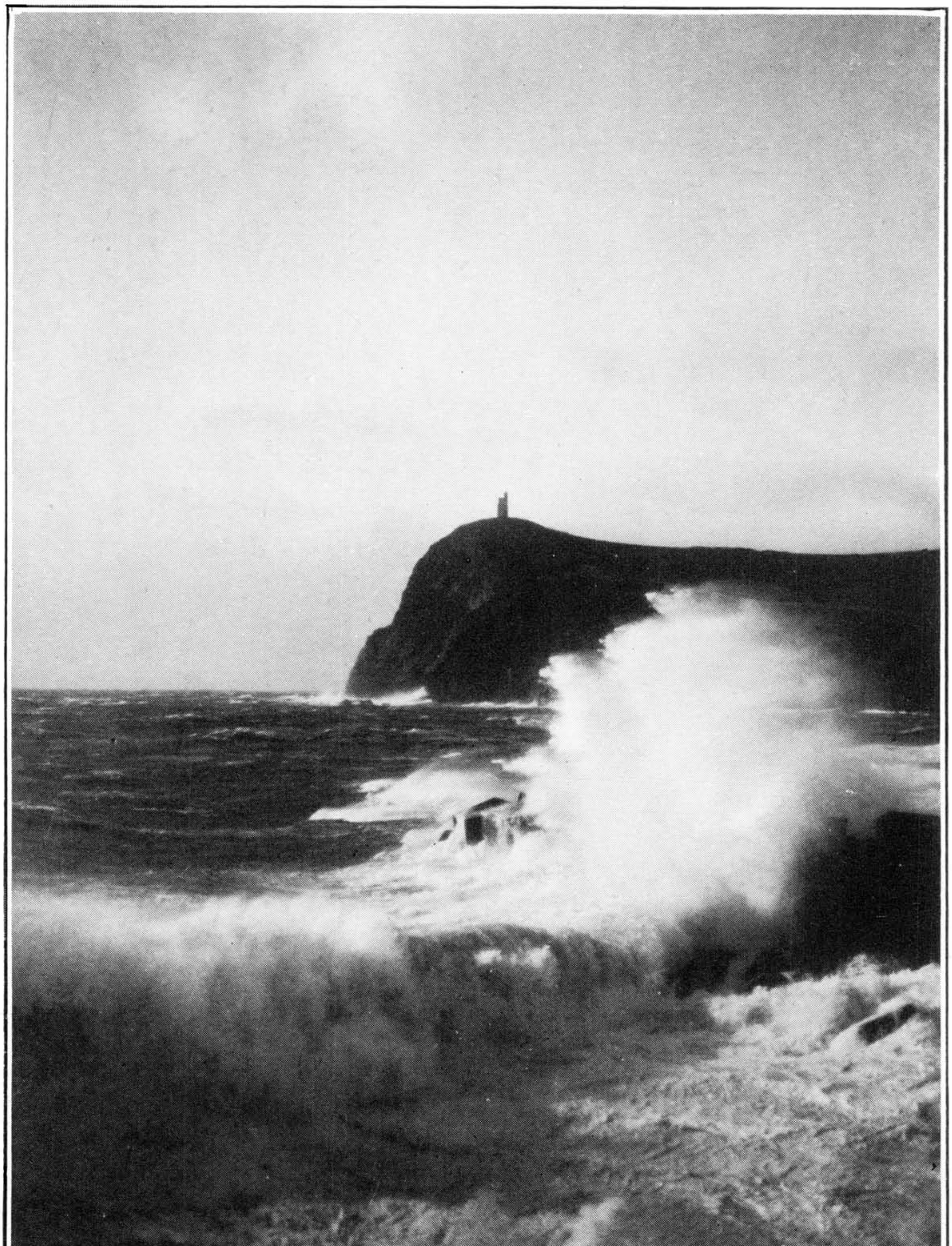

[*Photo by* EDWIN THOMPSON.

THE NATIVE LAND—AND SEA—OF EDWARD FORBES.

FOUNDERS OF OCEANOGRAPHY AND THEIR WORK

AN INTRODUCTION TO THE SCIENCE OF THE SEA

BY
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WITH MANY ILLUSTRATIONS

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PREFACE

This is not a textbook of Oceanography. The comprehensive textbook, drawing contributions from various branches of science—ranging from astronomy to biology—has still to be written, and possibly the time to write such an encyclopædic work on the sea has not yet come. But it is not too soon to let the young university student, and the intelligent public in general, know that the oceans present wonderful phenomena and profoundly interesting problems to the observer and the investigator, and that a science of the sea having its roots in the remote past has of recent years developed greatly and is now growing fast into an organized body of interrelated knowledge.

I have myself lived through the period that has seen the development of the Natural History of the Sea into the Science of Oceanography, and have known intimately most of the men who did the pioneer work. There can be but few others now living who have worked, as I did, along with Wyville Thomson and John Murray in Edinburgh more than forty years ago, and that is my justification for the introduction in the earlier chapters of some personal impressions of these and other nineteenth-century oceanographers. And even in regard to that earlier pioneer Edward Forbes, although I could not have known him personally as he died several years before I was born, still in my boyhood and early youth in Edinburgh some of his old friends, realizing my keen interest in the subject, talked to me of their lost hero, his ways and his work. So that I almost came to believe that I also had known him and heard him discourse in glowing words of starfish and nudibranchs at the Isle of Man, of the graceful medusœ of the Clyde sea-lochs and of dredging with Goodsir and MacAndrew in the Hebrides—and so felt that I too had dwelt in Arcady.

The book is really based upon a course of about twenty public lectures given in the winter of 1919–20 while I held, for the first year, the newly established Chair of Oceanography in the University of Liverpool. The purpose of the lectures was to put before my colleagues and students what I regarded as the scope and nature of this new university subject, and to interest the public of Liverpool in the deeper knowledge of the seven seas that mean so much to that great port, by giving examples of the phenomena and some explanation of the methods of investigation of the problems of the ocean.

The book follows the same lines. The first half-dozen chapters are in the main biographical, dealing with the lives and work of some of the leading men who have made our science; and those were selected in regard to whom I had something to say at first hand. The remaining chapters treat of subjects rather than men, and here again I have had to be eclectic and have deliberately limited myself, in the almost science-wide as well as world-wide range of Oceanography, to those matters in which I was myself most interested, and about which, as one had found in lectures and conversation, the intelligent non-specialist inquirer for information in regard to the sea wanted to know more. The treatment of the matter, then, is not intended to be exhaustive even in the subjects chosen. The aim is rather to show that the field of inquiry is wide and varied, that the phenomena observed—many of them familiar to ocean voyagers—are all matters requiring scientific investigation and are frequently interdependent, so that the explanation of one requires a knowledge of another, as in the case of the migratory fish and the distribution of plankton, or the American Tile-fish and the movements of the Gulf Stream; and further that Oceanography has practical applications, such as those bearing on the sea-fisheries and the possible cultivation of our barren shores, all requiring further exploration, in the hope that man in the future may become less of a hunter and more of a farmer of the sea.

I desire to record my grateful thanks to various colleagues, assistants and students, with whom I have worked at Liverpool and Port Erin, for information and co-operation and for the use of some of their photographs of natural objects taken in the laboratory or at sea. I would mention especially Professor R. Newstead, Mr. Andrew Scott, Mr. Edwin Thompson, Dr. Francis Ward, Mr. E. Neaverson and Mr. A. Fleming. I am indebted also to Professor Kofoid of California, Dr. Jules Richard of Monaco, Mr. James Chumley of the "Challenger" office, the Editor of the *Popular Science Monthly* and the Controller of H.M. Stationery Office for their courtesy in lending me photographs or in permitting me to reprint articles or illustrations.

Finally, I would add that this book is associated in my mind with the memory of my wife—the constant companion by land and sea, in work and play, of close on thirty years—who helped me to establish the University Department of Oceanography, who encouraged me to give the course of lectures and frequently urged me to prepare them for publication, and whose helpful criticism of the material in its present form would have been invaluable.

W. A. HERDMAN.

LIVERPOOL,

July, 1923.

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CHAPTER I

INTRODUCTORY—THE EARLIEST FOUNDERS OF OCEANOGRAPHY

Oceanography, the Science of the Sea, is a subject of modern development though of ancient origin. It is only of recent years that, for very good reasons, it has come to be recognized as a distinct branch of science, an organized body of knowledge. Including, as it does, the study of the sea and its contents in all aspects—physical, chemical, and biological—it was not until other sciences were sufficiently advanced to admit of their methods and results being applied to the phenomena of the sea that oceanography became a strictly scientific study. Moreover, the development of modern oceanography has been largely dependent upon the use of steam, both for the purpose of taking up and maintaining exact observing stations at sea, and also for working the complicated apparatus that is necessary in scientific investigation. To show the comprehensive nature of this science of the sea, we need only recall its division into Hydrography, Metabolism, Bionomics, and Tidology, in which sections physics, chemistry, biology, and mathematics are respectively involved.

But the foundations of oceanography can be traced back to the earliest times, to the observations of naturalists and the records of seamen from the voyages of the Phœnicians onwards. Vasco da Gama, who first reached India by the

Cape of Good Hope, and Magellan, who first tried to sound the Pacific, were early oceanographers; so were Captain James Cook and Sir J. Clark Ross, who first dredged the Antarctic; but long before their days the early Phœnician, Carthaginian, and Greek explorers, starting with their home sea, the Mediterranean, brought back the first records of the nearer parts of the Indian Ocean and of the Atlantic outside the Pillars of Hercules. The records of the early voyages of the Phœnicians and the Carthaginians, all apparently undertaken with commercial ends in view, have unfortunately not been preserved;[1] but we know that the Phœnicians reached Britain, and there is reason to believe that the Carthaginians discovered the Sargasso Sea off the west coast of Africa, and that Hanno the Carthaginian, about 500 B.C., penetrated as far south as the Gambia. Herodotus states that Necho II, King of Egypt about 600 B.C., sent certain Phœnician sailors to go down the Red Sea and along the east coast of Africa, and that in the third year they came back by the Pillars of Hercules and reached Egypt by the Mediterranean, reporting that as they sailed round Africa, after a time they had the sun on their right hand—that is, to the north—which Herodotus does not believe possible; but the observation as to the sun is very convincing. It is doubtful whether the circumnavigation was ever repeated until Vasco da Gama, two thousand years later, in the fifteenth century, doubled the Cape of Good Hope from the west.

It is unnecessary to trace all the stages[2] in the accumulation of this earliest knowledge of the sea: they may be illustrated by three examples selected from the writings and

[1] It is thought that Marinus of Tyre, the first really scientific geographer, who lived towards the close of the first century A.D., in the time of Trajan and Hadrian, made use of the store of geographic and hydrographic knowledge accumulated by the Phœnicians in the construction of his improved maps; and that Ptolemy of Pelusium in turn founded his geographical work upon the maps of Marinus.

[2] A very full account will be found in Sir John Murray's "Summary" in the "Challenger" Reports, which I have used freely.

maps of the ancients. First, the traditional voyages which are crystallized in the mythical adventures of Jason in the Argo, and of the world as known to Homer (say, 1000 B.C.), and may also be represented by the map of Hecatæus (about 500 B.C.), showing the great river-like "Oceanus" surrounding the known lands bordering the Mediterranean (see Plate I)—a poetical misrepresentation, which was corrected by Herodotus in the following century.

The second stage may be represented by the discoveries of the astronomer Pytheas, a contemporary of Alexander the Great, who sailed from Massilia, in the fourth century B.C., through the Strait of Gibraltar, along the coasts of Spain and France, penetrated to the North Sea and up the east coast of the British Isles, and heard, if he did not actually see it, of a land still farther north, six days' sail beyond Britain, which he called Thule; and where, he reports, the sea became thick and sluggish like a jelly-fish (possibly the earliest record of a planktonic phenomenon, due either to dense swarms of Medusæ or to gelatinous masses of Diatoms). He was the first scientific investigator of the Atlantic, and penetrated where we have no record of others following for about four centuries. Pytheas, moreover, made notable contributions to oceanography in his determination of latitudes and in ascribing the phenomena of tides to the action of the moon. The state of knowledge after his explorations may be illustrated by the map of Dicæarchus (about 300 B.C.—a pupil of Aristotle), extending from Thule (possibly Iceland) in the north-west to Taprobane (Ceylon) in the south-east.

Two names, more celebrated in other spheres of knowledge but belonging to this period, require passing mention. Plato's myth of the lost "Atlantis," a mass of land in the external sea beyond the Pillars of Hercules, which disappeared in a day and a night, rendering the Atlantic muddy and unnavigable, has given rise throughout the ages to many attempts to interpret this tradition by means of geological phenomena, such as the possible transposition of continents and ocean basins, culminating in the vain "search for Atlantis with the microscope" in the modern investigation of oceanic deposits.

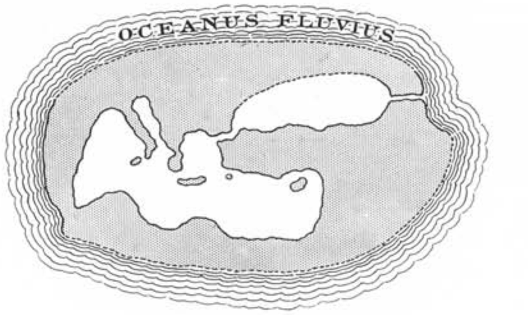
Aristotle, also about the time of Pytheas, took all knowledge for his province, and may be regarded as contributing to oceanography mainly from the points of view of the marine naturalist and the philosophic geographer. His death, if there is any truth in the legend that he threw himself into the whirlpool in despair at being unable to understand the currents in the Strait of Euripus, is unworthy alike of a philosopher and an oceanographer.

Although the Romans had extended their empire over most of the known world, they made no noteworthy contributions to scientific discovery. But in their time the Greek geographer Strabo, in the first century B.C., wrote a comprehensive work on the physiography of land and sea; and Posidonius asserts that he measured the sea in the neighbourhood of Sardinia to a depth of 1,000 fathoms. It would be interesting to know how he did it. There is no further record of deep-sea sounding till we come to the time of Magellan, fifteen centuries later.

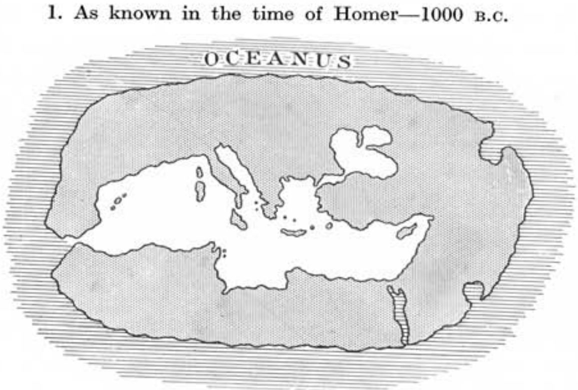
I may just refer in passing to their contemporary, Pliny, whose work (the *Historia Naturalis*) is little more than a compilation, and not entirely free from errors. He records in all 176 marine animals (four less than Aristotle recorded from the Ægean alone), and yet is so pleased with his catalogue that he writes: "By Hercules, in the sea and in the ocean, vast as it is, there exists nothing that is unknown to us, and, a truly marvellous fact, it is with those things that nature has concealed in the deep that we are best acquainted!" I only wish that we moderns, after nearly two thousand years of further investigation, were able to say as much. The more we find out about the sea, the more new problems open up before us for investigation.

The third stage in early knowledge may be represented

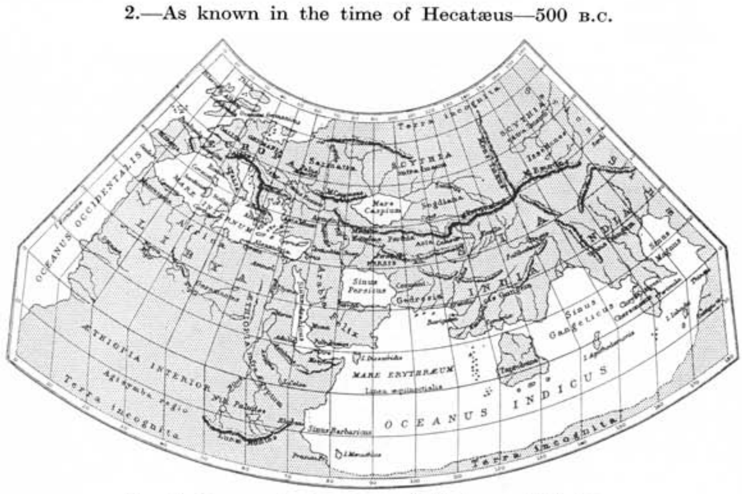
PLATE I.



