SCIENCE

A WEEKLY JOURNAL DEVOTED TO THE ADVANCEMENT OF SCIENCE, PUBLISHING THE OFFICIAL NOTICES AND PROCEEDINGS OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

FRIDAY, MAY 31, 1901.

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*THE SEA BOTTOM—ITS PHYSICAL CONDITIONS AND ITS FAUNA.**

IT is hard to realize the fact that, up to a comparatively recent date, nearly three-fifths of the actual solid surface of the earth was absolutely a 'terra incognita,' a region as unknown as the poles, and as full of mystery as the center of the earth. Yet, if it be true that the sea covers nearly three-fifths of the surface of the earth, it is also true that its bottom, which is the actual solid surface of the globe, was, up to the middle of the century just ended, absolutely unexplored, excepting a very narrow strip around the edges.

For the purpose of our study this evening, we may define the deep sea as all that is deep enough to exclude sunlight and vegetable life in appreciable quantities from the bottom. We may safely assume that this limit is at a depth of about 150 fathoms. Sensitive photographic plates are said to be unaffected beyond the depth of about 125 fathoms clear water.

It thus becomes apparent that we shall have to include as deep sea almost all the area covered by the oceans of the world, there being but an inconsiderable strip around the edges that is within the 150-fathom line. The average depth is very

* Lecture delivered before the Nebraska Chapter of the Society of the Sigma Xi, February 14, 1901, by Professor C. C. Nutting, of the State University of Iowa.

much greater than that. Indeed, we now know that more than one half of the actual surface of the globe is over two miles beneath the surface of the water, and that about seven million square miles are buried under more than 3,000 fathoms of ocean.

Still greater depths are by no means uncommon. The *Challenger* sounded at a depth of 4,561 fathoms in the North Atlantic, and Uncle Samuel, not to be outdone by his British brother, very recently found a depth of 5,200 fathoms near the lately acquired Island of Guam. This is, so far as we know, the deepest abyss of the ocean, being 31,200 feet, or nearly six miles. Into such a depth the highest terrestrial mountain could be plunged without any resultant peril to navigation, as there would still be some 2,000 feet above the highest crest.

As already indicated, this vast realm of darkness was unexplored previous to about the middle of the nineteenth century. The pioneer explorer of the sea bottom was a Norwegian zoologist, Michael Sars. Then followed several expeditions under the patronage of the British Government, culminating in the *Challenger* voyage, the results of which stand to-day as a peerless example of a wise and liberal policy in the encouragement of scientific research.

The United States has come well to the front in deep-sea investigation, and now owns the best equipped vessel for this work in the world. I refer to the *Albatross*, of which we shall hear more later. Americans may well take pride in remembering that the oceanic basins near our eastern and southern coasts are more thoroughly explored than any other parts of the sea bottom.

Investigations of this nature have been attended with almost insuperable difficulties, necessitating the devising of a number of entirely novel instruments and machines for this particular work. Several of the most successful of these were invented by American naval officers, of whom Captain Sigsbee, of the ill-fated *Maine*, has been the most prominent. Our knowledge of the sea bottom has been gained mainly by the use of the following appliances :

1. The *sounding machine*. To drop a weight attached to a line to the bottom of the sea would seem to be as simple a proposition as could well be devised. As a matter of fact, however, its successful accomplishment has taxed the inventive genius of the most accomplished engineers. Sigsbee's sounding machine, with detachable weight and piano-wire line has proved the best device for obtaining accurate soundings and adequate samples of the bottom. This and the other instruments about to be mentioned will be illustrated and briefly explained later.

2. The *thermometer*. Temperature observations have been of the utmost importance in determining the physical conditions of the deep sea, and various kinds of thermometers have been devised to withstand the enormous pressure and register the maximum and minimum heat. Not infrequently these expensive instruments have been brought to the surface with their bulbs crushed to powder by the terrific pressure of the abyss.

3. The *water bottle*. Not only must depth and temperature be ascertained, but the actual composition and condensation of the water must be found by means of samples that can be secured free from admixture with sea water of other depths. Here also the genius of Captain Sigsbee was equal to the emergency, and the 'Sigsbee water bottle' has proved itself a convenient and efficient instrument, being so constructed that it will take a sample of water at any given depth and then automatically seal itself and remain hermetically closed until opened by hand.

