XLIII.—PHYSICAL CHARACTERS OF THE PORTION OF THE CONTINENTAL BORDER, BENEATH THE GULF STREAM, EXPLORED BY THE FISH HAWK, 1880 TO 1882.

By A. E. Verrill.

Although several extended surveys along the region of the Gulf Stream had been made by the officers of the United States Coast Survey since 1844, no systematic dredging had been done along its course, north of Florida, until 1880. During the previous surveys large numbers of bottom samples had been saved. Some of these were studied many years ago by Professor Bailey, and later by Mr. L. F. de Pourtales. Many of the *Foraminifera* and other microscopic forms have been described by them. A few small shells from the same source were described by Dr. A. A. Gould, in 1862. These investigations gave a partial knowledge of the nature of the materials of the bottom and the depth. But many errors existed in the earlier surveys in the determinations of temperature, and little else was known of the physical conditions. In many cases the recorded depths were also unreliable. The extensive surveys made by the Blake since 1880 have been conducted with much better apparatus and far greater accuracy. In 1872 one haul was made by Messrs. S. I. Smith and O. Harger, while on the Bache, in 430 fathoms, south of George's Bank, on this slope, but it happened to be on a comparatively barren spot. In 1877, the United States Fish Commission party dredged on the northward continuation of the Slope, about 120 miles south of Halifax, in 90 and 190 fathoms, but the bottom was of barren gravel and the results meager and unsatisfactory. In that region the cold currents are rapid and the slope of the bottom is exceedingly steep, making the dredgings very difficult.

The real character of the rich fauna inhabiting the bottom beneath the Gulf Stream, off our eastern coast, was completely unknown until 1880,* when numerous and successful dredgings were made, first by Mr.

* The Challenger, on her celebrated voyage, made a line of dredgings from Bermuda toward New York, but after approaching our coast she turned northward, and went to Halifax. Her station nearest to our coast was about 160 miles off New York, in 1,240 fathoms. The few dredgings made by the Challenger off Halifax were partly on the shallow fishing banks (Le Have Bank) and partly in the deep water of the Atlantic Basin. By mere chance, therefore, the Challenger missed the discovery of the exceedingly rich and varied deep-water fauna that is now known to occupy the Gulf Stream Slope at moderate depths all along our coast.

Alexander Agassiz, on the Coast Survey steamer Blake, J. R. Bartlett, U. S. N., commander, and later in the season by the United States Fish Commission party, on the Fish Hawk.

The Blake made several lines of dredgings off our eastern coast, crossing the Gulf Stream Slope. The most southern of these were off the Carolina coasts, and the most northern stations were just south of George's Bank. These dredgings extended from shallow water to about 1,400 fathoms. The Blake was furnished with excellent apparatus for sounding and dredging, temperature determinations, &c. The officers of the Blake secured, by this exploration, a large amount of reliable physical data, and Mr. Agassiz obtained very interesting collections, including large numbers of new forms of animal life, many of which have already been described in the "Bulletin of the Museum of Comparative Zoology." Later in the season of 1880 the United States Fish Commission dredging party, under the supervision of the writer, made its first expedition to the Gulf Stream Slope, in the steamer Fish Hawk, Lieut. Z. L. Tanner commander. The region visited was about 75 to 80 miles south of Martha's Vineyard, in 65 to 192 fathoms. On September 4, when this ground was first visited by us, a long day was spent in dredging and trawling, and with marvelous results. The bottom was found to be occupied by an exceedingly rich and abundant fauna, including great numbers of new and strange forms of animals, belonging to nearly all the marine orders.

This first trip having been so successful, two others were made, later in the season, to other parts of the Slope, in depths ranging from 85 to 500 fathoms. Each trip proved equally productive, and added many species to the long lists of new discoveries.

In 1881 seven trips were made by us to the Gulf Stream Slope, from Wood's Holl, and in 1882 five trips. During these fifteen trips, on most of which a single entire day was employed in dredging, we occupied about 113 stations. At nearly all these stations we used a large trawl of improved construction. In a few instances we used a large rake-dredge.

Our dredgings in this region during the three seasons cover a belt about 160 miles long, east and west, and about 10 to 25 miles wide. The most eastern stations are southeast of Cape Cod, the most western are south of Long Island. They are mostly between 90 and 110 miles from the coast-line of Southern New England (see Plate I). The depths are mostly between 65 and 700 fathoms. Probably no other equally large part of the ocean basin, in similar depths, has been more fully examined than this. In addition to the regular work of the party during the season, Captain Tanner made a special trip to the Gulf Stream Slope, off Chesapeake Bay, in 1880, and another off Delaware Bay, in 1881. On both of these occasions valuable collections were made and additional data in regard to the depths and temperature were obtained. He occupied seven stations, in 18 to 300 fathoms, in 1880, and eight stations, in 104 to 435 fathoms, in 1881. These dredgings show the direct southward continuation of the inshore cold belt and the warm belt outside of it, as well as the cold deep-water belt, with but little change in the fauna of each.

At most of the localities that we have examined the temperature of the water, both at the bottom and surface, was taken, as well as that of the air. In many cases series of temperatures, at various depths, were also taken. Many other physical observations have also been made and recorded. Lists of the animals from each haul have been made with care and arranged in tables, so far as the species have been determined, up to date. Lists of the fauna will soon be published in these reports.