1. As known in the time of Homer—1000 B.C.



2.—As known in the time of Hecatæus—500 B.C.



3.—As known in the time of Ptolemy—150 A.D.

THREE STAGES IN THE OCEANOGRAPHIC KNOWLEDGE OF THE ANCIENTS.

by the celebrated map usually attributed to the Alexandrian astronomer and geographer, C. Ptolemy, in the second century A.D., one of the notable features of which is that it represents the Indian Ocean as an enclosed sea bounded to the south by land extending from Africa to China—an error which remained uncorrected till the time of Captain James Cook, towards the end of the eighteenth century. (Plate I.)

Ptolemy, like others before him, believed that the furthest known land to the east (Asia) came so near to the known west coast of Europe that a ship might easily sail from Spain to India, and there can be no doubt that this error which Ptolemy's map did so much to perpetuate had great weight in determining the voyages of Columbus and others towards the end of the fifteenth century, and so led eventually to the discovery of America. With Ptolemy we come to the end of the scientific oceanographers of classical times.

Let us now pass over the dark ages and some succeeding centuries during which the scientific investigation of nature was at a standstill. With the exception of the explorations of the Norsemen in the North Atlantic and of the Arabs in the Indian Ocean, in mediæval times, when it is said they obtained the idea of the mariner's compass from China, little advance was made till the glorious period at the end of the fifteenth and the beginning of the sixteenth century, when the Portuguese and Spaniards opened up enormous new areas of ocean and demonstrated that the Earth is a sphere.

Prince Henry of Portugal, surnamed "The Navigator" (grandson of "Old John of Gaunt"), founded in 1420 his school of maritime research at Sagres, near Cape St. Vincent, on the south-west corner of Portugal, where he trained the men who led successive voyages of exploration in the Atlantic. At the time of his death, in 1460, the west coast of Africa was known down to about a third of the way to the Cape of Good Hope. The Cape was finally rounded by Bartholomew Diaz in 1486, but it was not till 1497 that Vasco da Gama completed the circuit of Africa and reached India by the Cape. Columbus, seeking the treasures of the East, landed on the Antilles in the New World in October, 1492, and believed he had reached Asia, from which he was now farther off than when he left Spain. He is said to have had with him on his first voyage the map of the learned Florentine, Toscanelli[1] (1474), which shows Japan and other islands off the coast of Cathay in the position really occupied by the North American continent. A century later, the map of the world according to Ortelius (1570) shows in contrast the enormous changes in knowledge of land and sea effected by these and other exploring voyages of the late fifteenth and early sixteenth centuries.

Magellan, finally, sailed from Spain with five ships in September, 1519, passed through the straits that bear his name in November, 1520, crossed the Pacific, and, although he and some of his companions were killed by the natives of Zebu in the Philippines in April, 1521, the survivors of his expedition reached Spain in their one remaining ship the following year (September 1522), having circumnavigated the globe in three years—in which enterprise he was followed by our English circumnavigator, Sir Francis Drake, who rounded Cape Horn fifty-seven years later. In his passage through the Pacific, Magellan attempted to determine the depth, and failing to reach bottom with the ship's sounding lines of a few hundred fathoms, concluded that he had reached the deepest part of the ocean. As a matter of fact, the depth at that spot is about 2,000 fathoms, or nearly three English miles. This is supposed to be the first attempt at sounding in the open sea, and no further attempt is recorded for centuries after.

As Sir John Murray points out: "The memorable discoveries

[1] This is disputed by H. Vignaud (*Toscanelli and Columbus,* London, 1902), who declares that the Toscanelli map is a forgery, and that Columbus really got his sailing directions from an obscure pilot he met at Madeira about 1484.

in the thirty years from 1492 to 1522 doubled at a single bound all that was previously known of the surface of the earth, and added a hemisphere to the chart of the world. . . . Columbus, Gama, Magellan, America, the route to India, the circumnavigation of the globe; three men and three facts opened gloriously a new era of history, of geography, and especially of oceanography." (See the group bracketed together in the middle of the following statement of a few important ancient and modern approximate dates):—

Age of Homer (and voyage of the "Argo"?)	about 1000 B.C.
Map of Hecatæus	about 500 B.C.
Voyage of Pytheas	fourth century B.C.
Map of Dicæarchus	about 300 B.C.
Map of Ptolemy	150 A.D.
{ Bartholomew Diaz	1486 A.D.
{ Columbus	1492 A.D.
{ Vasco da Gama	1497 A.D.
{ Magellan	1521 A.D.
James Cook	1772 A.D.
James C. Ross	1840 A.D.
"Challenger" Expedition	1872 A.D.

We now come upon a period of comparative inactivity, from the early sixteenth to the late eighteenth century when Captain James Cook (1728–1779), that truly scientific navigator, sent to the South Pacific on a Transit of Venus Expedition in 1769, with Sir Joseph Banks as naturalist, subsequently in 1772 circumnavigated the South Sea about latitude 60°, and finally disproved the existence of a great southern continent. He sailed round New Zealand, rediscovered Australia and annexed it to Great Britain, incidentally making known to science that strange animal the kangaroo. He discovered innumerable islands in the Pacific, such as New Caledonia and the Sandwich group, where he was killed by the natives in 1779.

Thus, in this brief story of the growth of knowledge of the oceans, we have first the ancient explorers and writers up to the time of Ptolemy (about 150 A.D.), then the great age of geographical discovery at the end of the fifteenth and beginning of the sixteenth century, and finally the modern expeditions beginning with Cook's voyages of 150 years ago and extending up to the present time.

Taking the century that elapsed between Cook's last voyage and the "Challenger" expedition of 1872, it is interesting to notice the names of the great men of science who went as naturalists on some of the more notable expeditions, and who all contributed in their turn to our knowledge of the sea and its contents.

Date.	Ship.	Captain.	Naturalist.
1768–71	"Endeavour"	Cook	Sir Joseph Banks
1831–6	"Beagle"	Fitzroy	Charles Darwin
1839–42	"Porpoise"	Wilkes	J. D. Dana
1839–43	"Erebus" & "Terror"	James C. Ross	Joseph Hooker
1846–50	"Rattlesnake"	Stanley	T. H. Huxley
1860	"Bulldog"	McClintock	G. C. Wallich
1868	"Lightning"	May	Wyville Thomson and W. B. Carpenter
1869–70	"Porcupine"	Calver	Wy. Thomson, Carpenter, and Gwyn Jeffreys
1872–76	"Challenger"	Nares	Wy. Thomson and others

Cook and his immediate successors bring us to about the end of the eighteenth century, and we may conveniently group the advances in knowledge of the science of the sea during the nineteenth century in three periods—the period of Edward Forbes, the great Manx naturalist; the period of Wyville Thomson, ending with its climax, the "Challenger" expedition; and the post-"Challenger" period of Sir John Murray and modern oceanography, which brings us practically to the methods and knowledge of to-day.

The first of these three periods, the earlier half of the nineteenth century, was the time of the field-naturalists and collectors, and of the beginnings of marine biology and scientific dredging in shallow water round the coasts. Forbes was the type of a whole series of men who did notable pioneer work in marine biology during the middle part of last century, and produced authoritative books and monographs which mark a great advance in knowledge of the natural history of the British seas. Many of these men were amateurs of science who had other professions; but Forbes was not. He was all his life a hard-working professional teacher of the natural sciences, but he did much to inspire and encourage these other workers of his day—especially in the use of the dredge as an instrument of research.

The "dredge" of science is a modification of the fisherman's oyster-dredge, and the Italians Donati and Marsigli used some such simple contrivance for bringing up material from the sea-bottom in the Mediterranean before the middle of the eighteenth century.

The use of the naturalist's dredge (introduced to science by O. F. Müller, the Dane, in 1799) for exploring the sea-bottom was brought into prominence almost simultaneously in several countries of North-west Europe—by Henri Milne-Edwards in France in 1830, by Michael Sars in Norway in 1835, and in our own country by Edward Forbes about 1832. The last-named genial and many-sided genius was a man of Scottish descent, who was born rather more than a hundred years ago, and died in 1854, when not yet forty years of age. He produced an extraordinary amount of first-rate work in his short life, and inspired advances in oceanography which he did not live to see carried out. As a result of observations in the Eastern Mediterranean, he published a list of "zones" of marine life, much of which is still accepted, though his supposed "azoic" zone at 300 fathoms was shown by Wyville Thomson and others to be a mistake. Forbes's theories on distribution and on the origin of the British fauna and flora, even if in part erroneous, have had an important position and influence in the history of science, and have led up to the very researches which resulted in more correct views. He was the most original, brilliant, and inspiring naturalist of his day, with a broad outlook over nature and a capacity for investigating border-line problems involving several branches of science; he was, in a word, a pioneer of oceanography. His work will be dealt with in some detail in the following chapter.

If Edward Forbes was the pioneer of shallow-water dredging, Wyville Thomson played a similar part in regard to the exploration of the depths of the ocean. His name will go down through the ages as the leader of the famous "Challenger" expedition, by far the most important scientific deep-sea exploring expedition of all times. This and the immediately preceding British expeditions in the "Lightning" and "Porcupine" demonstrated that there is no azoic zone in the sea, but that numbers of animals are found living down to the greatest depths of five or six miles from the surface, and that some of these animals are related to extinct forms, known as tertiary and cretaceous fossils. These "Challenger" oceanographic results will be dealt with more fully in a future chapter.

The work of Sir John Murray brings us to the third or post-"Challenger" period in nineteenth-century oceanography. Murray's work during the great expedition was chiefly on three subjects of primary importance—plankton, coral reefs, and submarine deposits, which have all been most fruitful of results both in his own hands and those of others since.

After the return of the "Challenger," in 1876, Murray took part in the two subsidiary expeditions of the "Knight-Errant" and the "Triton" to explore the "warm" and the "cold" areas of the Faroe Channel, which had been first noticed by Wyville Thomson in the "Lightning" in 1868. These cruises resulted in the discovery of the "Wyville-Thomson Ridge," which separates the cold Arctic water from the warmer Atlantic, and causes very different faunas to exist in close proximity. Murray's oceanographic work concluded with his joint exploration of the North Atlantic with Dr. Johan Hjort in the "Michael Sars" during the summer of 1910, with notable results, which are now in course of publication.

Several other national exploring expeditions followed that of the "Challenger," and a few private or non-official oceanographers have carried out very notable investigations in their own vessels. Two of these stand out prominently on account of the extent of their explorations, viz., (1) Alexander Agassiz in America, who has, it is said, undertaken more extensive cruises, chiefly for the purpose of examining the details of coral reefs, than any other man; and (2) the late Prince of Monaco, the munificent founder of the Oceanographic Institute at Paris and the Museum of Oceanography at Monaco. The work of both these non-official oceanographers will also be discussed in later chapters.

Each of these pioneers, and founders as they may be considered, of oceanography presents to the historian of science so much of interest and real importance in relation to the rapid growth of our knowledge of the sea, and is so much a prototype of the workers of his period, that I propose to devote the next few chapters to short biographical studies of the main events in the life and work of each of the men I have mentioned from Edward Forbes onwards. It is surely only right that the younger generations of oceanographers who are making the advances of the present and the future, should be informed what manner of men their predecessors were, and how they lived and did their work.

CHAPTER II
THE LIFE AND WORK OF EDWARD FORBES, THE MANX NATURALIST (1815–1854)

During the year 1915 enthusiastic meetings were held at Douglas, in the Isle of Man, and by Manx societies in London[1] and elsewhere, to celebrate the centenary of the birth of Edward Forbes, the distinguished Manx naturalist, who was a notable figure in British science during the second quarter of the nineteenth century.

A century before, in 1815, the Napoleonic wars were just ending. In the earlier part of the year when Edward Forbes was born, Waterloo had not yet been fought. Napoleon was still at large, and the state of public affairs was, in some respects, not unlike what we were passing through a few years ago. Europe was then also an armed camp, most of the great nations were at war, and then, as again a hundred years later, this country was fighting, along with allies, against the greatest military power of the time—fighting for the cause of humanity and freedom against the tyranny of a military autocracy.

Before the time of the Crimean War and the Indian Mutiny, Forbes was dead; so his brief life was lived in a time of peace, when notable advances were made in the Arts and Sciences, and in their application to University education, in all of which he played a prominent part.

[1] For some of the statements in the following pages I am indebted to speeches made on these occasions, and more especially to the excellent *Memoir of Edward Forbes,* published in 1861, by Professors George Wilson and Archibald Geikie.

Edward Forbes was born on the 12th of February, 1815, at Douglas, where his father was a banker. Though settled in the Isle of Man for several generations, the Forbes family was of Scottish descent, the great-grandfather, who was involved in the Jacobite rising of 1745, having fled to the island for refuge. The mother of Edward Forbes was Jane Teare, heiress of the estates of Corvalla and Ballabeg at Ballaugh, where her ancestors had lived for centuries, combining, no doubt, in their blood both the Scandinavian and the Celtic elements which are found in the Manx people. As his paternal grandmother again was English, our naturalist, though born and bred a Manxman, was of mixed blood, and may have inherited qualities from all that is best in our complex British nation.

As seems frequently to be the case with naturalists, it was from his mother that Forbes derived his love of nature, and more particularly his early taste for botany. It was certainly inborn in him, as we hear that at the early age of seven he had already collected and arranged a museum of natural objects, and had appointed a younger sister as assistant curator. He was a delicate boy, unable to go to school till the age of twelve, and it was, no doubt, to encourage these self-taught home studies that his father built an addition to their house to contain the boy's museum, and it was there that in his early youth Forbes started those collections which, in later life, formed the basis of his celebrated books on British Echinoderms and British Mollusca.

Home education in the case of a clever child probably always favours precocity, introspection, and over-ambitious attempts. Still, he must have been a remarkable boy to have produced in his twelfth year a MS. work entitled *A Manual of British Natural History in all its Departments.* He was, we are told, a gentle and sweet-tempered child, and probably his keenest interests were in the living things and wild nature around him. He must have been very unlike most boys of his age, and so was liable to be misunderstood and unappreciated.

It is recorded that his grandmother Teare, seeing him grubbing for snails in a hedge, said (in Manx): “Ta mee credjal naugh vod slane Ellan Vannin sauail yn guilley shoh veich cheet dy ve ommydan” (= I believe the whole Isle of Man cannot save this boy from being a fool).

He was at school for a few years at Douglas, where he is described as never having his pencil out of his hand, and as covering his books and exercises and the margins of his Latin verses with sketches of animals and caricatures and fancy pictures of all kinds. Then he left home for good at the age of seventeen. His mother had hoped he would enter the Church; his father wished him to be a doctor. As a compromise he went to London to study Art! Although exceedingly clever with his pencil, as the illustrations in many of his books abundantly testify, four months in London convinced him that he could never be a professional artist, and he then decided to fall in with his father’s wishes and study medicine in Edinburgh. It is of interest to note that at that time (1831) it took three days to travel from London to the Isle of Man, and another three from there to Edinburgh.

We hear most about two of the professors during his earliest years at Edinburgh—Graham and Jameson. Graham was Professor of Botany, and it is said to have been a matter of dispute amongst his students whether it was seven or only six diagrams that illustrated his course of lectures. The microscope was unknown, and the only practical work consisted in collecting flowers and pulling them apart with the fingers. Jameson, who united Geology and Zoology, was a celebrated man, a noted mineralogist, and the founder of the Natural History part of the well-known museum at Edinburgh.

It is evident that what Forbes appreciated most was the collecting excursions into the country around Edinburgh, and even farther afield to the Northern Highlands or to the Western Islands, which some of the professors organized from time to time. That was really the practical work in natural science of those days. It is curious to recall now-a-days, when we use the microscope so constantly, that the study of histology and microscopic structure in general was only introduced into medical studies, in 1841, by Professor Hughes Bennett, who had been a fellow-student of Edward Forbes. Forbes was, at Edinburgh, the centre of a group of brilliant young men, some half-dozen of whom, after being fellow-students, later on became fellow-professors in the same university. Among these we may note John Goodsir, the great anatomist; Balfour, the professor of botany; George Wilson, the biographer of Forbes; and Sir Robert Christison.