4. The *dredge*, for scraping over the bottom and securing specimens of the animal life of the deep.

5. The *trawl.* A large bag-like net, useful on soft bottoms, over which it will pass without digging into the soil. It has a larger mouth and greater capacity than the dredge.

6. The *tangle-bar*, to sweep over rocky bottoms on which the other instruments would foul and often be lost. It is in effect a series of long swabs that will entangle in its hempen fibers almost anything from coral rock to fishes. It is probably the most effective all-around instrument for general work, and the least likely to fail or be lost. We found it invaluable in West Indian waters of moderate depths.

With these six instruments, then, the sea bottom has been sounded, its temperature taken, samples of both water and bottom secured and specimens of its animal life brought to light, both figuratively and literally. As yet this vast territory has been but scratched here and there. We can speak with confidence, however, concerning the general physical conditions, and we are acquainted with thousands of the strange and bizarre creatures that constitute its fauna.

Regarding the physical features of this under world, the following points are worth consideration :

The temperature is uniformly low, probably below 40°, except in enclosed seas in tropical regions such as the Red Sea. In many places the temperature is actually below the freezing point of fresh water. I well remember the surprise felt by the members of a dredging party one excessively hot day off Havana, indeed within sight of the now famous Morro Castle, when they plunged their hands in a mass of mud brought up in the dredge and found it so cold as to make them fairly ache. Of course the cold water reaches the surface in high latitudes, but it covers the entire floor of the ocean at depths over 150 fathoms. This practical uniformity of temperature over the entire submarine surface of the globe plays an important part in the well-known wide distribution of deep-sea species.

The general impression that high temperature is more favorable than a low one for the best development of animal life is certainly not true of marine animals in general, whatever may be the facts concerning some special groups. If other conditions are favorable, a luxuriant fauna will be developed in any temperature short of the freezing point of salt water. But a *change* of temperature, if a sudden one, is sometimes the cause of oceanic tragedies of frightful extent, a fact illustrated by the following example :

The tile-fish is a deep-water species, living upon the bottom on what is known as the Gulf Stream slope, off the New England coast. Here the water is normally comparatively warm, coming as it does from the superheated region of the Gulf of Mexico.

During a series of unusually severe gales in the summer of 1882 this mass of water was pushed aside, as it were, and replaced by the colder water. As a result, millions and millions of these fish were killed, and their dead bodies literally covered the surface of the sea for hundreds of square miles. So great was the slaughter that for years it was feared that the tile-fish were exterminated. Fortunately, however, the region has been recolonized, probably from the south, and numerous tile-fish have been taken during the past two seasons.

Probably the most remarkable of the conditions of deep-sea life is the enormous pressure, which varies of course with the depth. At the average depth (2,000 fathoms) the pressure is about two tons to the square inch of surface, and at 4,000 fathoms each square inch of surface is subject to a pressure of about four tons. This fact led the earlier physicists to maintain that organic life was impossible in the great depths. It has been proved, however, that animals of all classes, except the higher vertebrates, have been dredged from even the deepest abysses of the ocean.

The great pressure to which they have been subjected has a curious effect on the deep-sea fishes when they are brought to the surface. Under these circumstances, being released from the accustomed pressure, they fall to pieces, as it were. The eyes bulge out, the swim-bladder protrudes from the mouth, the scales fall off and the flesh comes off in patches, the tissues being remarkably loose. Now these fishes, disreputable as they appear when brought to the surface, were doubtless respectable enough in their proper habitat, and, like some other creatures, become loose and far from correct in appearance when away from home, simply because the pressure is less.

In the depths they are doubtless no more conscious of the pressure of four or five tons to the inch than we are of the fifteen pounds of atmospheric pressure under which we live and move and have our being.

Owing to the incompressible nature of water it does not differ appreciably in density at different depths, and any object that will sink at the surface will continue to sink until the bottom is reached, however deep that may be.