South of New England the bottom slopes very gradually from the shore to near the 100-fathom line, which is situated from 80 to 100 miles from the mainland. This broad, shallow belt forms, therefore, a nearly level submarine plateau, with a gentle slope seaward. Beyond the 100-fathom line the bottom descends rapidly to more than 1,200 fathoms, into the great ocean basin, thus forming a rapidly-sloping bank, usually as steep as the side of a great mountain chain and about as high as Mount Washington, New Hampshire. This we call the "Gulf Stream Slope," because it underlies the inner portion of the Gulf Stream all along our coast, from Cape Hatteras to Nova Scotia (Plate II). In our explorations a change of locality of less than 10 miles, transverse to the Slope, would sometimes make a difference of more than 3,500 feet in depth.

Farther from the coast the depth continues to increase, but much more gradually, until the depth of about 3,000 fathoms is reached. The Albatross, in 1883, dredged in these deeper waters down to 2,949 fathoms, in N. lat. 37° 12′ 20″, W. long. 69° 39′, station 2099.

INFLUENCE OF THE GULF STREAM.

The bottom along the upper part of this slope and the outermost portion of the adjacent plateau, in 65 to 150 fathoms, and sometimes to 200 fathoms or more, is bathed by the waters of the Gulf Stream. Consequently the temperature of the bottom-water along this belt is decidedly higher than it is along the shallower part of the plateau nearer the shore, in 25 to 60 fathoms. The Gulf Stream itself is usually limited in depth to about 150 fathoms, and often even less, in this region; below this the temperature steadily decreases to the bottom of the ocean basin, where it is about 38°, in 1,000 to 1,400 fathoms. We may, therefore, properly call the upper part of the Slope, in about 65 to 150 fathoms, the "warm belt." According to our observations, the bottom temperature of the warmer part of this belt, in 65 to 125 fathoms, is usually between 47° F. and 53° F., in summer and autumn. Between 150 and 200 fathoms, the temperatures, though variable, are usually high enough to show more or less influence from the Gulf Stream. On the warm belt we took numerous kinds of animals that were previously known only from the Gulf of Mexico or the Straits of Florida. Some belong to genera that have always been considered as tropical or sub-tropical, such as *Dolium*, *Marginella*, *Solarium*, and *Avicula* among the shells. In fact this belt is occupied by a northern continuation of the southern or West Indian Gulf Stream fauna. Our observations, both on the animal life and the temperature, demonstrate that the western edge of the Gulf Stream is much nearer this coast than it is located on most modern charts. According to our experience the influence of the Gulf Stream becomes decidedly marked, by the rise in temperature a few fathoms below the surface, along a belt corresponding nearly with the 65-fathom line, in summer. This is shown both by the abundant occurrence of the various pelagic animals, gulf-weed, &c., characteristic of the Gulf Stream water farther south, and by the temperatures taken by us. The temperature curves, in 5, 10, 20, 30, and 50 fathoms, all illustrate this, as well as the bottom temperatures. The English Admiralty charts, and others, place the inner edge of the Gulf Stream in summer entirely outside of the Slope, or 40 to 50 miles farther from the coast than we found it. In summer, as is well known, the Gulf Stream is noticed nearer the coast than in winter, but this doubtless applies strictly, or chiefly, only to the surface water. But in summer, owing to the heat of the sun, there is often very little difference between the temperature of the *surface water* at the Gulf Stream and on the inshore plateau. Our investigations show that the warm belt, in 65 to 125 fathoms, is inhabited by a peculiar southern fauna that could not exist there if the Gulf Stream did not flow along this area, at the bottom, both in winter and summer. It is evident that what many of these species require is not a very high, but a *nearly uniform temperature*, all the year round. Such an equable temperature could not exist in this region except under the direct and constant influence of the Gulf Stream. On the lower part of the Slope, in 300 to 780 fathoms, we found numerous arctic forms of life, corresponding to the lower temperature, which at 300 to 500 fathoms is usually 41° F. to 40° F., and at 500 to 1,200 fathoms, 40° F. to 38° F. On the inshore plateau, which is occupied by a branch of the cold, arctic current, about 30 miles wide, we found that the temperature of the bottom water usually varied from 46° F. to 42° F., in August, at the depths of 25 to 60 fathoms. In some instances it was higher than this nearer the shore, and especially opposite the mouths of the bays and sounds, where the tidal flow rapidly mingles the warm surface water (70° F. to 75° F.) with the bottom water.

On the cold part of the shore plateau we also found an abundance of arctic species of animals, such as are found at similar and less depth north of Cape Cod and in the Bay of Fundy. During the colder season of the year the temperature of the water over this plateau is decidedly lower, for codfish even are taken here in large numbers in winter. This plateau, especially over its shallower portions, has, therefore, a *variable cold climate*. But the deep water below 300 fathoms has a *uniform* *cold climate.* It is evident that the "warm belt" is here a comparatively narrow one along the bottom, wedged in between the cold waters of the inshore plateau and the still colder waters that cover the outer and deeper part of the Gulf Stream Slope. The actual breadth of this warm belt varies, however, according to the steepness of the slope and in consequence of variations in the currents. Just south of Martha's Vineyard, as will be seen by the map, the slope appears to be less rapid than it is either to the eastward or southward, and consequently there is here a broader area occupied by the warm belt, especially between the 65 and 150 fathom lines. Probably this warm belt finally narrows out and disappears from the bottom before reaching the coast of Nova Scotia. We have hitherto obtained no evidence of such a belt off that coast from temperature observations and the character of the fauna. Therefore it is probable that the cold water of the greater depths there mingles directly with that of the inshore plateau. Southward the warm belt continues to the Straits of Florida, and beyond, the depth of the water characterized by identical temperatures gradually increasing as we go south. At Cape Hatteras this belt becomes very narrow, owing to the abruptness of the slope, and approaches nearer to the shore; but off the Carolina coasts it spreads out over a wide area, which is inhabited by a rich fauna, similar to that investigated by us off Martha's Vineyard. Many of the species are already known to be identical.