Goodsir was Forbes's first and probably his best friend. We are told that when he first called at his lodging he found the future malacologist boiling in his kettle a rare mollusc, *Clausilia nigricans,* he had found on Arthur's Seat, in order to get the animal from the shell—and Goodsir thereupon gave him a first lesson in dissecting a mollusc. We get curious glimpses of student life in Forbes's accounts—which are characteristically added up incorrectly—such as, "Leg, £2; Church, 6d.; Insects, 2/–." The "Leg" was, of course, his "part" in the dissecting room. We are told he was one of the idlest students of medicine Edinburgh ever saw—which is surely a strong statement—and yet we may be sure he was always fully employed in some interesting study, literary, artistic, or scientific. The point is that he was not doing what he was intended to do, and in that sense his time was wasted. He began each lecture with serious notes, which very soon degenerated into caricatures of the lecturer and fancy sketches of nymphs and gnomes.

His friend, Hughes Bennett, who undertook to coach him in anatomy, tells of the many dismal evenings of yawning over the bones, and of how Forbes would arrange that jovial friends should come in and interrupt, when the textbooks and bones would be thrown aside and the rest of the evening devoted to gaiety and philosophical discussions. After which it need not surprise us that when summoned to appear for examination on a certain afternoon, he at the appointed time was *non inventus.*

Of course, these young men ran a journal, and, of course, they formed a select students' club, the Brotherhood of the Magi, the symbol of which was a silver triangle on which was engraved *ΟΙΝΟΣ, ΕΡΩΣ, ΜΑΘΗΣΙΣ*—wine, love, learning. Their wine was not, I think, excessive; the love was brotherly love; and the learning was certainly on a high level. They were all clever, and most of them became celebrated men. This "oineromathic" brotherhood they defined as "a Union of the Searchers after Truth."

I have dwelt at some length on his student years in Edinburgh, as they were clearly the most stimulating and formative time of his life, definitely related to all he did later on, and brightened by friendships which persisted to the end. It was a lengthy student's career—nine years—four years of medical study, which he finally abandoned in 1836 to devote all his energies to Science. But during this time he spent considerable periods away from Edinburgh, travelling for study and always adding to his natural history collections wherever he went.

Several summers between 1832 and 1839 he spent in dredging the Irish Sea, and exploring the fauna and flora of the Isle of Man, and we see the results later on in his first-published book, *Malacologia Monensis,* and in certain papers in the Annals and Magazine of Natural History.

Another summer (1833) he and a fellow-student explored far from beaten tracks in Norway, going in a trading brig from Ramsey to Arendal, and then shouldering their knapsacks and packs of scientific collecting apparatus, which, no doubt, became heavier day by day as the collections grew. He had, of course, the noticing eye and the acquisitive hand of the true collector. On arriving at Bergen, his first action was to note that a spitting-box or spitoon in the room he entered was filled with a fine shell-sand, which he promptly emptied into his handkerchief and took away with him for

PROFESSOR EDWARD FORBES.

microscopic examination. Another year he spent some time in Paris, and the following summer made an expedition to Algeria. In 1839, he and Goodsir were dredging in the Shetland seas, with results which Forbes made known to the meeting of the British Association at Birmingham that summer with such good effect that a "Dredging Committee" of the Association was formed to continue the good work.

It was at this meeting of the Association that Forbes and his friends founded the "Red Lion Clubbe," which still meets, not with the regularity of its early days, but on occasions, for jovial dinners and good-fellowship—the old "Lions," and even the youngsters or "Cubs," under the presidency of the "Lion King," roaring and growling their approval and disapproval, and even getting up and waving their (coat-) tails, while some make witty speeches and others sing amusing songs, generally specially composed for the occasion, and as often as not parodying in a good-natured way some of the serious papers or addresses given to the Association at the meeting. Just as some of Forbes's best work was expounded in successive years to the British Association, so some of the happiest of his lighter efforts first made their appearance at the "Red Lion" dinners. In this particular year (1839), when he gave the scientific results of his Shetland dredgings to the Section, he sang or chanted to the "Red Lions" his "Song of the Dredge," of which I may quote a few verses here:—

Hurrah for the dredge, with its iron edge,
And its mystical triangle.
And its hided net with meshes set
Odd fishes to entangle!
The ship may move thro' the waves above,
'Mid scenes exciting wonder,
But braver sights the dredge delights
As it roves the waters under.

Chorus: Then a-dredging we will go, wise boys!
A-dredging we will go!
A-dredging we will go, a-dredging we will go,
A-dredging we will go, wise boys, wise boys,
A-dredging we will go!

Down in the deep, where the mermen sleep,
   Our gallant dredge is sinking;
Each finny shape in a precious scrape
   Will find itself in a twinkling!
They may twirl and twist, and writhe as they wist,
   And break themselves into sections,
But up they all, at the dredge's call,
   Must come to fill collections.
                    Then a-dredging, etc.

The creatures strange the sea that range,
   Though mighty in their stations,
To the dredge must yield the briny field
   Of their loves and depredations.
The crab so bold, like a knight of old,
   In scaly armour plated,
And the slimy snail, with a shell on his tail,
   And the star-fish—radiated!
                    Then a-dredging, etc.

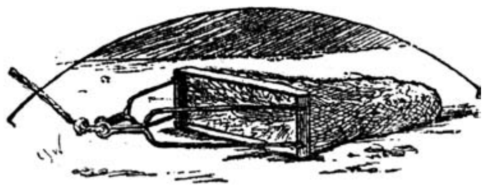


FIG. 1.—THE NATURALIST'S DREDGE.

And on another occasion, when at the Oxford Meeting in 1847 there had been a notable discussion on the nature and relations of the extinct dodo, Forbes brought out his "Song of the Do-do," of which the following are some of the verses:—

Do-do! Vasco da Gama
Sailed from the Cape of Good Hope with a crammer,
How he had met, in the Isle of Mauritius,
A very queer bird wot was not very vicious,
Called by the name of a do-do;
And all the world thought what he said was true.

Do-do! although we can't see him
His picture is hung in the British Museum;

For the creature itself, we may judge what a loss it is
When it's claw and it's bill are such great curiosities.
Do-do! Do-do!
Ornithologists all have been puzzled by you.

Ending with the moral—

Do-do! alas there are left us
No more remains of the *Didus ineptus,* etc., etc.

During his last few years at Edinburgh, Forbes made strenuous efforts to earn a livelihood by science. He prepared and announced courses of lectures at Edinburgh, St. Andrews, and elsewhere, which, I fear, were but poorly attended, and probably little more than paid expenses. It is interesting to notice that in January, 1840, he gave a course of eight lectures in Liverpool; and it was probably on the occasion of these lectures that he made the acquaintance of Mr. Robert MacAndrew, a Liverpool merchant and yachtsman interested in the mollusca, who during the last decade or so of Forbes's life, frequently took him and Goodsir or other friends on shorter or longer dredging expeditions.[1] For example, in the summer of 1845 we find that he was with MacAndrew on his yacht dredging in Shetland seas, and on the way back amongst the sea-lochs of the Hebrides. On other occasions MacAndrew took him in the yacht to dredge Milford Haven, or off the coast of Cornwall, or other localities which Forbes required to examine in connection with the great work on the British Mollusca upon which he was then engaged. Again, we find Forbes and Goodsir, in their important paper, *On Some Remarkable Marine Invertebrata new to the British Seas,* published by the Royal Society of

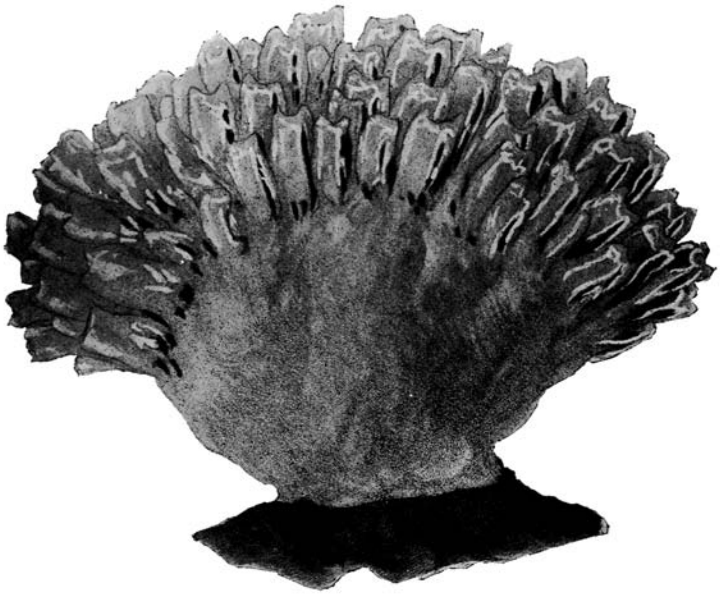
[1] I am glad to have the opportunity of paying this tribute to a Liverpool yachtsman who found or helped to find many of the rarer mollusca of British seas. His name occurs frequently in the records of Forbes and Hanley's *British Mollusca,* and it is perpetuated in science in *Calocaris macandreoe,* one of the rarer deep-water Crustacea, and in the names of several species of new shellfish which he had been instrumental in discovering.

Edinburgh in 1851, recording that: "The animals, either wholly new, or new to Britain, described in the following communication, were taken during a yachting cruise with our indefatigable friend, Mr. MacAndrew, among the Hebrides, in the month of August, 1850." Amongst the strange animals described and figured in this paper is the remarkable Ascidian, *Diazona violacea* (the *Syntethys hebridica* of Forbes and Goodsir), which, I may add, as an example of the constancy and reliability of nature, was dredged in quantity by myself nearly seventy years later in the exact locality where it was first discovered by Forbes and Goodsir. (See Plate III.)

Returning to 1840, his age was now twenty-six, and this was the year when he published his *British Starfishes*—the first of his larger and more important works. It remained as the standard work on the subject for many years, and is still a classic. In addition to its solid science and its value as a work of reference, there are scattered through it touches of humour, and the artistic and sometimes quaintly comic vignettes and tail-pieces, with which the author's pencil has adorned the beginnings and ends of the sections, are a pleasing feature of the work. Let me quote just one passage, his description of the dredging of the Starfish, *Luidia fragilissima* (as it was appropriately named at that time):—

"The first time I ever took one of these creatures I succeeded in getting it into the boat entire. Never having seen one before, and quite unconscious of its suicidal powers, I spread it out on a rowing bench, the better to admire its form and colours. On attempting to remove it for preservation, to my horror and disappointment I found only an assemblage of rejected members. My conservative endeavours were all neutralized by its destructive exertions, and it is now badly represented in my cabinet by an armless disk and a diskless arm. Next time I went to dredge on the same spot, determined not to be cheated out of a specimen in such a way a second time, I brought with me a bucket of cold fresh

PLATE III.



Diazona violacea, Savigny;
(the "Syntethys hebridica" of Forbes and Goodsir—green in the living condition, violet when dead). About half natural size.

water, to which article Starfishes have a great antipathy. As I expected, a *Luidia* came up in the dredge, a most gorgeous specimen. As it does not generally break up before it is raised above the surface of the sea, cautiously and anxiously I sunk my bucket to a level with the dredge's mouth, and proceeded in the most gentle manner to introduce *Luidia* to the purer element. Whether the cold air was too much for him, or the sight of the bucket too terrific, I know not, but in a moment he proceeded to dissolve his corporation, and at every mesh of the dredge his fragments were seen escaping. In despair I grasped at the largest, and brought up the extremity of an arm with its terminating eye, the spinous eyelid of which opened and closed with something exceedingly like a wink of derision" (*British Starfishes,* p. 138).

In turning over these earlier works of Forbes, we think of him as the typical "field-naturalist" of the older days, when it was still possible to take all nature for your province and do useful work in many fields—constantly investigating, constantly observing wherever he went, and throwing welcome light on science by all his observations.

All Forbes's later and more famous work in Marine Biology and the relations between Zoology and Geology—work that extended from Hebridean and Scandinavian seas, through the Mediterranean to the far Æean—may be said to have sprung from and been founded on his early work done as a lad in the college vacations in his home Manx waters.

A little to the north of Peel, on the west coast of Man, lies a submarine elevation, the Ballaugh fishing bank, which was the scene of some of Forbes's earliest explorations—more than ninety years ago. The path of the pioneer is proverbially rough, and no doubt it is easier for us now, when, on occasions, we take our students to the Ballaugh bank for a day's dredging from Port Erin. Forbes, in his day, must have gone in a small sail-boat from the shore below his house, or possibly in one of the "nobbies" of the Peel fishing fleet, and was certainly more dependent upon wind and weather than is now the case, when we can steam to the bank from Port Erin in an hour or two, and carry on our work there without much regard to wind or tide, in any moderate weather. But we find, in going over Forbes's records from Ballaugh, that his work was wonderfully detailed and accurate, and there is little or nothing to add. He found nearly all there is to find, and he marked out the distribution of life upon the various depths and parts of the bank with remarkable precision. And that, I think, is characteristic of much of his work. That he did so much, and did it so well in so short a life, full of other duties and cares, must constantly excite the wonder and admiration of those who humbly follow in his footsteps.

British naturalists are justly proud of the thorough manner in which the contents of the home seas have been made known by their distinguished predecessors; and of these famous monographs, which will remain classics of science throughout all time, some of the chiefest glories both in text and plates are those bearing the honoured name of Edward Forbes.

In 1841 came the great opportunity of his life to make marine investigations outside the British seas. Captain Graves, then in command of H.M. Surveying Ship "Beacon," engaged on hydrographical work in the Eastern Mediterranean, offered Forbes the post of naturalist to the expedition, which was promptly accepted. The work so far as Forbes was concerned was partly on land and partly at sea, partly zoological and partly archæological. After some months of surveying and dredging amongst the Isles of Greece, the "Beacon" was ordered to the coast of Lycia for the purpose of conveying to England the remarkable carved marbles and inscriptions discovered in the ruins of the ancient city of Xanthus by Sir Charles Fellows. For this task the vessel proved eventually to be quite unfitted, but it gave the opportunity for Forbes, along with Lieut. Spratt, to join the archæologist, Mr. Daniell, in a series of important explorations in the interior of Lycia, in the course of which they determined the sites of no fewer than eighteen ancient cities previously unknown, and rescued many inscriptions and carvings from the ruins. They copied upwards of 200 Greek and 30 Lycian inscriptions, and Forbes and Spratt a few years later (1847) produced an interesting work in two volumes entitled *Travels in Lycia,* giving the story of their explorations. In addition to his share of the narrative and the archæology, the chapters on the Natural History of Lycia and the neighbouring seas are clearly the work of Forbes. Mr. Daniell fell a victim to the malignant malarial fever of the country, and Forbes himself apparently had a narrow escape. His companion, writing in 1842, says: "Poor Forbes, the naturalist, was taken ill on the way from Rhodes to Syra, of the country fever, and remained for thirteen days together without tasting food, and without medicine or medical advice."

During this expedition, however, his main work was not on land, but at sea; and his marine dredgings in the Ægean gave great results. Captain Graves tells us how Forbes converted every one on board—officers and men alike—into ardent naturalists, bringing back shells and other offerings, "curios," as they called them, from every surveying trip in the boats.

Of the Greeks, in one letter, he foretells—"they will be a great people yet, and are almost as interesting as the shellfish that live on their shores." One of the points of interest, of course, in the shellfish was that they and many of his other captures were precisely the animals collected and described by Aristotle from these same coasts over two thousand years before. He dredged successfully at a greater depth (230 fathoms) than anyone had done before, and to his surprise he brought up living starfishes and other animals from 200 fathoms. He writes that the shellfish from the deeper water all belong to types only known in the fossil condition, and that, so far, he is the only zoologist who has seen them alive. His report on the distribution of animals in the Ægean Sea, which eventually appeared before the British Association at Cork in 1843, was, a contemporary tells us, a most important and philosophic summary of the facts, which at once raised him to a high rank among living naturalists. He defined, in the Ægean, eight zones of depth characterized by peculiar assemblages of animals, and he "conjectured that the zero of animal life would probably be found somewhere about 300 fathoms," so he named the region below that the "Azoic zone"—a conclusion which has since been found to be erroneous. Much of his zoological work in the East was unfortunately never published, on account of the pressure of other duties in which he became absorbed on his return to London.