The presence of oxygen is of course of vital import to animal life in the deep sea as elsewhere, and it was long deemed impossible that any considerable quantity of oxygen could exist at great depths. It has been found, however, that there is no lack of this vital element either near the surface or in the deepest soundings. Sir Wyville Thomson, the naturalist in charge of the *Challenger*, made a very careful study of oceanic currents and found that the cold water of the polar regions, charged with oxygen derived from the superincumbent atmosphere, creeps along the bottom towards the equator from both poles, thus carrying oxygenated water over the vast area of sea bottom throughout the oceanic floor of the world. It also appears that the general trend of the surface water is toward the poles. This great scheme of circulation involves the general rise of the cold, deep water of the equatorial regions toward the surface, where it receives a fresh supply of heat and oxygen, carries much of the heat to northern regions and, after giving it off, returns southward again in the form of oxygen-bearing undercurrents. To my mind there are few terrestrial phenomena more impressive than this majestic cosmic current with circulation slow and sure, carrying with it the tremendous potency of life to and throughout the uttermost depths of the sea. Were it not for this world circulation, it is altogether probable that the ocean would in time become too foul to sustain animal life, at least in its higher manifestations, and the sea, the mother of life, would itself be dead.

The condition of the physical environment of the life of the ocean depths that strikes one as the most forbidding is the practical absence of sunlight from the enormous area included in the deep sea. As already stated, actual experiment has shown that photographic plates are not affected at a depth of over 125 fathoms in clear water, and light, which can not be detected by the exceedingly delicate eye of the camera, is surely invisible to any organ of vision constructed on the same general plan as the human eye. There is practical agreement among all the authorities, save one, that I have been able to consult that the rays of the sun do not penetrate perceptibly below the 200-fathom line at the farthest. Professor Verrill is the exception referred to, and he has advanced the theory that a pale green light penetrates even to the deepest waters. He thinks that all the other colors of the spectrum are removed from the sun's rays by absorption, leaving the green rays only. He comes to this conclusion from a study of the colors of the animals of the deep sea, which demonstrate, in his opinion, the presence of light of some kind. He apparently assumes that this light comes from the sun, and resorts to the explanation just referred to to prove its presence in the oceanic depths.

We shall see presently, I hope, that it is not necessary to assume the presence of sunlight at the sea bottom in order to meet the demands for light revealed by a study of the coloration of its inhabitants.

The bottom waters, then, are almost freezing cold, subject to tremendous pressure, moved by slow currents creeping from pole to equator, supplied with sufficient oxygen to sustain animal life, and devoid of sunlight. Could a more uncomfortable and altogether forbidding habitat be conceived of for an animal population? Certainly not, from our standpoint. But it must be remembered that we are neither fishes, nor mollusks, nor jelly-fishes; and that everything depends upon being used to environment. A practical application of this fact would result in the saving of a lot of otherwise wasted sympathy in human as well as zoological affairs.

Let us now turn our attention briefly to the topography of the sea bottom. It may be said, in general, that there are few abrupt changes of level; that the ascents and descents are gradual, and that there are few areas which, if laid bare, would present anything like the broken contours of a mountainous region. In areas adjacent to continents and archipelagoes the topography is often considerably broken, but away from the land masses the sea bottom is, ordinarily, as level as a western prairie. Few, if any, bare rocks are to be found, except where recent submarine volcanic explosions have torn up the subjacent strata, or the cooling lava has encrusted the bottom. Practically the entire sea bottom is covered to an unknown depth by a soil that varies with the depth in a definitely determinate manner. This soil, like that of the upper world, is organic in its origin, being composed in large proportion of the remains of a few species of very widespread forms, individually minute, but collectively of stupendous bulk. These animals belong almost exclusively to the Protozoa, or one-celled forms, and largely to the class Rhizopoda. They are of immeasurable importance from a biological standpoint, furnishing, as they do, the food basis for all marine life. As a type of these organisms *Globigerina bulloides* stands forth preeminent, a form of exquisite beauty of structure, being like a series of minute chalky spheres, exquisitely sculptured, from which radiate many and almost infinitely slender and delicate spicules which serve to support the living animal on the water, which, in places, is rendered of a reddish color by the hosts of these Rhizopods. It has fallen to the lot of but few naturalists to examine these creatures in a living and perfect state, as the slightest touch will rob them of their beautiful spicules and cause the living protoplasm to retreat within the hollows of the spheres. Minute and fragile as they are, the skeletons of these animals, and of others equally small, cover at the present time many millions of miles of the sea bottom, and in times past were the main element in building up the mighty chalk deposits of the world.