In the following summary table are shown the usual range of variation and the approximate average temperature at the bottom in the more characteristic zones of depth, beyond 20 fathoms, in summer:

Fathoms.	Usual range.	Approximate average.
	° F.	° F.
20 to 25	45–51	49
25 to 58	42–46	44
65 to 130	47–53	50
65 to 150	46–53	49.5
150 to 200	43–50	47
200 to 300	41–46	43
300 to 450	40–42	40.5
450 to 600	40–41	40
600 to 800	39–40.5	39.5
800 to 1,400	38–39	38.5

From this table and from the diagrams a few of the published temperature observations, which were abnormally high, have been excluded, because they were probably erroneous, owing to a displacement of the index, or some other accident.

A singular feature of the serial temperatures taken at many stations is illustrated by Plates IV and V. In twenty-nine localities out of thirty-six, where sufficiently full series of temperatures were taken, the temperature was lower at 20 to 30 fathoms than at 50 fathoms. Usually the temperature falls pretty regularly from 5 to 30 fathoms. It then rises often three or four degrees, and sometimes eight to ten degrees, at 50 fathoms, falling again at 100 fathoms, but the temperature at 100 fathoms was often higher than at 30 fathoms. In some cases, as shown in Plate V, the temperature was lower (45° F.) at 30 fathoms than even at the bottom, in 200 to 250 fathoms. There is, therefore, often a stratum of colder water, in 20 to 40 fathoms, overlying the warmer Gulf Stream water, between 50 and 100 fathoms, in this region. This stratum of cold water may be a lateral extension of the cold water of the inshore plateau, situated at similar depths. Perhaps the greater density of the Gulf Stream water, due to evaporation, may so nearly balance the increase in density due to lower temperature as to make this a phenomenon of constant occurrence at these depths.

It happened, not infrequently, that the surface temperature early in the morning, when we usually began dredging, was one or two degrees lower than that at 5 fathoms, but during the middle of the day the surface water was generally slightly warmer than that at 5 fathoms. These changes are illustrated by some of the lines on Plates III and V.

NATURE AND ORIGIN OF THE SEDIMENTS—OCCURRENCE OF FOSSILIFEROUS MAGNESIAN LIMESTONE-NODULES.

Lists of most of the stations occupied in 1881 and 1882 by the United States Fish Commission steamer Fish Hawk have been given in a pervious article. In the lists the general character of the bo tom is indicated, as well as the depth and temperature.

A detailed description of the materials covering the bottom in this region cannot be given at this time, but certain facts observed by us are of sufficient geological interest to justify a brief notice. At several localities, but especially at stations 1121, 1122, and 1124, in 234, 351, and 640 fathoms, respectively, we dredged fragments and nodular masses, or concretions, of a peculiar calcareous rock, evidently of deep-sea origin, and doubtless formed at or near the places where it was obtained. These specimens varied in size from a few inches in diameter up to one irregular nodular or concretionary mass, taken at station 1124, in 640 fathoms, which was 29 inches long, 14 broad, and 6 thick, with all parts well rounded. This probably weighed 60 pounds or more. The masses differ much in appearance, color, texture, and fineness of grain, but they are all composed of grains of siliceous sand, often very fine, cemented by more or less abundant calcareous matter. In some the grains of sand are large enough to be easily seen by the naked eye, and small quartz pebbles often occur in them, but in others the sand grains are so fine that a microscopic examination is needed to distinguish them. These fine-grained varieties of the rock are often exceedingly compact, heavy, hard, and tough, usually grayish or greenish in color. They usually weather brown, from the presence of iron (probably both as sulphide and carbonate). The sand consists mainly of rounded grains of quartz, with some feldspar, mica, garnet, and magnetite. It is like the loose sand dredged from the bottom in the same region. The calcareous cementing material seems to have been derived mainly from the shells of foraminifera abundantly disseminated through the sand, just as we find the recent foraminifera, in the same region. In some cases I was able to identify distinct casts of foraminifera in the rock. In some pieces of the rock distinct fossil shells were found, apparently of recent species (*Astarte*, etc.).

The larger masses appear to have been originally concretions in a softer deposit, which has been more or less worn away, leaving the hard nodules so exposed that the trawl could pick them up. The age of these rocks may, however, be as great as the pleistocene, or even the pliocene, so far as the evidence goes. Moreover, it is probable that they belong to a part of the same formation as the masses of fossiliferous sandy limestone and calcareous sandstone often brought up by the Gloucester fishermen from deep water on all the fishing banks from George's to the Grand Bank. No rocks of this kind are found on the dry land of this coast.