The Council of the British Association gave him congratulations and encouragement, and the material support of a grant of £100, "to be expended in comparing the fauna of the Red Sea with that of the Mediterranean." Forbes therefore planned an extended expedition to Egypt for this purpose, which was first postponed by his severe illness and then abandoned when he was recalled in October, 1842, to London to take up the duties of Professor of Botany at King's College—a post he had been elected to in his absence.

There were probably few men then, and there are none now, who could be elected to a post in botany, in geology, or in zoology with equal success. We see him now holding two such posts simultaneously, and he eventually went on to the third. His professorship at King's College brought in less than £100 a year, so he had to supplement that scanty income by taking other work, and he applied for and was appointed to the curatorship of the Geological Society, and a few years later (1844) to the more important post of Palæontologist to the Geological Survey.

During the years in London when he filled these several posts, it is evident that his duties as Professor of Botany took up comparatively little of his time and energies, and that he was then, in fact, mainly a geologist. He identified himself thoroughly and intimately with the members of the Geological Society and with his colleagues of the Geological Survey, with whom, of course, he was constantly working both in the field and at the Jermyn Street Museum. His work as palæontologist was to identify the large numbers of fossils collected by the surveyors, and to give any information he could as to the conditions under which they had lived. In all this work, which occupied some of the best years of his life, he was, however, what he called a "Zoo-Geologist," working on the border-line of the two sciences and throwing light on both, bringing zoological knowledge in regard to the animals represented by the fossils to bear upon geological problems, and showing on the other hand how geological changes in the past help to explain the distribution of animals and plants at the present day. In some respects this was the finest and most original work that he ever did. During this period he was one of the founders of the Palæontographical Society, which has issued a noble series of volumes, some of the earlier of which (e.g., *British Tertiary Echinoderms*) are Forbes's work. He also contributed largely to other geological publications.

We can only mention two of the more important of these pieces of work. One of these was his careful investigation of the layers of supposed Wealden rocks, known as the Purbeck beds. In the autumn of 1849 he went down to the coast of Dorset and spent some months making a most minute investigation of the strata, with the result that he proved that these beds really belong to the Oolitic series. Sir Archibald Geikie tells us that, "with magnifying glass at eye, he crept over the faces of the rock, layer by layer, noting the peculiarities of each from top to bottom. As the result of this detailed scrutiny, while there was no evidence that any physical disturbance had taken place in the area during the deposition of the whole of the strata, the testimony of the included fossils revealed a remarkable series of alternations of fresh, brackish, and salt-water conditions over this part of England when the Purbeck group was in course of deposition. Our naturalist made the further important discovery that on several separate horizons these strata enclose the shells of some genera of still existing air-breathing mollusks—creatures which had not till then been found in so ancient a formation. It was characteristic alike of his humour and of his habit of making fun of his scientific brethren, and even of himself, that in some verses on what he called ‘Negative Facts,’ given at the Red Lion Dinner at Ipswich, and published in the *Literary Gazette* for 12th July, 1851, he instanced the finding of these shells as upsetting a premature conclusion:

Down among the Purbecks deep enough,
   A Physa and Planorbis
Were grubbed last year out of freshwater stuff,
   By Bristow and E. Forbes.
(Agassiz just had given his bail
   ‘Twas adverse to creation
That there should live pulmoniferous snail
   Before the Chalk formation.)

“The discovery, however, carried with it a wider significance. The occurrence of these snails suggested to Forbes that if air-breathing mollusks existed in Purbeck time, remains of mammalian life might hopefully be searched for in the same stratum as that which contained the shells. His sagacious prognostication was fulfilled not long after, when bones of reptiles and insectivorous mammals were exhumed where he had indicated.”

The second example of Forbes’s geological work which I have selected for mention is his celebrated paper, “On the Connexion between the Distribution of the Existing Fauna and Flora of the British Isles and the Geological Changes which have affected their Area,” published in 1846, in Vol. I. of the *Memoirs of the Geological Survey,* and universally regarded as a classic on the subject.

Forbes recognized that the origin of the fauna and flora of a country could not be solved from biological studies alone, but would require in addition the evidence supplied by geology in regard to former changes in climate, land, and water. Dealing with the flora of the British Islands, he distinguished five sub-floras or assemblages of plants—(1) a limited "Lusitanian" flora in the west and south-west of Ireland, comprising saxifrages, heaths, the arbutus, a Pinguicula, and other plants which are identical with species found abundantly in the north of Spain; (2) another local flora in the south-west of England and south-east of Ireland, resembling the vegetation of the Channel Isles and Northwestern France; (3) a restricted flora found on the chalk downs of the south-eastern counties of England; (4) a remarkable though limited flora, flourishing on the tops of the mountains, chiefly in Scotland, but also on the hills of Cumberland and Wales, and even on some uplands in Ireland, in which vegetation all the plants are specifically identical with Scandinavian forms; (5) and last, a general or Germanic flora, like that of Central Europe, everywhere present either alone or mingled with the others.

Forbes accounted for this distribution of the flora by migration or colonization from neighbouring lands previous to the isolation of the British Islands from the rest of Europe. He supposed that the southern parts of our islands were probably not submerged under the glacial sea, and that over land now covered his three southern assemblages of plants may have migrated successively northwards from Spain and from France, before, during, or after the Ice Age. If the floor of our seas was raised by even 100 fathoms, the British Isles would become a part of the European continent, the North Sea would become a great plain continued south and west through what is now the English Channel, and a strip of land would run from Britain along the west coast of France so as to join the north of Spain. This was the "Continental Platform" over which, according to Forbes, the plants, and even possibly some of the lower land animals, may have migrated into the south and west of Ireland.

The fauna of our seas also, like the land flora, presents distinct northern and southern relations. This is clearly seen both amongst the invertebrata, such as the molluscs, and also amongst fishes. In discussing these relations, one of the most interesting points that Forbes demonstrated was the presence of "boreal outliers" or assemblages of northern species occupying the deeper areas of about 80 to 100 fathoms that occur here and there on the west coast of Scotland. Such molluscs as *Puncturella noachina, Trichotropis borealis, Natica grœnlandica, Astarte elliptica, Nucula pygmœa, Emarginula crassa, Pecten danicus, Neœra cuspidata,* and the brachiopods *Terebratula caput-serpentis* and *Crania norvegica,*[1] are characteristic forms in these boreal outliers, and Forbes's view was that they were a part of the original northern fauna which formerly occupied our seas and which had retreated northwards when the climate became more genial subsequent to the glacial epoch, leaving these colonies isolated in the deeper holes (see map, P1. IV, Fig. 2).

Some of the chief conclusions, to which the facts and arguments stated in his detailed memoir lead, he summarizes as follows:—

> "(1) The fauna and flora, terrestrial and marine, of the British Islands and seas have originated, so far as that area is concerned, since the Miocene epoch.
>
> "(2) The assemblages of animals and plants composing that fauna and flora did not appear in the area they now inhabit simultaneously but at several distinct points of time.
>
> "(3) Both the fauna and flora of the British Islands and seas are composed partly of species which appeared in that area before the glacial epoch, partly of such as inhabited it during that epoch, and in great part of those which did not appear there until afterwards.
>
> "(4) The greater part of the terrestrial animals and flowering plants now inhabiting the British Islands arose outside

[1] I have given throughout the names as used by Forbes.

> that area and have migrated to it over continuous land.
>
> "(5) The Alpine floras of Europe and Asia are fragments of a flora which was diffused from the North. The deep-sea fauna is in like manner a fragment of the general glacial fauna.
>
> "(6) The termination of the glacial epoch in Europe was marked by a recession of the Arctic fauna and flora northwards, and of a fauna and flora of the Mediterranean type southwards, and in the interspace thus produced there appeared on land the general Germanic fauna and flora, and in the sea that fauna which is termed Celtic.
>
> "(7) All the changes before, during, and after the glacial epoch appear to have been gradual and not sudden, so that no marked line of demarcation can be drawn between the creatures inhabiting the same element and the same locality during two proximate periods."

I have omitted some of his conclusions which can no longer be regarded as based on fact: others require some modification. Much has been found out during the last eighty years, and it is not surprising if some of Forbes's brilliant and far-reaching speculations have proved incorrect or incomplete. For example, the three southern sub-floras of Forbes, in place of being the oldest as he supposed, we now know must have been the most recent; and it is now very doubtful to what extent they migrated over continental land now submerged, as he supposed, or were carried by birds, currents, or other natural agencies.

But while admitting some such imperfections due to the scanty knowledge of that day, we must recognize that this was a notable contribution to the theory of distribution, far in advance of anything known at the time. It practically opened up a fresh field of investigation, and proved to be the starting-point and stimulus of much subsequent research. About 1850 Forbes prepared his remarkable map of distribution of marine life over the oceans of the world, and of homoiozoic belts, which was probably the first attempt to divide the oceans into provinces on scientific grounds.

There are many of his writings, and of his lectures, which I have no space to refer to, though all have their points of interest. Take this, for example:—In 1847, he writes to a friend: "On Friday night I lectured at the Royal Institution. The subject was the bearing of submarine researches and distribution matters on the fishery question. I pitched into Government mismanagement pretty strong, and made a fair case of it. It seems to me that at a time when half the country is starving we are utterly neglecting or grossly mismanaging great sources of wealth and food. . . . Were I a rich man, I would make the subject a hobby, for the good of the country and for the better proving that the true interests of Government are those linked with and inseparable from Science." We must still cordially approve of these last words, while recognizing that our Government Department of Fisheries is now organized on better lines, and is itself carrying on scientific work of national importance.

I have laid more stress upon Forbes's theoretical papers than upon his matter-of-fact descriptive works. Useful as these latter are, indispensable to the systematic zoologist and palæontologist, works some of them, such as Forbes and Hanley's *British Mollusca* (published in 4 vols. between 1848 and 1853), which will remain as classics for all time, still they are books to consult rather than to read. On the other hand, his theories—such as those on the distribution of marine animals in the Mediterranean, and on the relations of the British fauna and flora to the great Ice Age, even if in some respects they are now regarded as erroneous or incomplete—have had a position and an influence in the history of science, have been an inspiration to many both in his own generation and since, and have led up to and guided the very researches which have, in some cases, resulted in more correct views. His theory of the "azoic zone" in the sea, that no life existed below 300 fathoms, based upon his observations in the Eastern Mediterranean, was justified by the facts known at the time, but required to be modified later on when the deep-sea dredging expeditions, which Forbes's work had stimulated, made known that an abundant living fauna extended down to the greatest depths of the abysses.

Taken altogether, it is a wonderful volume of work both in quantity and quality for a man to have produced who died before reaching the age of forty. His working life, even considering that he began original work very young, was limited to about twenty years, and it is reasonable to suppose that, had he lived, he would have made Edinburgh the greatest centre of marine biological work in Europe. That was evidently the opinion of his contemporaries. It is on record that he was worshipped by the men, old and young, who attended his first and only course of lectures in Edinburgh. They spoke of the wonderful influence, charm, and fascination that Forbes exercised on all who came in contact with him, and of the gloom and consternation which spread over the university when it was realized that he would never again meet his class.

Forbes was appointed to the goal of his ambition, the Chair of Natural History, at Edinburgh, in March, 1854. He gave a course of lectures in the summer term to a large and enthusiastic audience, after which he returned to London to finish off work for the Geological Survey until driven to take a brief holiday in the country by a severe attack of illness. In September the British Association met in Liverpool, and Forbes occupied the honourable position of President of the Geological Section, in which, we are told, he acquitted himself with great distinction—as he did likewise when presiding, in the character of a Scottish Lion, at the Red Lion Dinner during the same meeting.

His last published article, written at this time, a review of Sir R. Murchison's *Siluria,* contains a memorable passage, beginning:—

"The old Scandinavian gods amused themselves all day in their Valhalla hacking each other to small pieces, but when the time of feasting came, sat down together whole and harmonious, all their wounds healed and forgotten. Our modern Thors, the hammer-wielders of Science, enjoy similar rough sport with like pleasant ending." His purpose was to show that scientific disputes need not lead to unfriendly relations—that after tearing each other to pieces, metaphorically, in the section room the protagonists can dine together amicably as "Red Lions."

There is no doubt that he was in poor health during this summer, and had had no adequate rest. He returned to Edinburgh in October to prepare for his winter course, which started on November 1st. But after a week's lecturing he broke down completely from weakness and an attack of fever, which soon showed symptoms of kidney trouble, and became rapidly worse, leading to his death a few days later. His old friend, Professor Hughes Bennett, who was with him to the last, in an obituary notice, states: "A chronic disease contracted when in the East, re-excited and rendered violent by a severe cold caught last autumn, and which burst out with uncontrollable fury about ten days ago, was the immediate cause of his premature death."

In judging of the man it is important to bear in mind the dominating influence of his personality and conversation, quite apart from his publications. Few can now be alive who have held converse with him, but from remarks in the writings of his contemporaries we gain the impression of a genial and lively genius, with a free and independent spirit that roamed over a wide range in quest of knowledge and occupation.

Although an ardent student, he was far from being the recluse or the typical absent-minded "philosopher," as the man of science was called in those days. Accomplished, and with high social gifts, he appreciated versatility and sportsmanlike qualities in others, and he once stated (in an article on Sir Humphry Davy's *Salmonia*) that he "would undertake, without travelling far, to furnish philosophers, of various scientific callings, who could ride a race, hunt a fox, shoot a snipe, cast a fly, pull an oar, sing a song, or mix a bowl, against any man with unexercised brains, or even with none at all, in the United Kingdom." Mixing of bowls has gone out of fashion in scientific circles, but with that exception, and with such additions as may have resulted from the developments of sport and locomotion, the boast might be repeated of the "philosophers" of the present generation.

Forbes was certainly the most brilliant and inspiring naturalist of his day—a day when it was still possible to make original contributions to knowledge in several departments of nature. As we have seen, he held posts successively as Professor of Botany in London, as Palæontologist to the Geological Survey, and as Professor of Natural History in Edinburgh; but to my mind the best description in brief form is that he was the pioneer of oceanography—the science of the sea.

It is true that the term oceanography was not coined till much later, and that Forbes in his marine explorations probably did not realize that he was opening up a most comprehensive and important department of knowledge. But it is also true that in all his expeditions—in the British seas from the Channel Islands to the Shetlands, in Norway, in the Mediterranean as far as the Ægean Sea—his broad outlook on the problems of nature was that of the modern oceanographer, and he was the spiritual ancestor of men like Sir Wyville Thomson, of the "Challenger" expedition, and Sir John Murray, who carried on the work, through more recent post-"Challenger" times, almost to our own day.

Forbes in his marine investigations, as we have seen, worked at border-line problems, dealing, for example, with the relations of geology to zoology, and the effect of the past history of the land and sea upon the distribution of plants and animals at the present day, and in these respects he was an early oceanographer. For the essence of that new subject is that it also investigates border-line problems and is based upon, and makes use of, all the older fundamental sciences—Physics, Chemistry, and Biology—and shows, for example, how variations in the great ocean currents may account for the movements and abundance of the migratory fishes, and how periodic changes in the chemical characters of the sea are co-related with the distribution at the different seasons of the all-important microscopic organisms that render our oceanic waters as prolific a source of food as the pastures of the land.

Oceanography is as yet scarcely known in most universities, and when it does come to be more generally recognized and provided for, it will probably be in the main as a research department, carrying on investigations partly by experiments in the university laboratories on shore, partly by observations on special expeditions at sea, and partly, no doubt, by the accumulation and comparison of data as to temperatures and salinities, obtained from commercial vessels making ocean traverses—all on the lines shown by the magnificent "Musée Océanographique" at Monaco, and also by the programme of work of the "Conseil Permanent International pour l'Exploration de la Mer," a scheme of co-operation between the nine or ten maritime nations of North-west Europe, and, I think I may add, although the methods and the objects may now be somewhat different, also quite in the spirit of the pioneer work performed in the Irish Sea by Edward Forbes seventy to eighty years ago.