If we were to run a line of soundings from the continent of North America eastward to the mid-Atlantic, we should find that the bottom could be easily divided into three regions on the basis of the soil, as I have termed it, covering everywhere the actual rocks. For the first few miles the bottom would be covered with débris of many kinds from the adjacent land.

Rocks and gravel and sand, together with mud and silt, if near the mouth of a river, would succeed each other. The surface might be broken into rocky pinnacles and caverns, water-worn in fantastic shapes in the region of a rocky coast; or, if the coast be low and sandy, there might be a perfectly even and gradual slope from the shore to a depth of 150 or perhaps 200 fathoms.

This slope, covered with continental débris, is known as the 'continental slope,' and is very apt to be more uneven and broken in its topography and to support a more luxuriant fauna than any other part of the sea bottom. Beyond the continental slope the descent becomes more abrupt, leading down to a depth of 1,500 fathoms or more.

The bottom samples will now take on a distinctly different character, being composed of a grayish mud. If a little of this is examined under a microscope, it will be found to be made up of countless millions of the tests of *Globigerina* and other unicellular animals. Not a single thimbleful of this mud is devoid of its hosts of skeletons. This wet and slimy bottom soil is known the world over as '*Globigerina ooze*,' and it covers the ocean floor for many millions of square miles.

In a line of dredgings made by the *Challenger* from Teneriffe to Sombrero, taking in the widest part of the Atlantic, about 710 miles were found to be covered with *Globigerina ooze*, which was found in characteristic form from a depth of 1,525 to one of 2,220 fathoms. Beyond the latter depth the bottom was of a distinctly different character, changing to an extremely fine-grained reddish-brown mud, oily to the feel. It is so finely divided that it takes many hours to settle when mixed in a glass of water. This is known among oceanographers as 'red clay,' and is supposed to be derived almost exclusively from two widely different sources:

First: The residue of the innumerable hosts of pelagic animals remaining after their calcareous skeletons have been dissolved in sea water.

Second: Pumice and volcanic dust, either from submarine upheavals or from the atmosphere. From either or both of these sources the accumulation of the red clay must have been almost infinitely slow, taking perhaps millions of years to deposit a few inches in thickness on the ocean floor. This sort of bottom deposit is of much greater extent than either of the others, and is supposed to cover about one-half of the sea bottom, an area greater than the total land surface of the globe.

It can easily be conceived that no stretch of the land surface can compare in dreary monotony with those awful solitudes of the *Globigerina ooze* and the red clay. Even if illuminated by the sun's rays, they would be forbidding and dreary beyond compare.

Resting immediately upon the bottom already described is a layer of unknown depth of a flocculent material that is of incalculable importance in our discussion. When first discovered this substance, owing to its strange movements in alcohol, was supposed to be alive, and was described by Huxley under the name of *Bathybius*, and considered as a sort of primordial organism from which the entire life of the globe may have originated. *Bathybius*, however, was doomed to be regarded as one of the colossal jokes of science, and a thorn in the flesh of its describers.

But, after all, it is now thought that the much-derided *Bathybius* is fully as important as claimed by Huxley, but in another way. It is not alive, to be sure, but still it is organic, consisting of the partially decomposed remains of the pelagic animals, such as *Globigerina* and other forms already referred to. These have died near the surface, and have gradually but surely found their way to the bottom, where they remain partially suspended in a layer of soup-like consistency and character. *Bathybius*, then, is now no longer known as *Bathybius*, but as '*bottom broth*,' an exceedingly suggestive term, and it is supposed to be the inexhaustible supply of nourishment, the basal food store-house of the innumerable creatures that live and move, or simply live without movement, at or near the bottom of the sea, the simplest and most helpless of which have but to open their mouths, if mouths they have, and suck in bottom broth as the infant does pap. If Old Ocean is really, as so often asserted, the mother of terrestrial life, then bottom broth can truly be regarded as a sort of mother's milk, for the nourishing of her weak and helpless offspring.

Having discussed the physical conditions under which the animals of the deep sea exist, let us now turn our attention to the animals themselves.

Personally, I may say that nothing regarding the animals dredged from deep water has impressed me more than their colors. It seems an unquestionable fact that they live in practical darkness, and one naturally expects them to be colorless.