The chemical composition of these limestone nodules is of much interest geologically. Analyses made by Prof. O. D. Allen prove that they contain a considerable amount of magnesia. They are, therefore, to be regarded as magnesian limestones or dolomites of recent submarine origin. They also contain a notable quantity of *calcium phosphate*. The presence of the latter is not surprising, when we consider the immense number of carnivorous fishes, Cephalopods, etc., which inhabit these waters, and feed largely upon the smaller fishes, whose comminuted bones must, in part at least, be discharged in their excrements. In fact, it is probable that the greater part of all the mud and sand that covers these bottoms has passed more than once through the intestinal canals of living animals. The *Echini*, *Holothurians*, and many of the star-fishes and worms continually swallow large quantities of mud and sand for the sake of the minute organisms contained in it, and from which they derive their sustenance.

The following partial analysis of one of the limestone nodules is by Prof. O. D. Allen, of the Sheffield Scientific School:

ANALYSIS OF DEEP-SEA LIMESTONE.

(Specific gravity, 2.73.)

Lime	24.95
Magnesia	14.41
Iron, estimated as protoxide	2.00
Insoluble residue	16.97

Throughout the Gulf Stream Slope examined by us the bottom, in 70 to 300 fathoms, 60 to 120 miles from the shore, is composed mainly of very fine sand, largely quartz, with grains of feldspar, mica, magnetite, etc. With it there is always a considerable percentage of shells of foraminifera and other calcareous organisms, and also spherical, rod-like, and stellate, sand-covered rhizopods, often in large quantities. In the deeper localities there is usually more or less genuine mud or clay, but this is often almost entirely absent, even in 300 to 500 fathoms. The sand, however, is often so fine as to resemble mud, and is frequently so reported when the preliminary soundings are made and recorded. In many instances, even in our deepest dredgings (over 700 fathoms), and throughout the belt examined, we have taken numerous pebbles and small rounded bowlders, of all sizes, up to several pounds in weight, consisting of granite, syenite, mica-schist, etc. These are sometimes abundant and covered with *Actiniæ*, etc. Probably these have been recently floated out to this region, while frozen into the shore-ice, in winter and spring, from our shores and rivers, and dropped in this region, where the ice melts rapidly under the influence of the warmer Gulf Stream water. Possibly much of the sand, especially the coarser portions, may have been transported by the same agency. Another way, generally overlooked, in which fine beach sand may be transported long distances, is by reason of its floating on the surface of the water after it has been exposed to the air on the beaches and dried. The rising tide always carries off a certain amount of fine dry sand floating in this way. In our fine towing nets we always take more or less fine siliceous sand, which evidently was floating on the surface, even at considerable distances from the shore.

The prevalence of fine sand along the Gulf Stream Slope in this region, and the remarkable absence of actual mud or clay deposits indicate that there is here, at the bottom, sufficient current to prevent, for the most part, the deposition of fine argillaceous sediments over the upper portion of the slope, in 65 to 150 fathoms. Such materials are probably carried along till they eventually sink into the greater depths nearer the base of the slope or beyond, in the ocean basin itself, where the currents are less active. It is probable that such a movement of the water may be partly due to tidal currents, as well as to the actual northward flow of the Gulf Stream, which is here slow, even at the surface.* It is not probable, however, that the bottom currents are strong enough to move even the fine sand after it has once actually reached the bottom; nor is it strong enough to prevent the general deposition of oceanic foraminifera, pteropods, etc. I have above suggested that the loose nodules of limestone may have been derived from softer rocks or unconsolidated materials by the removal or wearing away of the latter. The existence of actual currents sufficiently powerful to directly effect such erosion is not supposable. I believe, however, that such a result may be due directly to the habits of certain fishes and crustacea

* Our observations fully demonstrate that the western edge of the Gulf Stream is nearer the coast than it has hitherto been located on the charts. In summer, as is well known, it is nearer the coast than in winter, but this doubtless applies strictly to the *surface water*. Our researches show that the warm belt in 65 to 125 fathoms is inhabited by a peculiar southern fauna that could not exist there if the Gulf Stream did not flow along this area *at the bottom* both in winter and summer. But it is evident that what many of these species require is not a very *high* but a *nearly uniform* temperature. Such an equable temperature cannot exist in this region except under the direct and constant influence of the Gulf Stream.

that abound on these bottoms. Many fishes, like the "hake" (*Phycis*), of which two species are common here, have the habit of rooting in the mud like pigs for their food, which consists largely of Annelida and other mud-dwelling creatures. Other fishes, those with sharp tails especially, burrow actively into the mud or sand, tail first, and in all probability *Macrurus*, abundant in this region, has this habit. Several species of eels and eel-like fishes are very abundant on these bottoms. These are all burrowers. The "slime-eel" or hag (*Myxine glutinosa*) was also taken in large numbers both in the trawl and in traps. Many crabs and allied forms are active burrowers. Such creatures, by stirring up the bottom sediments continually, would give the currents a chance to carry away the finer and lighter materials, leaving the coarser behind.