It must always remain an interesting speculation as to what part Edward Forbes would have played, had he lived in the great controversy which raged a few years later round the Darwinian theory of Evolution by means of Natural Selection. Forbes and Darwin were practically contemporaries,[1] but whereas Forbes's life-work was ended in 1854, Darwin's more celebrated works were not published until after 1858, the year when he and Wallace laid their epoch-making

[1] Darwin was precisely six years senior, being born on February 12, 1809.

communication upon "The Tendency of Species to form Varieties" before the Linnean Society of London.

Forbes, at the time of his death, was, in the opinion of his contemporaries, the most original naturalist of the time, and he had certainly had as much to do with the recognition and description of species—species of animals, of plants, and of fossils—as anyone of his day. Would this knowledge have helped him to appreciate Darwin's new views, or would it have confirmed him in the more orthodox opinions of the time? Huxley was his junior by ten years, and Huxley was the protagonist of Darwinian Evolution. Would Forbes have been found in the same camp, or would he have been one of those more senior men in regard to whom Darwin said that he did not expect to convince experienced naturalists whose minds had been accustomed during many years to an opposite point of view, but looked with confidence "to young and rising naturalists, who will be able to view both sides of the question with impartiality"?[1]

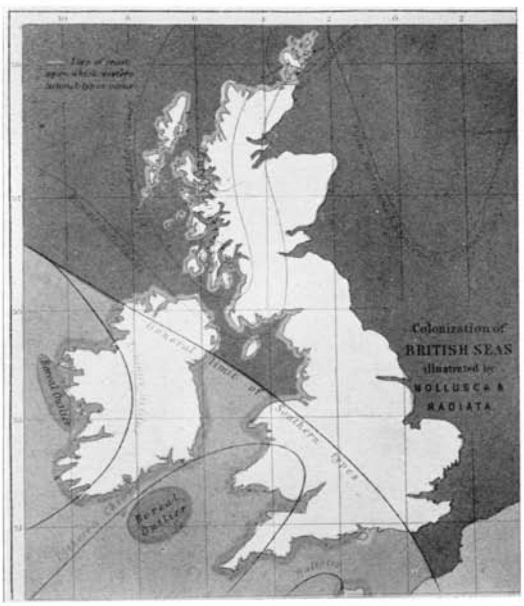
When reading Forbes's views on specific and generic centres of distribution, or his work in tracing the migrations of species both in space and time, or the description of his great map of "homoiozoic belts," one feels that surely he was not far from a belief in the mutability and community of descent of organic forms, and that, had he lived, he must have readily seen that the Darwinian theory gave a reasonable explanation of the great series of facts in distribution which his industry had collected and his genius had marshalled. These, taken along with his unrivalled palæonto-logical knowledge, are the grounds for hoping that Forbes would have been found with Huxley in the Darwinian camp.

In the entrance hall of the Port Erin Biological Station, the most conspicuous object is the large white bust of Edward Forbes (Plate IV, Fig. 1), whose clear-cut, intellectual features and genial expression at once arrest the eye, and appear to preside over the activities and destiny of the institution. And

[1] *Origin of Species,* 6th Edition, p. 423.

what better position could there be for this finely formed reminder of the Manx pioneer of science than in this workshop of Manx marine biology, devoted to the continuation and extension of Forbes's work in his native land? For here, all researchers who work in the laboratory, every one of the hundreds of senior students who enter on a course of study at Port Erin, and all who care of the many thousands of visitors who frequent the Aquarium, recognize or learn who Professor Edward Forbes was, and what he did. His works are in our library at the Biological Station, the starfishes and molluscs he described so well with pen and pencil are in the sea before our doors, his home at Ballaugh is almost in sight. In all our work at Port Erin, we keep his words, as well as his familiar features, constantly before us as an example, an inspiration, and a reminder of the great Manx naturalist, who first made known the abundant treasures of our seas.

BUST OF EDWARD FORBES.



FORBES'S DISTRIBUTIONAL MAP OF BRITISH SEAS.

CHAPTER III

SIR C. WYVILLE THOMSON AND THE "CHALLENGER" EXPEDITION

It seems quite appropriate that the last chapter, dealing with the life and work of the great Manx naturalist and early oceanographer Professor Edward Forbes should be followed by some account of the scientific career of that later oceanographer Sir Wyville Thomson, whose name will go down through the ages as the leader of the famous "Challenger" Deep-sea Exploring Expedition. There are many links between these two men. Both were naturalists in the widest sense, with an extensive knowledge of the natural sciences and a great appreciation of nature in all its aspects. Each occupied at the end of his life the Chair of Natural History in the University of Edinburgh, though neither had time to develop the great school of marine biology which might have been expected from such men in such a place had opportunity permitted. Forbes was only fifteen years the senior, and was at the zenith of his fame—publishing epoch-making views on the distribution of living things in the sea—at the time when Thomson entered the University of Edinburgh, and no doubt these views would arrest the attention and guide the thoughts of any keen young student of the natural sciences. It was Forbes who, on a basis of observations which were then thought to be sufficient, but are now known to be exceptional, placed the zero of life in the sea at 300 fathoms or thereabouts, and it was Wyville Thomson more than any man who proved that Forbes's views were in this particular erroneous, and that many and varied living things inhabit the greatest depths of the ocean. It may seem to some readers that Forbes lived very long ago, in a remote period of last century, but Wyville Thomson bridges over the gap to our time. He knew Edward Forbes, and I was fortunate enough to be the student, and later on assistant, of Sir Wyville Thomson. It is then, as will be realized, a peculiar satisfaction to me to make known to a younger generation of marine biologists what I am able to recollect or recover as to the life-work of my respected master, and as to the part he played in that great development of oceanography as a science which characterized the latter part of the nineteenth century.

Charles Wyville Thomson was born on March 5, 1830, at his ancestral country house of Bonsyde, within sight of the famous loch and ruined royal palace of Linlithgow, and not far from the shores of the Firth of Forth. His family had been connected with Edinburgh and the neighbourhood for generations, his great-grandfather, for example, being a law officer of the Crown at the time of the Jacobite rising in 1745. He was educated at Merchiston Castle School, formerly the home of Napier the inventor of logarithms, and, as in the case of some other men of science, his favourite study at school was, we are told, the Latin poets. We are apt to forget that in these cases there was probably no science taught in the school, and no opportunity given to the boy of studying anything more interesting than the Odes of Horace.

At the age of sixteen he matriculated as a student of medicine in the University of Edinburgh, but his main interests were said to be zoology, botany, and geology, and he was suspected of sometimes wandering as an observer and collector of marine invertebrates along the prolific shores of the Firth, when he ought, according to rules and regulations, to have been engaged with lectures and textbooks. Like many of the more intelligent students of science in Edinburgh, both at that time and later, he joined the Royal Physical

Society—which, despite its name, is a Society of Natural History—and for a couple of years he filled the office of secretary, surely one of the youngest on record. Fortunately for oceanography, after about three years of study, ill-health caused our young naturalist to give up all idea of the medical profession, and to turn his attention definitely to the natural sciences as his life-work. He left the university in 1850, without taking a degree, but his ability and reputation were such that he made rapid progress in the chosen career, and filled successively the posts of Lecturer on Botany in the University of Aberdeen (1851), Professor of Natural History in Queen's College, Cork (1853), Professor of Geology in Belfast (1854), and a few years later (1860) Professor of Zoology and Botany in the same college. It will be noticed that, like Edward Forbes, Wyville Thomson was capable of filling with success posts in all the natural sciences in succession, and this wide range of interest and of knowledge was, of course, of immense advantage in the great work that was to come in exploring the oceans.

A former student and assistant of Professor Wyville Thomson, at Belfast, has kindly provided me with the following impressions:—Thomson had a bright, handsome face and a light, springy step; he was a delightful and instructive lecturer, who had on his table a profusion of specimens of which he made incessant use, but spoke without notes. His Saturday excursions must have been delightful. We have a picture of him striding along, vasculum on back, at the head of his students, pointing out specimens and objects of interest as they were encountered. His hospitality to his students has left pleasant memories of the music and games at their social evenings. Amongst other activities at Belfast, he took a prominent position at the Natural History and Philosophical Society, the Belfast Naturalists' Field Club, and also the Literary Society, at all of which he read papers. We hear that he gloried in his beautiful garden and was a valued judge at the local flower shows.

It was during this period of teaching at Belfast that he began to make his mark in the scientific world as a marine biologist who studied animals both living and extinct, and published his investigations on British Cœlenterates and Polyzoa and on fossil Cirripedes and Trilobites. In working at Palæontology he became interested in fossil Crinoids, and so was led to the investigation of their only living representatives in our seas—the Rosy Feather Stars—a study which, we shall see, led him step by step to the great climax of his career, the leadership of the "Challenger" expedition. In 1862 Thomson completed his well-known memoir, "On the Embryogeny of *Antedon rosaceus*" (published in the *Philosophical Transactions of the Royal Society* for 1865), illustrated by a beautiful series of drawings representing the development and structure of the "pentacrinoid" stages in the life-history of the young Antedon.

It was at this time, also, that he became interested in those questions concerning life in the great depths of the ocean, the elucidation of which was to be his life-work and make him famous. It will be remembered that Edward Forbes, from his observations in the Mediterranean (an abnormal sea in some respects), regarded depths of over 300 fathoms as an azoic zone. It was the work of Wyville Thomson and his colleagues on various successive dredging expeditions to prove conclusively, what was beginning to be suspected by naturalists, that there is no azoic zone in the sea, but that abundant life belonging to many groups of animals extends down to the greatest known depths of from four to five thousand fathoms—nearly six statute miles from the surface. We can trace the gradual growth of Thomson's ideas in regard to the sea with the natural widening of his scope—from collecting as a student on the shores of the Firth of Forth to dredging as a young professor along the coasts of Ireland, and then to the successive deep-water expeditions in the surveying vessels "Lightning" and "Porcupine," and finally to the great world-wide exploring voyage of the

"Challenger." We can also trace the steps in his Echinoderm studies which seem to have led him to the fruitful field of deep-sea exploration. Palæontological investigation suggested work on living Crinoids, and the news that a strange new stalked Crinoid *(Rhizocrinus),* related to the fossil Apiocrinidæ, had been found living in Northern seas, induced him, in 1866, to visit Professor Michael Sars at Christiania, and examine for himself the remarkable collection of rare animals that his son, George Ossian Sars, had brought up from deep water (over 300 fathoms) in the Lofoten fjords. He was struck by their novelty and deep interest and by their resemblance to and bearing upon some of the extinct animals of former geological periods, and especially of the Chalk.

Thus inspired, he urged his friend, Dr. W. B. Carpenter, with whom he was then working at the later development of Antedon, to join him in endeavouring to promote an expedition to explore the deep waters of the Atlantic along the northwest coasts of Europe. Dr. Carpenter's powerful advocacy induced the Council of the Royal Society to use its influence with the Hydrographer, with such success that the Admiralty consented to place first one and then another small surveying steamer at the disposal of a committee of scientific experts for expeditions under the leadership of the two enthusiasts. After the first summer, a third naturalist of European fame, Dr. Gwyn Jeffreys, author of the five volumes on *British Conchology,* joined Carpenter and Thomson in conducting the practical work at sea; and the account of how, in 1868, H.M.S. "Lightning," and, in 1869 and 1870, H.M.S. "Porcupine," were equipped by the Admiralty and sent out to explore the depths, from the Faroes in the North to Gibraltar and beyond in the South, is given in full detail in Wyville Thomson's great work, *The Depths of the Sea,* which may be regarded as the first general textbook of oceanography. It was published just as the "Challenger" expedition was leaving England, and so gives us a statement of matters and opinions up to that important point in the history of the science. It is too long to summarize; but I may give some idea of its contents by quoting a few passages, and stating a few facts:—

"The surveying ship 'Lightning'" (Sir Wyville writes, p. 57) "was assigned for the service—a cranky little vessel enough, one which had the somewhat doubtful title to respect of being perhaps the very oldest paddle-steamer in Her Majesty's Navy. We had not good times in the 'Lightning.' She kept out the water imperfectly, and as we had deplorable weather during nearly the whole of the six weeks we were afloat, we were in considerable discomfort. The vessel, in fact, was scarcely seaworthy, the iron hook and screw-jack fastenings of the rigging were worn with age, and many of them were carried away, and on two occasions the ship ran some risk."

Still, on this "cranky little vessel" in the rough seas of the North Atlantic, they dredged down to 600 fathoms; and in 1869 on the "Porcupine," a more seaworthy ship, they got successful hauls from the great depth of 2,435 fathoms, nearly three statute miles.

Part of the book is historical, and amongst other interesting matters gives an account of those earlier observations which afford glimpses of a fauna in the deep sea. For example, we are told how in 1860 Professor Fleeming Jenkin, in repairing a cable in the Mediterranean, found several animals, including a deep-sea coral, attached to the broken cable at a depth greater than 1,000 fathoms, and therefore much beyond the supposed zero of Edward Forbes. During the "Porcupine" expeditions, sixteen hauls of the dredge were taken at depths beyond 1,000 fathoms, and two in depths greater than 2,000 fathoms, and in all cases life was found to be abundant.

Let us take next Wyville Thomson's account of a remarkable discovery made by one of these hauls, viz., that of the first living representative of the fossil flexible sea-urchins of the Chalk ever seen by a scientific man (p. 155):—

"This haul was not very rich, but it yielded one specimen of extraordinary beauty and interest. As the dredge was coming in we got a glimpse from time to time of a large scarlet urchin in the bag. We thought it was one of the highly coloured forms of *Echinus flemingii* of unusual size, and as it was blowing fresh and there was some little difficulty in getting the dredge capsized, we gave little heed to what seemed to be an inevitable necessity—that it should be crushed to pieces. We were somewhat surprised, therefore, when it rolled out of the bag uninjured; and our surprise increased, and was certainly in my case mingled with a certain amount of nervousness, when it settled down quietly in the form of a round red cake, and began to pant—a line of conduct, to say the least of it, very unusual in its rigid, undemonstrative order. Yet there it was with all the ordinary characters of a sea-urchin, its inter-ambulacral areas, and its ambulacral areas with their rows of tube feet, its spines, and five sharp blue teeth; and curious undulations were passing through its perfectly flexible leather-like test. I had to summon up some resolution before taking the weird little monster in my hand, and congratulating myself on the most interesting addition to my favourite family which had been made for many a day."[1]

I shall quote one more description (p. 160) of a haul of a dredge supplied with rope "tangles" from deep water:—

"I do not believe human dredger ever got such a haul. The special inhabitants of that particular region—vitreous sponges and echinoderms—had taken quite kindly to the tangles, warping themselves into them and sticking through them and over them, till the mass was such that we could scarcely get it on board. Dozens of great *Holteniæ,* like

[1] Wyville Thomson gave a detailed description of this and the other new Echinoidea obtained on the "Porcupine" expeditions in his Memoir, published in the *Philosophical Transactions of the Royal Society* for 1874.

'Wrinkled heads and aged,
With silver beard and hair,'

a dozen of the best of them breaking off just at that critical point where everything doubles its weight by being lifted out of the water, and sinking slowly away back again to our inexpressible anguish; glossy wisps of *Hyalonema* spicules; a bushel of the pretty little mushroom-like *Tisiphonia;* a fiery constellation of the scarlet *Astropecten tenuispinis;* while a whole tangle was ensanguined by the 'disjecta membra' of a splendid *Brisinga.*"[1]

In the final chapters of the book he discusses such highly important and controversial matters as Deep-sea Temperatures, the Gulf Stream, and the Continuity of the Chalk. In summarizing the results obtained in regard to the deep-sea fauna, he says (p. 80):—

"Finally, it had been shown that a large proportion of the forms living at great depths in the sea belong to species hitherto unknown, and that thus a new field of boundless extent and great interest is open to the naturalist. It had been further shown that many of these deep-sea animals are specifically identical with tertiary fossils hitherto believed to be extinct, while others associate themselves with and illustrate extinct groups of the fauna of more remote periods; as, for example, the vitreous sponges illustrate and unriddle the ventriculites of the chalk."

