fauna contains predominantly Mesozoic types and in accordance with its whole character must be considered as a migration from the shallow sea; if therein almost all Paleozoic elements are lacking although such are represented rather numerously in the present shallow sea; then the deep sea must have originated at the end of Paleozoic time.

And if in the same period of time we find that mighty mountains have arisen almost everywhere on the earth, then it is easy to bring the depressions of the deep sea basins into direct connection with these folding processes.

General biological grounds, the stratigraphic position of the present deep sea fauna as well as tectonic investigations, force us to the conclusion that the deep sea as a life-region is not a characteristic of the earth in its oldest periods, and that its origin falls in the time when in all parts of the present continents began tectonic folding movements which so decidedly changed the relief of the earth's surface.