In many localities in the region under consideration there are great quantities of dead shells, both broken and entire. A small proportion of the bivalves have been drilled by carnivorous gastropods, but there are large numbers that show no injury whatever. There is no doubt in my mind but that these have for the most part served as food for the star-fishes and large Actiniæ, so abundant on these grounds, and from which I have often taken entire shells of many kinds, including pteropods. Many fishes, like the cod, haddock, hake, etc., have the habit of swallowing shells entire, and after digesting the contents, they disgorge the uninjured shells, and such fishes abound here.

The mollusks represented by the numerous broken shells have probably been preyed upon by the crabs and other crustacea, having claws strong enough to crack the shells. The large species of *Cancer* and *Geryon*, and the larger Paguroids, abundant in this region, have strength sufficient to break most of the bivalve shells. Although I have often seen such crustacea break open bivalves for food, I am well aware that they also feed on other things.* Many fishes that feed on mollusca break the shells before swallowing them, so that both fishes and crabs have doubtless helped to accumulate the broken shells that are very often scattered abundantly over the bottom, both in deep and in shallow water. Such accumulations of shells would soon become far more extensive if they were not attacked by boring sponges and annelids. Certain common sponges belonging to the genus *Cliona* very rapidly perforate the hardest shells in every direction, making irregular galleries, and finally utterly destroy them. In our shallower waters the most destructive species is *C. sulphurea* (Desor), which burrows in shells and limestone

* I have observed that when in aquaria, many different species of the larger crustacea, such as the crabs, *Libinia emarginata*, *Cancer irroratus*, *Panopeus Sayi*, *Carcinas mœnas*, *Platyonicus occellatus*; the hermit-crabs, *Eupagurus pollicaris*, *E. longicarpus*, and *Catapagurus socialis*; the shrimp, *Palæmonetes vulgaris* and *Virbius zostericola*; and *Limulus polyphemus*, are all extravagantly fond of the masses of diatoms and other fine algæ, intermingled with copepods, etc., which we often collect in our surface-nets. When a mass of such materials is thrown into an aquarium containing these crustacea they seize and devour it with great avidity.

when young, but later grows into large, rounded, sulphur-yellow masses, often a foot in diameter. In deep water other species occur. Rarely, we dredge up, on the outer grounds, fragments of wood, but these are generally perforated by the borings of bivalves (usually *Xylophaga dorsalis*) and other creatures, and are evidently thus soon destroyed. Very rarely do we meet with the bones of vertebrates at a distance from the coast. Although these waters swarm with vast schools of fishes, while sharks and a large sea-porpoise or dolphin (*Delphinus delphis*) occur in large numbers, we have, very rarely indeed, dredged up any of their bones, or, in fact, remains of any other vertebrate animals. In a few instances we have dredged a single example of a shark's tooth, and occasionally the hard otoliths of fishes. It is certain that not merely the flesh, but most of the bones, also, of all vertebrates that die in this region are very speedily devoured by the various animals that inhabit the bottom. Echini are very fond of fish-bones, which they rapidly consume.

Relics of man and his works are of extremely rare occurrence, at a distance from the coast, or outside of harbors, with the exception of the clinkers and fragments of coal thrown overboard with the ashes from steamers. As our dredgings are in the track of European steamers, such materials are not rare. A few years ago even these would not have occurred. A rock forming on this sea-bottom would, therefore, contain little evidence of the existence of man, or even of the existence of the commonest fishes and cetaceans inhabiting the same waters.

EVIDENCES OF THE EXISTENCE OF LIGHT AT GREAT DEPTHS.

The evidences of the presence of light at great depths and its quality and source are of much interest. At present very little experimental knowledge in regard to these questions is available. 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 living in 2,000 to 3,000 fathoms, and even deeper than that, the eyes are relatively larger than in the allied shallow-water species; in others the eyes differ little, if any, in size and appearance from the eyes of corresponding shallow-water forms; in certain other cases, especially among the lower groups, the eyes are either rudimentary or wanting in species of which the shallow-water representatives have eyes of some sort. This last condition is notable among the deep-water Gastropods, which are mostly blind, but many of these are probably burrowing species, and it may be that the prevalent extreme softness of the ooze of the bottom and the general burrowing habits are connected directly with the absence or rudimentary condition of the eyes in many species belonging to different classes, including Crustacea and fishes. Such blind species usually have highly-developed tactile organs, to compensate for lack of vision.

Other important facts, bearing directly, not only on the *existence*, but on the *quality*, of the light, are those connected with the coloration of the deep-sea species. In general it may be said that a large proportion of the deep-sea animals are highly *colored*, and that their colors are certainly *protective*. Certain species, belonging to different groups, have pale colors or are translucent, while many agree in color with the mud and ooze of the bottom, but some, especially among the fishes, are very dark or even almost black. Most of these are probably instances of adaptations for protection from enemies or concealment from prey. But more striking instances are to be found among the numerous brightly colored species belonging to the Echinoderms, decapod Crustacea, Cephalopods, Annelids, and Anthozoa. In all these groups species occur which are as highly colored as their shallow-water allies, or even more so. But it is remarkable that in the deep-sea animals the bright colors are almost always shades of orange and orange-red, occasionally purple, purplish-red, and brownish-red. Clear yellow, and all shades of green and blue colors are rarely, if ever, met with. These facts indicate that the deep sea is illuminated only by the sea-green sunlight that has passed through a vast stratum of water, and therefore lost all the red and orange rays by absorption. The transmitted rays of light could not be reflected by the animals referred to, and therefore they would be rendered invisible. Their bright colors can only become visible when they are brought up into the white sunlight. These bright colors are, therefore, just as much protective as the dull and black colors of other species.