These pioneering expeditions—the results of which are not even yet fully made known to the scientific world—were epoch-making inasmuch as they not only opened up this new world to the systematic marine biologist, but gave glimpses of world-wide problems in connection with the physics, the chemistry, and the biology of the sea which are only now being adequately investigated by the modern oceanographer. These results, which aroused intense interest amongst the

[1] For descriptions and figures of *Holtenia* and other new deep-sea Hexactinellid Sponges, see his Memoir in the *Phil. Trans. Royal Soc.* for 1869.

leading scientific men of the time, were so rapidly surpassed and overshadowed by the still greater achievements of the "Challenger" and other national exploring expeditions that followed in the seventies and eighties of last century, that there is some danger of their real importance being lost sight of; but it ought never to be forgotten that they first demonstrated the abundance of life of a varied nature in depths formerly supposed to be azoic, and, moreover, that some of the deep-sea animals were related to extinct forms belonging to Jurassic, Cretaceous, and Tertiary periods.

Naturally Wyville Thomson, the young (then about forty) and active originator and leading spirit of these new and successful investigations, became a famous man. In 1869 he was elected to the Fellowship of the Royal Society, and in 1870 he succeeded Allman as Professor of Natural History in the University of Edinburgh, the post held by Forbes some fifteen years before. Thomson was a fluent and lucid lecturer, and a successful professor, greatly appreciated by his many students. His classes at Edinburgh were amongst the largest in the university, and were probably unequalled in size by any classes of zoology elsewhere in the country. Had time and strength permitted, he might have developed a great school of Marine Biology in connection with his university, but larger schemes further afield almost immediately claimed his attention.

The undoubted success of the preliminary expeditions in the "Lightning" and "Porcupine" encouraged Carpenter and Wyville Thomson, again through the Council of the Royal Society, to induce the Government to equip a deep-sea expedition on a really grand scale to explore and make known the conditions of life in the great oceans. This resulted in the famous circumnavigating expedition in H.M.S. "Challenger," and Professor Wyville Thomson as the chief originator of the expedition was appointed director of the civilian scientific staff on board. Two other members of that staff, J. Y. Buchanan, the chemist, and John Murray, the naturalist—and future oceanographer—were also recruited from the University of Edinburgh.

It has been said that the "Challenger" expedition will rank in history with the voyageslof Vasco da Gama, Columbus, Magellan, and Cook. Like these, it added new regions of the globe to our knowledge, and the wide expanses thus opened up for the first time—the floors of the oceans—were vaster than the discoveries of any previous exploration.

H.M.S. "Challenger" (Fig. 2, p. 57) was a spar-deck corvette of 2,306 tons displacement, with auxiliary engines of 1,234 indicated horse-power. She sailed in December, 1872, and returned in May, 1876, and during these 3½ years she traversed about 69,000 miles in the Atlantic and Pacific Oceans, and penetrated as far south as the Antarctic ice barrier. Soundings and dredgings or trawlings were taken at 362 stations, and enormous collections, such as the scientific world had never seen before, of marine organisms large and small, and of samples of bottom deposits and of water from all depths and all latitudes, were brought home for detailed investigation. As Sir Ray Lankester has said: "Never did an expedition cost so little and produce such momentous results for human knowledge." A number of preliminary reports written during the voyage were sent from the "Challenger" by Wyville Thomson, as Director, to the Hydrographer of the Admiralty, and were published by the Royal Society in 1875 and 1876.[1] Some were written by the Director himself, others were reports to him by the other members of the scientific staff. Thus, Moseley reported on the more remarkable Hydroids and Corals discovered, Murray on the deep-sea deposits and on the surface organisms, von Suhm on some of the Crustacea and their larval forms, and Buchanan on the physics and chemistry of the sea. All these preliminary reports are of interest even now to look over, and must have been far more so nearly fifty years ago, when they were published, as they gave the first glimpses of a world

[1] See especially *Proc. Roy. Soc.,* No. 170, 1876.

of new knowledge which was afterwards elaborated and displayed in the finished series of "Challenger Reports," and has now found its way into textbooks and been incorporated in the fabric of established science.

The long voyage, a considerable part of it spent in the tropics, cannot but have affected to some extent the health of men not trained to a life at sea. One of the naturalists, Dr. R. von Willemoes-Suhm, died during the voyage; Sir Wyville Thomson's health broke down soon after his return, and he died early in 1882; Professor Moseley died comparatively young in 1891, after some years of ill-health. Sir John Murray, on the other hand, was still in vigorous health at the age of over seventy-two, when he was killed in a motor accident in 1914. Dr. Buchanan, the chemist to the expedition, is now the sole survivor of the civilian scientific staff. The members of that staff were all brilliant men, who all produced most distinguished work. It had been said of Moseley, when a young man, that you had only to put him down on a hillside with a piece of string and an old nail, and in an hour or two he would have discovered some natural object of surpassing interest. During the voyage, in addition to working at the groups of animals, such as Corals, entrusted to his care, he made very notable collections in Botany and Anthropology from the remote and little-known islands that were visited. He also investigated some of the more remarkable of the organisms encountered either on sea or land, such as a pelagic Nemertean and some deep-sea Ascidians. While the "Challenger" was at Cape Town he took advantage of the opportunity to search for Peripatus, at Wynberg, on the slopes of Table Mountain, and on his first-found living specimen succeeded in demonstrating its essentially Tracheate nature.

In his book, *Notes of a Naturalist on the "Challenger,"* Professor Moseley gives us an interesting account of the deep-sea dredging and sounding, and of the length of time required for these operations on board the "Challenger." At a depth of 4,500 fathoms the sounding weight took an hour and a quarter to reach the bottom, and a much longer time to wind in again. It used to take all day to dredge and trawl at any considerable depth, and the net was usually got in only at nightfall. The ship, when dredging, used to lie rolling about all day drifting along with the wind and dragging the dredge slowly over the bottom. "At last, in the afternoon, the dredge-rope was placed on the drum, and wound in for three or four hours, sometimes longer. Often the rope or net, heavily weighted with mud, hung on the bottom, and there was great excitement as the strain gradually increased on the line. On several occasions the rope broke, and the end disappeared overboard, three or four miles of rope and the dredge being thus lost. At first, when the dredge came up, every man and boy in the ship who could possibly slip away, crowded round it, to see what had been fished up. Gradually, as the novelty of the thing wore off, the crowd became smaller and smaller ... and as the same tedious animals kept appearing from the depths in all parts of the world, the ardour of the scientific staff even abated somewhat, and on some occasions the members were not all present at the critical moment, especially when this occurred in the middle of dinner-time, as it had an unfortunate propensity of doing. It is possible even for a naturalist to get weary of deep-sea dredging. Sir Wyville Thomson's enthusiasm never flagged, and I do not think he ever missed the arrival of the net at the surface."[1]

The conditions under which life exists in the deep sea are very remarkable. The pressure due to the weight of water is enormous, and amounts roughly to a ton on the square inch for every thousand fathoms; so that at 5,000 fathoms the pressure is about five tons, that is, between seven and eight hundred times as great as the 15 lb. on the square inch we are accustomed to at sea-level. On one occasion we are told that Mr. Buchanan, the chemist to the expedition, hermetically

[1] *Notes of a Naturalist on the "Challenger,"* p. 501.

sealed up a thick glass tube, wrapped it in flannel, and enclosed it in a wide copper tube with perforated ends, and then lowered the whole to a depth of 2,000 fathoms and hauled it up, when it was found that the copper tube was flattened by the pressure, and the glass tube inside the flannel was reduced to a fine powder like snow. This process was referred to by Sir Wyville Thomson as an "implosion," the converse of an explosion. The most delicate animals, however, are able to exist under these enormous pressures, as their tissues are permeated by fluids under the same pressure, and are consequently supported equally on the inside and the outside. It is only when some animal is brought up too suddenly from a great depth to the surface that the release of pressure has a disastrous effect. Some fishes arrive with their eyes burst out of their heads, their scales forced off, and other parts of the body horribly distorted.

The temperature in these great depths is at or about freezing-point; and, as the sunlight probably only penetrates for a few hundred fathoms, there must be total darkness with the exception of occasional dim, ghostly glimmers of light given out by phosphorescent animals.

Moseley gives an amusing account of their tame and somewhat dilapidated parrot, who, from his perch on one of the wardroom hat-pegs, talked away constantly and amused them during the whole voyage. His great triumph, we are told, was frequently to repeat: "What! 2,000 fathoms and no bottom! Ah, Dr. Carpenter, F.R.S.!"

On the return of the expedition, Wyville Thomson was appointed Director of the "Challenger" Expedition Commission, located in Edinburgh, for the purpose of seeing to the distribution and investigation of the vast collections, and the publication of the results; and from that time onwards for about twenty years Edinburgh was the centre of oceanographic research and the Mecca towards which marine biologists from all over the world turned to inspect the novelties of the wonderful collections and to discuss results.

In selecting specialists to prepare the reports, Thomson and his successor Murray very wisely chose the best men available, irrespective of nationality. Consequently, the fifty quarto volumes of reports contain some of the best work of the most distinguished naturalists of all countries. It was not, however, until twenty years after the expedition that the last of these volumes was issued, and the last of the collections was safely deposited in the British Museum.

It is unfortunate that the man of science has so frequently to make a choice between the necessary work of administration and original research. Let us trust that he does not invariably select the work for which he is least fitted. Sir Wyville Thomson was given little time for either. In the few years of work that remained before his health gave way, he was so occupied with his many and varied duties as director of the Commission and editor of the reports, that there was little time for the original work he had planned to do in connection with the collections of Stalked Crinoids and of Hexactinellid Sponges—the two groups that he had reserved for his own investigation, and upon which he was an acknowledged authority.

He was knighted in 1876, and was awarded one of the gold medals by the Royal Society. In 1877, he delivered the Rede Lecture at Cambridge, and in the following year presided over one of the sections of the British Association at Dublin. It was during these years, after the return of the expedition, that I was privileged to know him, first as a senior student and young assistant and then as naturalist on the "Challenger" Commission, when I had priceless opportunities of becoming acquainted with the wonderful collections, and with the distinguished men from all countries who came to Edinburgh to study them and to consult with Sir Wyville Thomson and with his Chief Assistant, Dr. Murray, afterwards Sir John. To mention just a few of those I recollect most vividly, either at the "Challenger" Office or at Sir Wyville's hospitable house of Bonsyde,

SIR WYVILLE THOMSON.

where I had frequently to help him in the editing of the first few volumes of reports, or by taking some of his more energetic distinguished guests out for a walk round the countryside, listening rather awe-struck to their wonderful conversation (it was frequently a monologue, and I believe I acquired merit as a good listener), there were: that veteran of science, Dr. W. B. Carpenter, Professor Huxley, Moseley, Hubrecht, Ernst Haeckel, Alexander Agassiz, McIntosh, Percy Sladen, the Abbé Renard, Hjalmar Théel, Sir William Turner, Canon Norman, Professor P. G. Tait, Hoek, Perceval Wright, and a number of younger men who have since attained distinction, but were then just launched on a scientific career. During that time the distribution of many of the groups of animals to specialists, and the form in which the reports were to be published, was being decided on, and many interesting details had to be arranged between Sir Wyville and his "Reporters" on the one hand, and the Stationery Office of the Government (which undertook the publication) on the other, the latter seeming to have great difficulty in understanding the curious requirements of scientific authors in regard to printing and illustration.

During this time at home Sir Wyville published (Macmillan & Co., London, 1877) his preliminary account of the general results of the expedition, in two volumes, entitled *Voyage of the "Challenger"—The Atlantic,* which were to have been followed by companion volumes on the Pacific that, unfortunately, never appeared. *The Atlantic* is a most readable work, full of observations on the botany, geology and antiquities of the places visited as well as on the marine biology and general oceanography of the cruise. A notable feature of the book is the series of really beautiful text-figures illustrating the new species of Echinodermata and Sponges, which Professor Thomson had to some extent investigated during the voyage, and which he briefly described in these two volumes. Some of the figures of Holothurians, Sea-urchins and Starfishes show interesting cases of "direct development" of deep water or Antarctic Echinoderms, where the young were found in curiously devised marsupial cavities, and had evidently never passed through a free larval stage.

I shall quote here a couple of passages from *The Atlantic,* to give some idea of the varied interest of the book and of Sir Wyville's descriptive power.

In writing of the masses of weed in the Sargasso Sea, he says *(Atlantic,* Vol. II, p. 10): "The floating islands have inhabitants peculiar to them, and I know of no more perfect example of protective resemblance than that which is shown in the gulf-weed fauna. Animals drifting about on the surface of the sea with such scanty cover as the single broken layer of the sea-weed, must be exposed to exceptional danger from the sharp-eyed sea-birds hovering above them, and from the hungry fishes searching for prey beneath; but one and all of these creatures imitate in such an extraordinary way, both in form and colouring, their floating habitat, and consequently one another, that we can well imagine their deceiving both the birds and the fishes. . . . A little short-tailed crab *(Nautilograpsus minutus)* swarms on the weed and on every floating object, and it is odd to see how the little creature usually corresponds in colour with whatever it may happen to inhabit. These gulf-weed animals, fishes, mollusca, and crabs, do not simply imitate the colours of the gulf-weed; to do so would to be to produce suspicious patches of continuous olive; they are all blotched over with bright opaque white, the blotches generally rounded, sometimes irregular, but at a little distance absolutely undistinguishable from the patches of *Membranipora* on the weed."

On one occasion he describes (p. 147) the loss of a great catch, when trawling at a depth of 2,350 fathoms in the South Atlantic. "The trawl was lowered, and on heaving in it came up apparently with a heavy weight, the accumulators being stretched to the utmost. It was a long and weary wind-in on account of the continued strain; at length it came close to the surface, and we could see the distended net through the water; when, just as it was leaving the water, and so greatly increasing its weight, the swivel between the dredge-rope and the chain gave way, and the trawl with its unknown burden quietly sank out of sight. It was a cruel disappointment, every one was on the bridge, and curiosity was wound up to the highest pitch: some vowed that they saw resting on the beam of the vanishing trawl the white hand of the mermaiden for whom we had watched so long in vain; but I think it is more likely that the trawl had got bagged with the large sea-slugs which occur in some of these deep dredgings in large quantity, and have more than once burst the trawl net."

Here is a record of an historic event in our knowledge of the Protozoa (p. 293):—

"On one occasion in the Pacific, when Mr. Murray was out in a boat in a dead calm collecting surface creatures, he took gently up in a spoon a little globular gelatinous mass with a red centre, and transferred it to a tube. This globule gave us our first and last chance of seeing what a pelagic foraminifer really is when in its full beauty. When placed under the microscope it proved to be a *Hastigerina* in a condition wholly different from anything which we had yet seen. The spines, which were mostly unbroken, owing to its mode of capture, were enormously long, about fifteen times the diameter of the shell in length; the sarcode, loaded with its yellow oil-cells, was almost all outside the shell, and beyond the fringe of yellow sarcode the space between the spines to a distance of about twice the diameter of the shell all round was completely filled up with delicate *bullœ,* like those which we see in some of the Radiolarians, as if the most perfectly transparent portion of the sarcode had been blown out into a delicate froth of bubbles of uniform size. Along the spines fine double threads of transparent sarcode, loaded with minute granules, coursed up one side and down the other, while between the spines independent thread-like pseudopodia ran out, some of them perfectly free, and others anastomosing with one another or joining the sarcodic sheaths of the spines, but all showing the characteristic flowing movement of living protoplasm. The woodcut [in *loc. cit.*], excellent though it is, gives only a most imperfect idea of the complexity and the beauty of the organism with all its swimming or floating machinery in this expanded condition."

The conclusion at which Wyville Thomson arrived from a consideration of deep-sea and shallow-water faunas was (p. 331):—"It would seem that the enormous pressure, the utter darkness, and the differences in the chemical and physical conditions of the water and in the proportions of its contained gases depending upon such extreme conditions, do not influence animal life to any great extent."

During these few years after the return of the "Challenger" a number of lithographic plates illustrating the new Stalked Crinoids and the new Hexactinellid Sponges of the expedition were drawn on stone under Sir Wyville's direction, and were afterwards made use of in the completed reports on the former group by Dr. P. H. Carpenter, and on the latter by Professor F. E. Schulze.