Now we know of a considerable number of animal forms that certainly do live in utter darkness in the subterranean waters of extensive caves, such as Mammoth or Wyandotte Caves. These animals have been very carefully studied, especially by my friend Dr. Eigenmann, of Indiana University, who tells me that true cave species are always practically blind and colorless. But the animals brought up from the deep waters of the ocean are often very brightly and conspicuously colored.

The question at once arises: What is the significance of these colors? Are they merely fortuitous, or have they a meaning that can be deciphered, giving a clue that may lead to a further understanding of the mysterious realm beneath the waters? It is my purpose this evening to attempt to answer these questions, but before doing so let us examine briefly the main facts regarding the colors of abyssal animals. We will call as witnesses some of the naturalists of the widest experience in the science of thalossography, and supplement this evidence by facts of personal observation.

Professor Mosely, of the *Challenger* staff, says: "Peculiar coloring matter giving absorption spectra has now been found to exist in all the seven groups of the animal kingdom. The Echinodermata and Cœlenterata appear to be the groups which are most prolific in such coloring matter. Pentocrinin and antodonin seem to be diffused in immense quantities throughout the tissues of the crinoids in which they occur and the Echinoderms generally seem to be characterized by the presence of evenly diffused and abundant and readily soluble pigments." Again, he says: "The same coloring matters exist in the deep-sea animals which are found in shallow water forms."

Alexander Agassiz, than whom no living man has had more experience in deep sea work, says: "There are many vividly colored bathyssal animals belonging to all the classes of the animal kingdom and possessing nearly all the hues found in living types in littoral waters. * * * There is apparently in the abysses of the sea the same adaptation to the surroundings as upon the littoral zone. We meet with highly colored ophiurans within masses of sponges themselves brilliantly colored at a depth of more than 150 fathoms. * * * While we recognize the predominance of tints of white, pink, red, scarlet, orange, violet, purple, green, yellow and allied colors in deep water types, the variety of coloring among them is quite as striking as that of better known marine animals. * * * There is as great a diversity in color in the reds, oranges, greens, yellows, and scarlets of the deep-water starfishes and ophiurans, as there is in those of our rocky and sandy shores. * * * Among the abyssal invertebrates living in commensalism the adaptation to surroundings is fully as marked as in shallow waters. I may mention especially the many species of ophiurans attached to variously colored gorgonians, branching corals and stems of *Pentacrinus* scarcely to be distinguished from the part to which they cling, so completely has their pattern of coloration become identified with it. There is a similar agreement in coloration in annelids when commensal upon starfishes, mollusks, actiniæ or sponges, and with Crustacea and actiniæ parasitic upon gorgonians, corals, or mollusks. The number of crustaceans * * * colored a brilliant scarlet is quite large."

Professor Verrill, of Yale University, in his report on the Ophiurans, collected by the Bahama expedition from the University of Iowa, repeatedly calls attention to the agreement in color between these animals and the forms upon which they grow.

My own observations fully confirm those of the naturalists just quoted. Among the crustaceans were many species colored a bright scarlet, and one was an intense blue. The echinoderms were particularly striking in their coloration. Yellow and purple Comatulæ abounded in deep water near Havana. Serpent-stars were brown, white, yellow, red, purple and deep violet. A basket-fish, colored chocolate-brown and vivid orange, was abundant off the Florida Keys. There were sea urchins with crimson and white spines; another particularly gorgeous one had a test with alternating zones of chocolate and orange, and spines barred with carmine and white. The cœlenterates told the same story, but it is unnecessary to multiply further the evidence. Enough has been given for our purpose, which was to demonstrate the existence of bright colors in considerable quantities in the deep waters of the ocean, and we feel justified in making the following general statements regarding these colors:

1. The colors are often as brilliant as in shallow water.

2. The reds, orange, yellows, violet, purple, green and white predominate.

3. The colors when present are usually in solid masses in striking contrast, or else the whole animal is brilliantly colored. Fine patterns are very scarce, and nature seems to have used a large brush in adorning her children of the depths.

Now let us return to our question: What is the significance of these brilliant and varied colors?