The deep-sea star-fishes are nearly all orange, orange-red, or scarlet, even down to 3,000 fathoms; the larger Ophiurans are generally orange, orange-yellow, or yellowish white, the burrowing forms being usually whitish or mud-colored, while the numerous species that live clinging to the branches of gorgonians and the stems of Pennatulacea are generally orange, scarlet, or red, like the corals to which they cling. Among such species are *Astrochele Lymani*, abundant on the bushy orange gorgonian coral, *Acanella Normani*, often in company with several other orange Ophiurans, belonging to *Ophiacantha*, etc. *Astronyx Loveni* and other species are common on Pennatulacea, and agree very perfectly in color with them. These and numerous others that might be named are instances of the special adaptations of colors and habits of commensals for the benefit of one or both. Many of the large and very abundant Actinæ or sea-anemones are bright orange, red, scarlet, or rosy in their colors, and are often elegantly varied and striped, quite as brilliantly as the shallow water forms, and the same is true of the large and elegant cup-corals, *Flabellum Goodei*, *F. angulare*, and *Caryophyllia communis*, all of which are strictly deep-sea species and have bright orange and red animals when living. The gorgonian corals, of many species, and the numerous sea-pens and sea-feathers (Pennatulacea), which are large and abundant in the deep sea, are nearly all bright colored, when living, and either orange or red. All these Anthozoa are furnished with powerful stinging organs for offense and defense, so that their colors cannot well be for mere protection against enemies, for even the most ravenous fishes seldom disturb them. It is probable, therefore, that their invisible colors may be of use by concealing them from their prey, which must actually come in contact with these nearly stationary animals, in order to be caught. But there is a large species of scale covered annelid (*Polynoë aurantiaca* V.) which lives habitually as a commensal, on *Bolocera Tuediæ*, a very large orange-red actinian, with unusually powerful stinging organs. Doubtless the worm finds on this account perfect protection against fishes and other enemies. This annelid is of the same intense orange color as its actinian host. Such a color is very unusual among annelids of this group, and in this case we must regard it as evidently protective and adaptive in a very complex manner.

It has been urged by several writers that the light in the deep sea is derived from the phosphorescence of the animals themselves. It is true that many of the deep-sea Anthozoa, Hydroids, Ophiurans, and fishes are phosphorescent, and very likely this property is possessed by members of other groups in which it has not been observed. But so far as known, phosphorescence is chiefly developed in consequence of nervous excitement or irritation, and is evidently chiefly of use as a means of defense against enemies. It is possessed by so many Anthozoa and Acalephs which have, at the same time, stinging organs, that it would seem as if fishes had learned to instinctively avoid all phosphorescent animals. Consequently, it has become possible for animals otherwise defenseless to obtain protection by acquiring this property. It is well known to fishermen that fishes avoid nets and cannot be caught in them if phosphorescent jelly-fishes become entangled in the meshes. Therefore it can hardly be possible that there can be an amount of phosphorescent light regularly evolved by the few deep-sea animals having this power sufficient to cause any general illumination, or powerful enough to have influenced, over the whole ocean, the evolution of complex eyes, brilliant and complex protective colors, and complex commensal adaptations.

It seems to me probable that more or less of the sunlight does actually penetrate to the greatest depths of the ocean, in the form of a soft sea-green light, perhaps at 2,000 to 3,000 fathoms equal in intensity to our partially moonlight nights, and possibly, at the greatest depths, equal only to starlight. It must be remembered that in the deep sea, far from land, the water is far more transparent than near the coast.

EXPLANATION OF THE PLATES.

PLATE I.

Sketch map of the southern coast of New England to the Gulf Stream Slope, showing lines of depth and the position of the principal dredging stations of the United States Fish Commission, 1880–1882, and some of those of 1871, 1874, and 1875. The crosses indicate dredging stations, part of which are accompanied by their serial numbers, corresponding to the records and published lists. Those bearing numbers between 309 and 347 were occupied by the Blake in 1880.

PLATE II.

To illustrate the relative slope or profile of the bottom from the shore to the Gulf Stream Slope and across portions of the slope in several lines. Vertical to horizontal scale, 1:360. The line *n′—o′* shows the actual slope along the line *n—o*. The vertical shading indicates the position of the comparatively warm water both of the surface and of the Gulf Stream; oblique shading to the right indicates the cold water of the shallow plateau; oblique to the left the cold water of the greater depths.

PLATE III.

Temperature-curves at the bottom and surface (*o*), and at 5, 10, and 20 fathoms in the same localities. The curves of the bottom-temperatures extend from the shore to near the 800-fathom line on the Gulf Stream Slope. The position of each station is indicated by the total depth placed at the head of the vertical columns.