Even after his health began to give way, he arranged for and directed, even if he did not actually conduct, a very important subsidiary expedition for the purpose of investigating further the very remarkable conditions of temperature and fauna which had been noticed in the Faroe Channel during the earlier cruises in the North Atlantic.

Carpenter and Wyville Thomson, during their preliminary investigations in the "Lightning" and "Porcupine," had found that the Faroe Channel between Cape Wrath and the Faroe Isles was abruptly divided into two regions under very different conditions—a "cold" and a "warm" area. The temperature of the water to a depth of 200 fathoms is much the same in the two areas; but in the cold area to the N.E. the temperature is about 34° F. at 250 fathoms and about 30° at the bottom in 640 fathoms, while in the warm area which stretches S.W. from the line of demarcation the temperature is 47° F. at 250 fathoms and 42° at the bottom in 600 fathoms. The warm area was found to have 216 species, while the cold had 217, and of these only 48 species were common to both.

Sir Wyville Thomson (see *Nature,* Sept. 2, 1880), as a result of his consideration of the "Challenger" temperatures, came to the conclusion that the cold and warm areas of the Faroe Channel must be separated by a very considerable submarine ridge rising to within 200 or 300 fathoms of the surface. He therefore addressed a letter in June, 1880, to the Hydrographer of the Admiralty, pointing out these facts, and asking for the use of a surveying vessel for a few weeks for the purpose of sounding the Faroe Channel with a view of testing his prediction. That was the origin of the "Knight Errant" expedition conducted by Captain Tizard and Dr. John Murray, under the general direction of Sir Wyville Thomson, who remained at Stornoway in the Outer Hebrides during the four traverses of the region in question. The results [1] completely justified Sir Wyville Thomson's prediction, and showed that a ridge rising to within 300 fathoms of the surface runs from the N.W. of Scotland by the Island of Rona to the southern end of the Faroe fishing banks.

This was followed by a further expedition in H.M.S. "Triton" in the summer of 1882, again under Murray and Tizard, which was very fruitful of zoological results. The discovery of two very different assemblages of animals living on the two sides of the Wyville Thomson ridge—Arctic forms to the north and Atlantic forms to the south—gives us a notable example of the effect of the environment on the distribution of marine forms of life.

Sir Wyville Thomson, however, did not live to see the "Triton" expedition and the full results of the exploration of the submarine ridge which so appropriately bears his name. His health had been failing for several years. In June, 1879,

[1] Published in the *Proc. Roy. Soc. Edin.* for 1882 (Vol. XI).

he had an attack of paralysis, and had to give up most of his university work. He resigned his professorship in October, 1881, and the Directorship of the "Challenger" Commission at the end of that year. He was able, in an invalided condition, to attend the Jubilee Meeting of the British Association at York in August, 1881, and died at Bonsyde on March 10th, 1882, in his 53rd year. He was a man of handsome presence and genial nature, with great personal charm of manner. His general culture, large fund of information on many subjects, his aptness and humour in conversation all contributed to make him a social success in Edinburgh and the beau-ideal of a host in his country home, where he gathered round him a large circle of friends by no means confined to scientific men.

He had a quaint way of occasionally bringing in old Scots sayings, or snatches of poetry, as for example, when he thought a question unimportant:—

Twenty peacocks in the air. I wonder how they all got there. I don't know—and I don't care!

or—more briefly, when with friends who understood him, simply—"Twenty Peacocks."

Judged from the scientific point of view, he probably turned out less original work than might have been expected. He is to be regarded as one of those who promoted science quite as much by his tact, influence and personality as by his own researches. Much that he had planned and begun was never completed, much that he might have done was prevented by his stirring life, frequent changes of post, his important administrative work and his numerous social duties. He was inspiring in conversation, kindly in his help and advice to younger workers, sagacious in counsel and highly valued by a wide circle of scientific friends in this country, in America, and on the Continent.

The important question now to be considered is, how has the "Challenger" expedition, which we owe mainly to the inspiration and the energy of Sir Wyville Thomson, advanced the science of the sea? This may be answered under various heads, and many leading authorities in different branches of oceanography have given their answer during the half-century that has elapsed since the expedition took place.

To take hydrography first, it must be remembered that every contribution to our knowledge of the ocean currents and their character, the ocean floor, its nature and depth, the prevalent winds and meteorological and magnetical conditions is an addition to the safety of the sailor, to the ease and speed with which a voyage

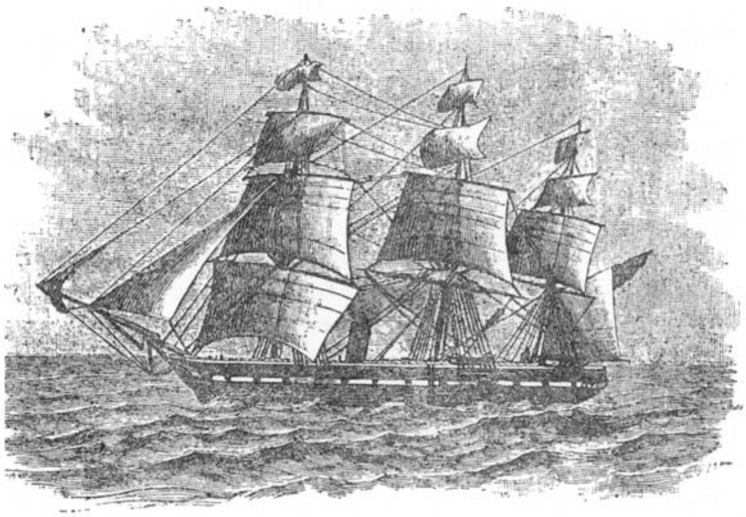


FIG. 2.—H.M.S. "CHALLENGER" PREPARING TO SOUND, 1872.
From Reports of the "Challenger" Expedition. (By permission of the Controller of H.M. Stationery Office.)

may be accomplished, and to the intercourse of nations. "Every Briton is proud of Britannia's navy; but let us remember that it is something more than our Empire's fighting machine, that it has been in the past, and will be still more in the future, the servant of the world, and a most potent agent in the peaceful union and advance of all its peoples."

Captain Tizard, who was the Navigating Officer on the "Challenger" during the expedition, tells us that the naval officers on board, equally with the scientific men, were all animated with the idea that it was their business to make the expedition a success, and we understand that while each member of the staff had his own work-room, in which he could pursue his own subject uninterruptedly, they all compared notes and got suggestions from one another in the smoking circle after dinner; a function which, we are told, was always well attended, and where the events and work of the day were freely and amicably discussed.

The chief hydrographic results which have benefited navigation are, according to Tizard (1895):—

> "(1) The proof that the variation of the compass can be determined as accurately in a ship as on shore, if the ship is magnetically suitable.
>
> "(2) The determination for the first time of the depths and main contour lines of the great ocean basins. It was shown that some of the great depths formerly reported had been much exaggerated, and the deepest sounding obtained was 4,475 fathoms, in the neighbourhood of the Mariana Islands in the N. Pacific. The investigations of many other expeditions (such as the "Tuscarora," the "Gazelle," the "Vettor Pisani," and the "Valdivia") since the "Challenger" have not altered in any material degree the contour lines of the great oceans drawn by our expedition in 1876, and have not resulted in the discovery of any depth exceeding 5,269 fathoms, about six statute miles. The "Challenger" explorations give no support to the fanciful theory of a lost "Atlantis." Microscopic investigations have revealed no traces of mythical continents now beneath the sea.
>
> "(3) The determination of oceanic temperatures and their independence of seasonal variation below the depth of 100 fathoms.
>
> "(4) The proof of constant bottom temperatures over large areas in the ocean. Thus, in the N. Atlantic the temperature

at depths exceeding 2,000 fathoms was found to be constant at about 36.5° F., while in the N. Pacific the bottom temperature was constant at 35°; in parts of the S. Atlantic the temperature at the bottom fell to 32.7°, while in the Sulu Sea it is 50.5°, and in the Arafura Sea 38.6°, while it is known that the bottom temperature of the Mediterranean is constant at 55.5°, and that of the Red Sea at 69°, these differences being due to certain oceanic areas being separated from each other by submarine ridges, which prevent a more general spreading of the cold bottom water from the poles. No bottom temperature was obtained as low as the freezing point of salt water.

"(5) The determination of the exact position of many islands and rocks, the longitude of which had been previously uncertain.

"(6) The charting and surveying of various little-known parts of the world, and their biological investigation.

"(7) The determination of the ocean currents both on the surface and at various depths.

One of the results of the "Challenger" expedition was undoubtedly an increase in our knowledge of the details of structure and the probable mode of formation of coral reefs and islands. Before the expedition, several geologists and naturalists had published doubts as to the universal applicability of the subsidence theory of coral reefs which we owe to Darwin. Semper, for example, showed that in the Pelew Islands up-raised reefs and atolls (which, according to the theory, indicate a sinking area) are found close together. The "Challenger" observations in regard to submarine elevations and the mode of accumulation of deep-sea deposits enabled Mr. Murray (afterwards Sir John) to formulate and publish a new theory as to the origin of atolls, which does not postulate any changes of level, but makes use merely of processes of growth and decay which we know to be at work and constantly acting. The matter is by no means finally settled even now, and it may well be that Darwin's theory holds good in certain parts of the ocean, while Murray's explanation is true for other series of atolls.

One of the principal additions to knowledge made by the "Challenger" observations was as regards the deposits now accumulating at various depths on the floor of the ocean. During the voyage the preservation and examination of these deposits was part of Murray's work, and subsequently, along with his friend the Abbé Renard, he made a most comprehensive study of all the submarine deposits (about 12,000) that could be obtained from various expeditions, and published in the "Challenger" series a most authoritative report, which will be for long the standard work on the subject. Omitting terrigenous deposits, which are formed close to the shore and are made up chiefly of matters washed down from the land or worn off from the coast, the deep-sea "oozes," as they have come to be called, are divided into various kinds, such as Globigerina ooze, Radiolarian ooze, Diatom ooze, Pteropod ooze, according to the nature of their chief constituents, while another most extensive deposit, occupying over 50 million square miles on the floor of the ocean at depths of over 2,000 fathoms, contains comparatively few conspicuous organisms and is known as Red Clay because of the alumina and iron and manganese which it contains. In some places associated with the Red Clay are found great deposits of manganese nodules, ear-bones of whales, and gigantic sharks' teeth apparently belonging to extinct species. It was the "Challenger" observations that first enabled oceanographers to map out the distribution of these pelagic oozes on the floor of the ocean, and which first gave us a rational explanation of their nature and process of formation.

In connection with deep-sea deposits, it may be appropriate to point out that it was the naturalists on the "Challenger" who pricked the bubble of "Bathybius" and made known the real nature of that mythical organism.

Some eminent biologists of the past, from an examination of some of the earlier deep-sea dredgings, had come to the conclusion that a grey gelatinous material, sometimes found in such deposits, was the remains of a primitive protoplasmic living slime covering the ocean bottom as a nutrient pabulum upon which, in the absence of plants, the more highly organized animals could graze—reminding one of the good old days in Ireland when—

The streets of Kilkenny were paved with penny loaves,
And the houses were thatched with pancakes.

In his book, *The Depths of the Sea,* Wyville Thomson speaks of it as "the universally distributed 'Moner' of deep water," and gives an excellent figure of "Bathybius" with its amœboid protoplasm and its contained Coccoliths.

The Bathybius myth had for a time a great vogue—particularly in Germany. Theoretically it was beautiful, it explained so much, but unfortunately on the "Challenger" it came in contact with hard facts of experiment and at once succumbed. It was proved by Mr. Buchanan that when a certain quantity of strong alcohol was added to a certain quantity of sea-water, the sulphate of lime was precipitated in the form of an amorphous deposit which clung around any particles, such as sand grains, mud, or the minute shells of an ooze, and gave exactly the appearances under the microscope which had been supposed to indicate the presence of protoplasm in the submarine deposit. Thus, as Huxley once said, "Bathybius has not fulfilled the promise of its youth," but from the experiments of the "Challenger" naturalists has been shown to be simply the sulphate of lime in the sea-water of the ooze precipitated by the alcohol which was added for preservation purposes.

There were great and widespread hopes and expectations amongst scientific men that the "Challenger" explorations would result in the discovery of many ancient and primitive types, belonging to extinct groups, still living in the great depths of the ocean. These hopes were not realized to any great extent. No Trilobites, no Cystoids and Blastoids, no archaic connecting links comparable in morphological importance with such land or shallow-water forms as *Ornithorhynchus, Amphioxus, Balanoglossus, Peripatus, Apus,* or *Limulus,* have been found in the depths of the ocean; and the accepted view now is that the deep-sea animals are not for the most part early and primitive forms, but have been derived from the more ancient shallow-water faunas. There are comparatively few "living fossils" in the deep sea. The vast number of new forms, however, added greatly to our knowledge of the infinite variety and range of structure of almost all groups. The expedition conclusively established the existence of abundance of living things, from the lowest of marine animals up to fishes, in even the great abysses of the ocean.

If we make a careful survey of the fifty large quarto volumes of reports, we find that most of the innumerable discoveries with which the "Challenger" expedition has enriched zoological science are additions to our knowledge either of the abyssal animals that live at the bottom of deep water or of the plankton, those that float near the surface. Beginning with the lower animals and working upwards, in the Radiolaria Haeckel, who reported on the material, made known more than 4,000 species, for the most part new to science. The numerous beautiful plates of the organisms forming Radiolarian and Globigerina ooze are amongst the most important additions to our knowledge of the Protozoa. A wholly new group of Radiolaria, the Challengerida (Phæodaria), having a remarkable skeleton of hollow spines formed of a peculiar combination of silica with organic matter, and living in intermediate waters at a considerable depth but not on the bottom, was added by the "Challenger" investigations.

Literally hundreds of new species of Sponges were described in the "Challenger" reports, and amongst these the greatest interest attaches to the representatives of that ancient and wonderfully beautiful group, the Hexactinellida, in which we find *Euplectella,* the "Venus' flower basket" of the Philippine Islands, and *Hyalonema,* the "glass rope" sponge.

In the Cœlenterata the work of greatest novelty and distinction was certainly that of the late Professor Moseley. His remarkable report on "Corals" contains a section on the Hydrocorallinâ, which is full of original discoveries of great value which have now been incorporated in all textbooks of zoology. He confirmed the view that *Millepora* is a stony Hydroid, and he was able to prove that all the Stylasteridæ also belong to that group, and incidentally his work overthrew the old-established group of the Tabulate Corals. In another section of this report he gives an account of the important discovery, which he made at the Philippine Islands, that *Heliopora,* the blue coral, is really an Alcyonarian.

Amongst the Echinoderm reports, that on the Crinoidea is perhaps the most interesting and important. It may be recalled that it was the discovery by G. O. Sars in 1864 of the stalked Crinoid *Rhizocrinus,* a member of the Jurassic and Cretaceous family Apiocrinidæ, still living in the deep fjords of Norway, that stimulated Sir Wyville Thomson and Dr. W. B. Carpenter to promote the cruises of the "Lightning" in 1868, and of the "Porcupine" in 1869 and 1870, and thus led up to the "Challenger" expedition. Sir Wyville had intended himself to describe the stalked Crinoids, and had made some progress in the examination and classification of the specimens and in the preparation of some of the plates when his break-down in health prevented any further work of the kind. The reports on these and on the Comatulida were eventually prepared by Dr. Carpenter's distinguished son, Dr. P. H. Carpenter, who as a lad had been his father's assistant on one of the cruises of the "Porcupine." The "Challenger" results definitely showed that, in place of being, as was supposed, "a group on the verge of extinction," the stalked Crinoids were widely distributed and showed scarcely any decrease in numbers since the times of their ancestors in Mesozoic seas. Some of the Echinoidea described in the report by Professor Alexander Agassiz resemble the Ananchytidæ of the Chalk, others are related to the extinct *Galerites;* while *Cystechinus,* with a thin flexible test, recalls the Palæozoic Palæechinidæ. Some of the Echinothuridæ, with flexible tests of imbricating plates, had long been known as Cretaceous fossils, and the first-found living representative, *Calveria hystrix,* of the "Porcupine," was added to on the "Challenger" expedition by various species of the remarkable allied genera, *Phormosoma* and *Asthenosoma.*

Many abyssal starfishes of primitive type were found, and a number of these, in place of passing through a free larval stage, have "direct" development, and keep their young for a period in some form of nidamental pouch. Many new and extraordinary deep-water Ophiuroids were added to knowledge, but it is perhaps in the Holothurians that we find the most surprising novelties. A whole new abyssal group of over fifty remarkable species—the Elasipoda—has been made known in the report by Professor Hjalmar Théel, nearly all found at depths greater than 1,000 fathoms and ranging practically from pole to pole. They are characterized, partly by primitive characters, such as the open madreporic canal on the surface of the body, and partly by adaptive characters fitting them to a life on the bottom ooze, over which they crawl and upon which they feed.