I must confess to being a Darwinian of the strict constructionist school, and believe fully in the doctrine that no animal possesses any character, including color, that is not of use to the species to which it belongs, or has not been of use to the ancestors of that species. It is my conviction that if we knew all the circumstances surrounding the past history and present life of any animal, we could explain on the score of utility every character, using the word in the zoological sense, possessed by that species. And it is my purpose to use the coloration of deep-sea animals to illustrate this law.

In my opinion, the presence of all these colors can mean but one thing, and that is that there is light even in the deepest depths of the ocean. Or, to state the matter in another way, if we can prove the presence of light in considerable quantity at the bottom of the sea, the colors of its inhabitants become entirely explicable. We can then explain them as we do the colors of the animals of shallow waters, regarding the colors as protective, aggressive, alluring, attractive, directive, and so forth, as the case may be.

There is another line of evidence tending to prove the presence of light at the sea bottom, and this is the fact that most of the vertebrates inhabiting the depths have functional eyes, often more highly developed than in shallow water, and only exceptionally are the eyes aborted or absent. Dr. Alexander Agassiz has the following to say on this point:

"We should not forget, on the one hand, that blind Crustacea and other marine invertebrates without eyes, or with rudimentary organs of vision, have been dredged from a depth of less than 200 fathoms, and, on the other, that the fauna as a whole is not blind, as in caves, but that by far the majority of animals living at a depth of about 2,000 fathoms have eyes either like their allies of shallow water, or else rudimentary or sometimes very large, as in the huge eyes developed out of all proportion in some of the abyssal crustaceans and fishes."

And Professor Verrill says: "That light of some kind and in considerable amount actually exists at depths below 2,000 fathoms may be regarded as certain. This is shown by the presence of well-developed eyes in most of the fishes, all of the cephalopods, most of the decapod crustacea, and in some species of other groups. In many of these animals the eyes are relatively larger than in the allied shallow-water species."

In view of the almost uniformly blind condition of cave animals on the one hand, and of the well-tested Darwinian doctrine that useless structures, unless rudimentary, do not exist, on the other, I think we are justified in saying that a study of the coloration of the deep-sea animals, in connection with the general presence of functional eyes, is reasonable proof that light in appreciable quantities exists even at the greatest oceanic depths.

This being granted, we naturally turn to a consideration of the question: What is the nature of this abyssal light?

As already intimated, it is incredible that sunlight could penetrate in appreciable quantities to any such depth as 2,000 fathoms or over, or even to one-tenth of that depth, notwithstanding the theory advanced by Verrill, who seems to consider the presence of sunlight necessary to explain the facts of coloration. I think we are safe in assuming with Agassiz that at 200 fathoms the light from the sun is possibly that of a brilliant starlight night, and we are also justified in concluding that coloration would be useless in such a light. Did you ever notice how little of color can be seen even in the clearest moonlight night?

Sunlight being out of the question, is there evidence of any other light that would satisfy the conditions of coloration and organs of vision already referred to?

I have, on other occasions, sought to collect the evidence of the existence of abyssal light, and to determine its nature and function in the life economy of the deep sea. These efforts resulted in the belief that the light sought for is a phosphorescent light, and that it is adequate to explain the phenomena already discussed in connection with the colors of deep-sea animals.

This idea has been suggested before by several writers, notably by Andrew Murray, of the *Challenger*, but it has heretofore been only a suggestion which no one has taken the pains to seriously investigate. It will be of interest, therefore, to consider the extent to which phosphorescent life is characteristic of the deep sea.

For the purposes of the discussion we will divide the animals of the sea bottom into two classes, the free swimming and the fixed forms.

Considering the free swimming forms first, we find among the fishes several allied to *Lophius* and *Antennarius*, which are provided with a bait said to be luminous, which serves to attract the prey. Others are luminous along the lateral line in definite spots. The utility in this case is not certainly known, but two suggestions may be made, one to the effect that the light attracts the mate and thus serves the purpose of attractive coloration; the other that it attracts the prey and serves the purpose of alluring coloration.

A very large number of crustaceans are highly phosphorescent. Many of these have large eyes and are particularly active in movement and voracious in appetite. They feed on minute organisms for the most part, and it can hardly be doubted that they often use their phosphorescent powers for the purpose of illuminating their surroundings and revealing their prey. Here again it is probable that the strangely attractive power of light serves a definite purpose in the life economy of the animal.