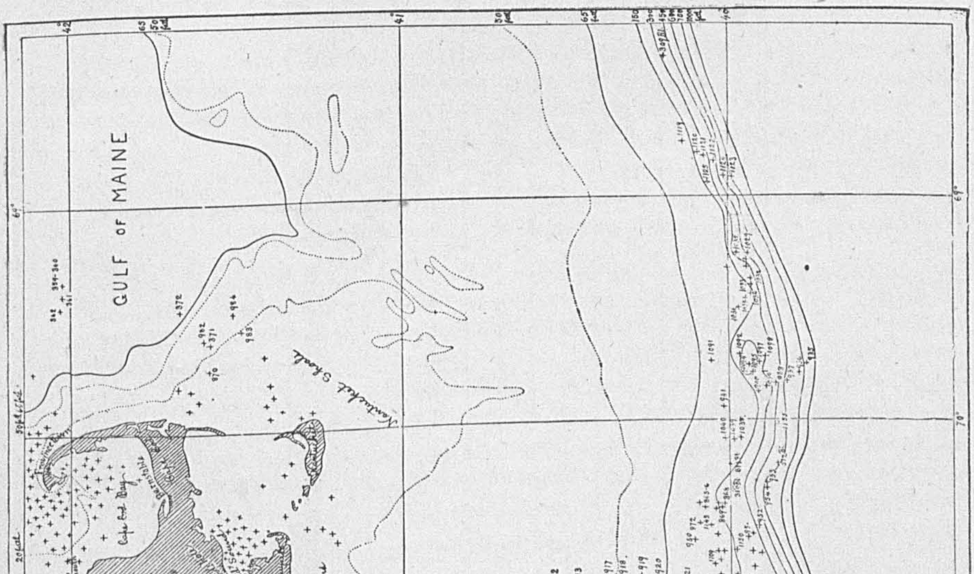
PLATE IV.

Temperature-curves at the surface and bottom, and at the intermediate depths of 5, 10, 20, 30, and 50 fathoms, arranged according to the distance in miles from the shore. The observations were made on three different days, as indicated by the letters *a—a*, *b—b*, *c—c*. The dotted lines indicate breaks in the actual series of observations. The numbers are those of the recorded stations where the observations were made.

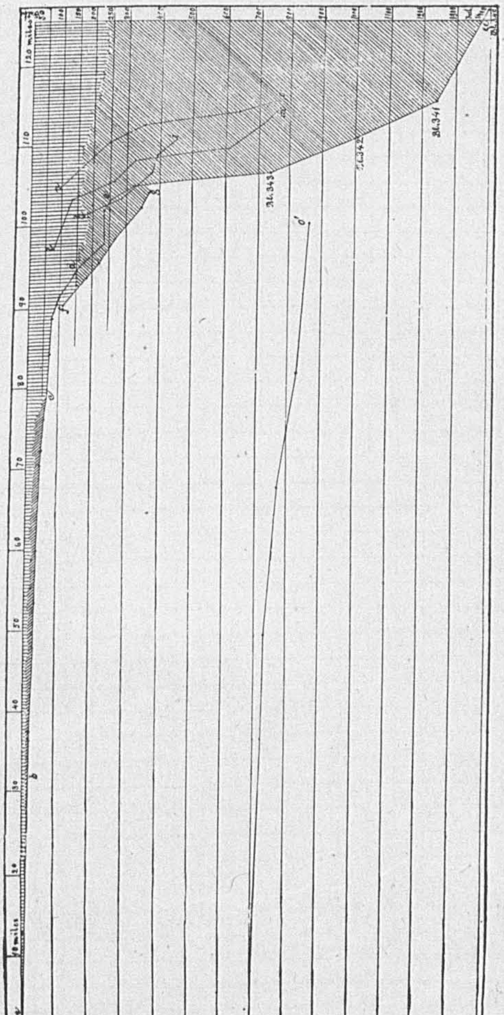
PLATE V.

Temperature-curves at the bottom and surface (*o*), and at the intermediate depths of 5, 10, 20, 30, 50, and 100 fathoms. These observations were all made September 14, 1881. This illustrates the rise in temperature between 30 and 50 fathoms from the surface.

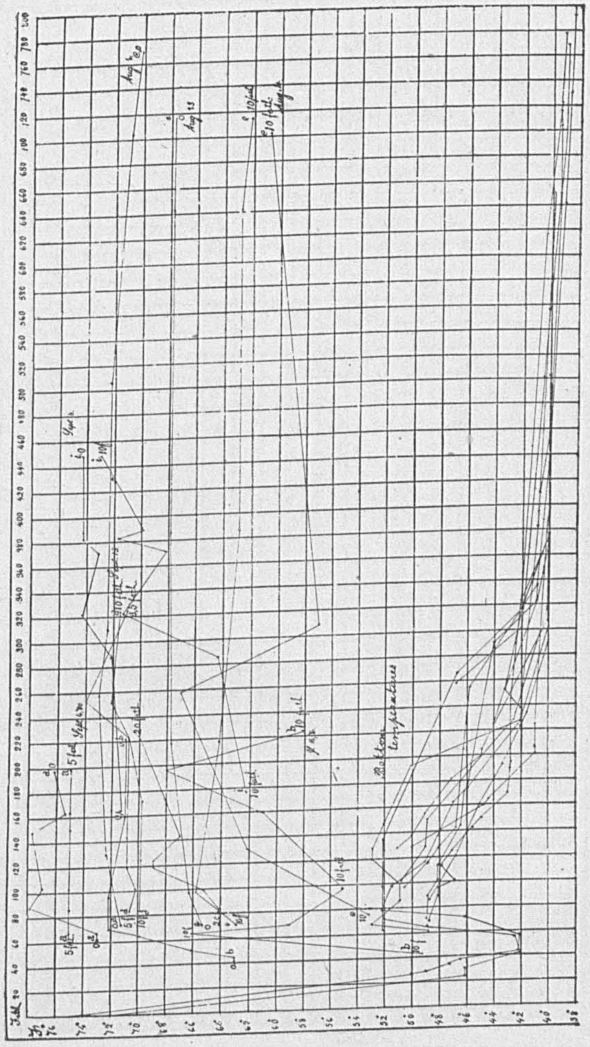
These plates were prepared to illustrate articles published by me in "Science," in 1882. I am indebted to the editor, Mr. S. H. Scudder, for the opportunity of using them in this place.