Among the mollusca we have few instances, so far as I know, of phosphorescent organs. At the Detroit meeting of the American Association for the Advancement of Science, Professor William E. Hoyle, of England, read an exceedingly interesting paper on certain organs possessed by cephalopods secured by the *Challenger*. These organs were regarded as phosphorescent by Professor Hoyle, who described a highly specialized apparatus designed to reflect light from the phosphorescent bodies downward to the bottom over which the animal passed. In this case it appears that there is not only a light, but also a reflector, an efficient bull's-eye lantern for use in hunting through the abyssal darkness. Among the worms are many forms possessing a high degree of light-emitting power, which may be either attractive, alluring or directive in function, and thus of direct advantage to its possessors.

Most of the echinoderms, although not truly fixed, are not capable of rapid locomotion, and we are, therefore, not surprised to find few references to phosphorescence in connection with them. Perhaps the most active of this group are the serpent stars, and it is interesting that the only account that I find of phosphorescence in the echinoderms is Agassiz's description of a serpent star, which he says 'is exceedingly phosphorescent, emitting at the joints along the whole length of its arm a bright bluish-green light.'

Coming to the cœlenterates, we find many notable phosphorescent organisms. The ctenophores and medusæ comprise the greater part of the free swimming members of this subkingdom, and it is among these that we encounter amazing displays of the living light. The most brilliant exhibition of phosphorescence that I have seen was caused by immense numbers of ctenophores in Bahia Honda, Cuba. The animals kept in a compact body, producing a maze of intertwining circles of vivid light. The phosphorescence may help to keep them together, and thus serve the purpose of directive coloration among vertebrates and insects. This same explanation may apply to many of the phosphorescent medusæ. In the subtropical Atlantic hundreds of square miles of the surface are thickly strewn with a medusa, *Linerges mercurius*, which glows like a living coal at night.

In general, it may be said that phosphorescence is found abundantly in free swimming marine animals, and serves the same purpose as protective, aggressive and alluring coloration, and at the same time, in many cases, aids in securing prey by illuminating its retreat.

We come, now, to a consideration of the phosphorescence of the fixed animals of the deep sea and its uses. Most of the light-emitting organisms of this group belong to the subkingdom cœlenterata. The sea-pens are mentioned by several writers as being especially brilliant in their flashes of light. The gorgonians, or flexible corals, are often phosphorescent, and Agassiz says: "Species living beyond 100 fathoms may dwell in total darkness and be illuminated at times merely by the movements of abyssal fishes through the forests of phosphorescent alcyonarians."

Many authors have noted the light-emitting powers of numerous hydroids. These occur in great quantities over certain areas of the sea bottom, and must add considerably to the sum total of deep-sea light.

It may, I think, be said that in general the fixed marine forms are not behind their free swimming allies in either the equality or the quantity of their light-emitting powers. The question now arises, of what value is the phosphorescence of fixed forms to its possessors? They have no eyes, and therefore can not be guided to their food by the light, neither can it aid them in finding mates nor in revealing the presence of enemies. Perhaps the most generally accepted explanation is that given by Professor Verrill, who says that the phosphorescence protects its possessors. Most cœlenterates, he says, are possessed of nematocysts or nettling cells, and the phosphorescence may serve to give notice to predaceous fishes that feed largely on hydroids, etc., that these nettling cells are present, and thus induce them to seek other provender. It is somewhat unfortunate for this argument that few if any of the cœlenterates that are remarkable for their phosphorescence possess nettling cells that are likely to be regarded by a hungry fish as at all formidable.

Another explanation is, however, possible. The food of the cœlenterates consists mainly of either crustacea of the smaller sorts, their embryos, protozoans, or unicellular plants. Now most of the crustacea have functional eyes, and it has been repeatedly demonstrated that they are attracted by light, both artifical and natural. Crustacean embryos usually have eyes that are proportionally very large. In many cases these too are attracted by light, and it is reasonable to suppose that they are attracted by phosphorescent light. If this is true, the light emitted by the fixed cœlenterates would cause the small crustaceans, and more surely their embryos, to congregrate near the illuminated areas and thus be captured. The process would be analogous, perhaps, to what is known as the effect of alluring coloration among insects and birds. The phosphorescence would thus be of direct utility to the fixed cœlenterates in securing food.

The application of this idea may be still further extended to include the attraction of Protozoa and even diatoms, both of which groups contain many species that are strongly attracted by light, which appears to act as a direct stimulus to both unicellular animals and plants by virtue of its well-known effect upon protoplasm itself.

One other fact, bearing directly on our discussion, that impresses itself strongly upon every one who has had actual experience in deep-water dredging, is the very uneven distribution of life over the sea bottom. In other words, the distribution is 'spotted.' A haul over certain areas will result in a dredge full of a profusion of animal forms, while the immediately adjacent bottom, although of apparently identical nature, will yield practically nothing. Our party repeatedly observed this while dredging on the Pourtales Plateau. It seemed as if species were distributed in densely crowded colonies of very limited areas. Sometimes one particular species seems to have fairly carpeted the bottom, and in other localities a great assemblage of species would be secured at a single haul, showing a profusion of life, perhaps greater than can be found on a similar area either in shallow water or on land. Again the tangles would come up with nothing but sand and bottom débris.

It seems, then, that we are justified in concluding that the sea bottom is, for the most part, utterly dark, but that there are scattered areas, often of considerable, extent where animal life is aggregated in masses, and where the phosphorescent light is of sufficient quantity to render the colors, laid on as we have seen in broad patterns, visible to animals with functional eyes. These colors would then be of the same utility to their possessors as in the upper world, and act as protective, aggressive, directive, attractive and alluring agencies. We are further justified in maintaining that phosphorescence is in all cases of direct utility to its possessors, and that in the fixed eyeless forms it serves to attract food, and perhaps in some cases to warn enemies of the presence of the irritating nettling cells.

As a sort of compensation for the feebleness of the phosphorescent light, and for its absence over vast areas, many animals, especially fishes and crustaceans, are furnished with very large eyes, or with organs which serve as lanterns, or with enormous mouths and stomachs to make the most of a very occasional square meal, or with greatly elongated feelers or tactile organs. Others still are provided with a luminous bait to attract the prey.

The main thing that I would impress upon you this evening is the fact that we have a right to expect to find utility for every character, not rudimentary, possessed by animals, a utility not necessarily to the individual, but certainly to the species. And I would protest most vigorously against the vain and impotent conclusion that anything is useless simply because we have been too ignorant or too indolent to find its function. I have small patience with a statement such as the following taken from a recent writer on animal coloration: "The inevitable conclusion, therefore, from these facts appears to be that the brilliant and varied colorations of deep-sea animals are totally devoid of meaning; they can not be of advantage for protective purposes or as warning colors, for the simple and sufficient reason that they are invisible."

This sort of thing is deeply injurious to science, because it is a helpless surrender of one of the most powerful of all incentives to research. If we can loll back in our easy chairs and declare that natural phenomena of widespread occurrence are meaningless, or, what amounts to the same thing, that Nature is guilty of a lot of vapid nonsense, we have indeed sold our scientific birthright for a mess of exceedingly thin pottage, and have stultified ourselves in the eyes of the thinking world.*

C. C. Nutting.
State University of Iowa.

REMINISCENT REMARKS ON THE TOP.

Some time ago, I wrote a short article in this journal,† in which among other things I endeavored to give an intelligible explanation of all that, from an elementary point of view, is interesting in the dynamics of the top. The treatment of this famous and ubiquitous apparatus in all text-books known to me is too sketchy and, didactically considered, useless. In my judgment this is a real gap and well worth filling. But my friends have so frequently and even quite recently taken me to task for my explanation, that I feel bound to reassert its correctness here.

Everybody will agree that up to the second order of approximation, and a vigorously spinning top or gyroscope, in which $\dot{\theta}$ is the polar velocity and φ and ψ the parameters of azimuth and altitude,

* Most of the facts and sometimes whole paragraphs concerning the coloration of deep-sea animals and phosphorescence, have been taken from the following papers by the author: 'The Color of Deep Sea Animals,' *Proc. Iowa Acad. of Sci.*, Vol. VI.; 'The Utility of Phosphorescence in Deep Sea Animals,' *Am. Nat.*, Oct., 1899.

† Science, V., pp. 171–5.