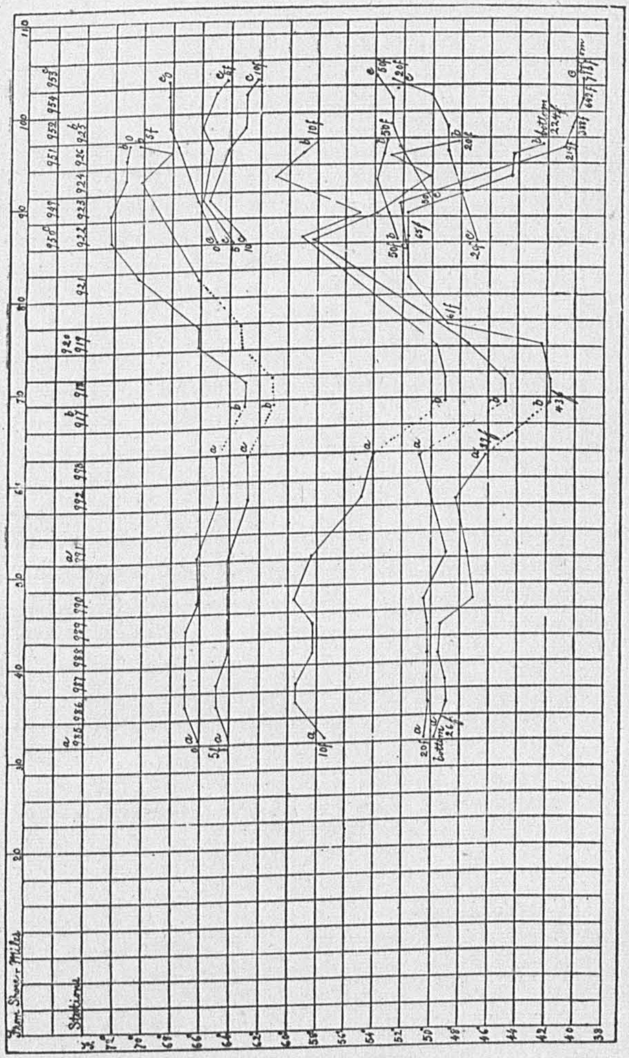
Southern coast of New England to the Gulf Stream Slope, showing lines of depth and positions of the principal dredging-stations of the United States Fish Commission.



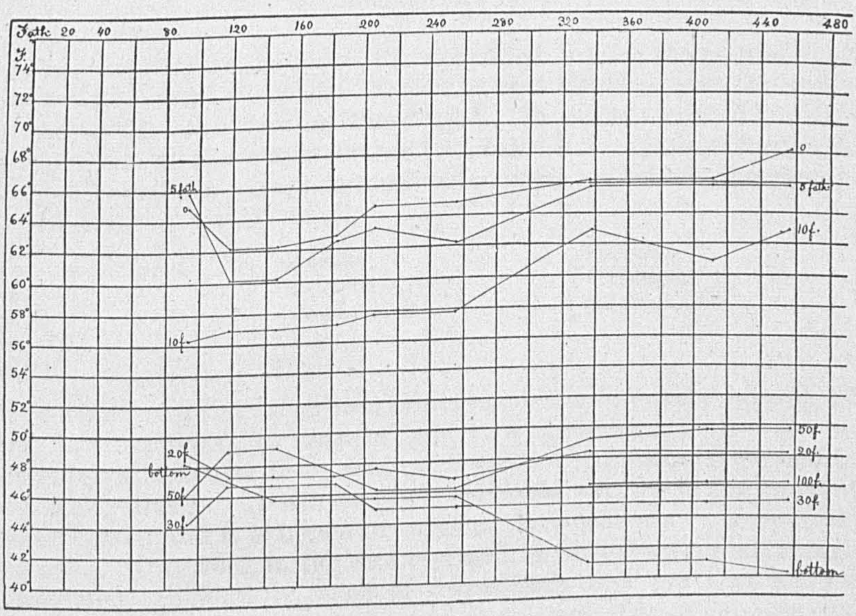
To illustrate the relative slope or profile of the bottom, from the shore to the Gulf Stream Slope, and across portions of the slope in several lines. Vertical to horizontal scale, 1:360.



Temperature curves at the bottom and surface (o), and at 5, 10, and 20 fathoms, and extending from the shore to near the 800-fathom line on the Gulf Stream Slope.



Temperature curves at the surface and bottom, and at the intermediate depths of 5, 10, 20, 30, and 50 fathoms, arranged according to the distance in miles from the shore.



Temperature curves at the bottom and surface (o), and at the intermediate depths of 5, 10, 20, 30, 50, and 100 fathoms.