Amongst novelties in the Worms may be noted an elaborately branched *Syllis,* spreading its numerous ramifications through the canal system of a Hexactinellid Sponge dredged off the Philippines. Another noteworthy form was *Pelagonemertes,* a pelagic Nemertine described by Moseley, from the North Pacific and the Southern Ocean.

The "Challenger" reports on Crustacea occupy nearly one-fourth of the whole, and describe nearly 1,000 new species, some of which show remarkable modifications induced by life at great depths. Certain of them are totally blind, and others have eyes that are profoundly degenerate in their minute structure and are probably useless as organs of sight.

Amongst the Pycnogonida, or Sea-Spiders, were some gigantic forms of *Colossendeis,* measuring about two feet across the outstretched appendages. Although not, of course, a discovery in marine biology, it may be noted here that Moseley was enabled, by the examination of fresh specimens of *Peripatus* obtained at the Cape, to demonstrate the essentially Tracheate nature of that primitive and annectent form. Living representatives of the fossil Trilobites were eagerly looked for—but never found.

In the Mollusca, as in Crustacea, we find a tendency for the eyes to degenerate or disappear, in deep water. The "Challenger" collections enabled Pelseneer to establish a phylogenetic classification of the Lamellibranchiata based on the structure of the gills, and to show that the pelagic Pteropods are a polyphyletic group, some of which are related to one, and the rest to another, section of the Opisthobranchiata. One of the prizes obtained was the living specimens of *Trigonia,* dredged off the coast of Australia, a primitive cockle-like form found fossil in European rocks of secondary age, and long supposed to be extinct.

In the Cephalopoda the single specimen of *Spirula,* of which only five individuals are known to science, is one of the priceless treasures of the expedition. A living *Nautilus pompilius* was brought up from 320 fathoms, off Fiji, and Moseley has given us a description of its swimming movements in a tub of water on deck. It had been confidently hoped that some deep-sea representatives of those extinct groups, the Ammonites and Belemnites of Mesozoic times, would be found, and Moseley tells us that "even to the last every cuttle-fish which came up in our deep-sea net was squeezed to see if it had a Belemnite's bone in its back"— all in vain—no such "living fossil" was found.

One of the greatest discoveries of the "Challenger" expedition was the remarkable *Cephalodiscus,* dredged in the Strait of Magellan from 245 fathoms. It is a gregarious member of the Hemichordata related to *Rhabdopleura* and *Balanoglossus,* and it buds off new individuals which all live together in the cavities of a hollow gelatinous cœnœcium, which they have jointly secreted. It has been shown that the regions of the body and the divisions of the cœlom correspond closely with those of *Balanoglossus,* and that there is a tubular notochord extending forwards from the pharynx to strengthen the proboscis region.

Amongst the Tunicata many remarkable new abyssal forms were obtained, which have added greatly to our knowledge of the range of structure in the group. For example, the new genus, *Octacnemus,* first described by Moseley, has a much reduced and degenerate branchial sac, and has required the formation of a new family. Then, again, several distinct genera, *Pharyngodictyon* amongst Compound Ascidians, and *Culeolus, Fungulus,* and *Bathyoncus* amongst Ascidiæ Simplices, have the branchial sac simplified by the total absence of the system of fine inter-stigmatic vessels, the result being that the wall of the organ is reduced to a network of very large meshes, in most cases strengthened by branched and curved calcareous spicules. These are all of them abyssal forms, and no such structure of the branchial sac has been found in shallow-water Ascidians. Very many of the deep-sea Ascidians, including the new genera *Culeolus, Fungulus, Ascopera, Hypobythius,* and *Corynascidia,* are pedunculated, as if they required to be supported upon stalks above the soft ooze in which their bases are entangled and upon which the animals evidently feed. The intestines are found distended with, in some cases, Globigerina and in others Radiolarian or Diatomaceous ooze. Amongst pelagic Tunicates a noteworthy form is a new *Pyrosoma* of gigantic size, of which a magnificent specimen, measuring over four feet in length, was obtained in the North Atlantic, but of which, unfortunately, only fragments were preserved for study. Moseley, in his book, *Notes by a Naturalist,* tells us that the officers amused themselves by writing their names with the finger on the surface of the giant Pyrosoma, as it lay on deck in a tub at night, and the names came out in a few seconds in letters of fire.

Many interesting discoveries were made on the "Challenger" in regard to the deep-sea fishes, which were shown to extend down to no less than 2,750 fathoms. Perhaps the most sensational novelty is the presence of light-producing organs on the heads, gill-covers, and bodies of many abyssal fishes, and apparently under the control of the animal's will. Delicate organs of touch are in other cases associated with imperfect eyes. All the deep-sea fishes are, however, modifications of shallow-water forms, and none of them represent types of earlier date than the Cretaceous period.

No reference can be made here to the valuable reports on Reptiles, Birds, and Mammals—nor to those on the Botany and Anthropology of the various little-known lands visited during the expedition.

I am afraid that I have been able to give only a brief and inadequate summary of some of the chief results of the "Challenger" expedition, but I must not omit to point out that one of the most important results is the improvement in methods of investigation seen in later expeditions. It is easy to criticize the "Challenger" equipment and methods, and even the contents of some of the reports, but it must be remembered that it all happened fifty years ago, and that the methods of science may become old-fashioned in a very few years. The naturalists on the "Challenger" were the pioneers of deep-sea exploration, and their experiences taught many lessons by which later expeditions profited. Improved methods of capture of oceanic animals have resulted from the uncertainty felt on the "Challenger" as to the zone from which particular organisms found in the nets had been really obtained. Instruments, invented since, that can be opened and closed at any given depth, will prevent, or at least minimize, any such possible errors in the future. Wire has been substituted for rope in both sounding and dredging, and all the physical and chemical apparatus and methods are now much more reliable and refined than those employed by the "Challenger" pioneers. This is merely the natural result of the progress of science, and especially of such a new and rapidly advancing science as oceanography, during half a century of strenuous endeavour.

Some of the "Challenger" reports may be found old-fashioned and unsatisfying in transcendental morphology by the student of the present day, but the fifty noble volumes form a zoological library in themselves, and every young specialist on a group of marine animals has still to consult them, and before proceeding to new and no doubt more profound researches, must ascertain what was made known by his predecessors from their work on the collections brought home from the abysses of the ocean by the "Challenger" circumnavigating expedition.

CHAPTER IV

SIR JOHN MURRAY, THE PIONEER OF MODERN OCEANOGRAPHY

We now pass to the third and last of the periods chosen to illustrate oceanographic research during the nineteenth century, and I associate it with the name of Sir John Murray, whose life and work extended to the year of the outbreak of war; and, as in the two former cases, I shall begin with some account of the man, his surroundings and the conditions under which he did his work, and then deal with some of the results of his contributions to oceanography. Murray's period was absolutely continuous with that of Sir Wyville Thomson, and in fact overlapped it; so that, as we shall see, it fell to Murray to continue and complete the work of Thomson, in addition to undertaking other more recent investigations. While Sir Wyville Thomson's name will always be remembered as the leader of the "Challenger" expedition, Sir John Murray will be known in the history of science as the naturalist who brought to a successful issue the investigation of the enormous collections and the publication of the scientific results of that memorable voyage: these two Scots share the honour of having guided the destinies of what is still the greatest oceanographic exploration of all times.

John Murray, although a typical Scot in all his ways, was born in Canada—at Coburg, Ontario, on March 3, 1841. But he was of Scottish descent, and returned in early life to maternal relatives in Scotland to complete his education. The lives of our three pioneers just occupied a century (1815 to 1914), and to some extent overlapped. Forbes was only fifteen years senior to Wyville Thomson, and Thomson eleven years senior to Murray. While John Murray was still a school-boy in Upper Canada, Forbes was running his brief meteoric career as professor in Edinburgh, and Wyville Thomson was a young lecturer on the natural sciences in Ireland. Curiously enough, all three went through unusually extended courses as students of medicine and science at the University of Edinburgh, and not one of them took a degree. Forbes was a genius who neglected his work and frankly "funked" his examinations when the time came. In Thomson's case ill-health, fortunately for science, stopped his proposed career in medicine; while Murray despised examinations and degrees, and probably never proposed to take them. He studied a subject because he wanted to know it, and in that spirit he ranged widely over the Faculties of his university. When I was a student and young graduate I used to hear him denounce in vigorous language all examinations and other formal tests of knowledge, and yet, late in life, there was probably no man of his time who had so many honorary degrees and titles conferred upon him by the universities and learned academies of Europe and America.

After returning to Scotland as a boy in the teens, he lived for some time with a grandfather at Bridge of Allan, and attended the High School at Stirling. During this time he seems to have been most interested in the physical sciences, and especially electricity. He established some electrical apparatus at his home, and in an address to his old school, in 1899, he gives an amusing account of some of the results of his experiments with a large induction coil, such as the following: "On another occasion, several companions arrived from Stirling to see my experiments; they had with them five dogs, one of them being 'Mysie,' a large dog belonging to Sir John Hay, and I had a large Newfoundland called 'Max.' We resolved to give the dogs a shock. They were duly arranged in the room, and the circuit was completed by bringing the noses of the two largest dogs together. Pandemonium was the result. Each dog believed he had been bitten by the other. They fought, chairs and tables were overturned, and much of the apparatus broken. In the future, I was requested to turn my attention to the observational sciences of botany, zoology, and geology."

He then spent some years, in the sixties, at the University of Edinburgh, where he was known as a "chronic" student, working at the subjects in which he was interested without following any definite course. Amongst the professors under whom he studied at that time, and who became his close friends in later life, were P. G. Tait in physics, Crum Brown in chemistry, Turner in anatomy and Archibald Geikie in geology. A decade or so later, after the return of the "Challenger" expedition, he became once more a student at the University of Edinburgh, and that was when I had the good fortune first to meet him.

In 1868 he visited Spitzbergen and Jan Mayen and other parts of the Arctic regions on board a Peterhead whaler, on which, on the strength of having once been a medical student, he was shipped as surgeon. This voyage of seven months probably did much to confirm that interest in the phenomena and problems of the ocean which had been first aroused on his passage home from Canada, ten years before. This interest was doubtless further stimulated during the immediately following years by the epoch-making results of the pioneer deep-sea expeditions in the "Lightning" and "Porcupine," then exploring, under the direction of Wyville Thomson, Carpenter, and Gwyn Jeffreys, the Atlantic coasts of Europe. And then, fortunately, in 1870, Wyville Thomson was appointed professor at Edinburgh, which now became the centre of the negotiations and arrangements with the Admiralty and the Royal Society that led eventually, in 1872, to the equipment and despatch of our great British Deep-sea Exploring Expedition.

It was only an odd chance that led to Murray's connection with the "Challenger." The scientific staff had already been definitely appointed when, at the last moment, one of the assistant naturalists dropped out, and, mainly on the strong recommendation of Professor Tait, in whose laboratory Murray was at the time working, Sir Wyville Thomson offered him the vacant post—surely one of the best examples in the history of science of the right man being chosen to fill a post.

In addition to taking his part in the general work of the expedition, Murray devoted special attention to three subjects of primary importance in the science of the sea, viz., the plankton or floating life of the oceans, the deposits forming on the sea bottoms, and the origin and mode of formation of coral reefs and islands. It was characteristic of his broad and synthetic outlook on nature that, in place of working at the speciography and anatomy of some group of organisms, however novel, interesting, and attractive to the naturalist the deep-sea organisms might seem to be, he took up wide-reaching general problems with economic and geological as well as biological applications. Amongst the preliminary reports sent home during the course of the expedition, and published in the *Proceedings of the Royal Society* (vol. xxiv, No. 170, p. 471), we find those by John Murray, written from Valparaiso, December 9, 1875, dealing with (1) Oceanic Deposits, (2) Surface Organisms and their relation to Oceanic Deposits, and (3) Vertebrata (mainly Fishes), which, though superseded by the later work of himself and others, are still of great historic interest. In that preliminary account of the Oceanic Deposits we find Murray's first classification into (1) Shore deposits, (2) Globigerina ooze, (3) Radiolarian ooze, (4) Diatomaceous ooze, and (5) Red and Grey Clays, which has been adopted with little or no change in all succeeding works; and, in his report on the surface organisms, we find the first figures of the living *Hastigerina, Pyrocystis,* and the remarkable deep-water Radiolaria known as "Challengerida."

Each of the three main lines of investigation—deposits, plankton, and coral reefs—which Murray undertook on board the "Challenger" has been most fruitful of results both in his own hands and those of others. His plankton work has led on to those modern planktonic researches which are closely bound up with the scientific investigation of our sea-fisheries. His observations on coral reefs, in conjunction with the "Challenger" results as to depths of the ocean and the presence of submarine volcanic elevations, resulted in his new and most original theory as to the formation of "atolls," which removed certain difficulties that had long been felt by zoologists and geologists alike to stand in the way of the universal acceptance of Darwin's well-known theory of coral reefs and islands.

His work on the deposits accumulating on the floor of the ocean resulted, after years of study in the laboratory as well as in the field, in collaboration with the Abbé Renard of the Brussels Museum, afterwards Professor at Ghent, in the production of the monumental *Deep-sea Deposits* volume, one of the "Challenger" reports, which first revealed to the scientific world the detailed nature and distribution of the varied submarine deposits of the globe and their relation to the rocks forming the crust of the earth.

These studies led, moreover, to one of the romances of science which deeply influenced Murray's future life and work. In accumulating material from all parts of the world and all deep-sea exploring expeditions for comparison with the "Challenger" series, some ten years later, Murray found that a sample of rock from Christmas Island, in the Indian Ocean, which had been sent to him by Commander (now Admiral) Aldrich, of H.M.S. "Egeria," was composed of a valuable phosphatic deposit.

Murray's interest in this rock was at first solely in relation to the "Challenger" deposits and its possible bearing on his coral-reef theory; but he soon realized its economic as well as scientific interest, and was convinced that the island would be of value to the nation. After overcoming many difficulties, he induced the British Government to annex this lonely, uninhabited volcanic island, and to give a concession to work the deposits to a company which he formed. He sent out scientific investigators to study and report on the products, and the results have been highly successful on both the scientific and the commercial sides. Sir John Murray visited Christmas Island himself on several occasions, he had roads cleared, a railway constructed, waterworks established, piers built, and the necessary buildings erected. In fact, the lonely island was colonized by about 1,500 inhabitants, and flourishing plantations of various kinds were established in addition to the working of the phosphatic deposits. Murray was able to show that some years before the war the British Treasury had already received in royalties and taxes from the island considerably more than the total cost of the "Challenger" expedition. This is one of these cases where a purely scientific investigation has led directly to great wealth—wealth, it may be added, which in this case has been used to a great extent for the advancement of science.

In the case of Sir John Murray, as in that of Sir Wyville Thomson, I am writing of a man who made a strong personal impression as one of my teachers in science at Edinburgh some forty-five years ago. It is not from one's formal instructors alone that one learns. Murray was never on the teaching staff of the university; but a few of us (generally Major-General Sir David Bruce, now of the Lister Institute, Professor Noel-Paton, now of Glasgow, and myself), who were then, in the late seventies, young students of science, and were privileged to have the run of the "Challenger" Office, learned more of practical Natural History from John Murray than we did from many university lectures.

This was in the few years following on the return of the "Challenger" expedition in 1876, and the vast collections of all kinds brought back from all the seas and remote islands were being classified and sorted out into groups for further examination in a house near the university, known as the "Challenger" Office. Murray, as First Assistant on the Staff, had charge of the office and the collections, and welcomed a few eager young workers who were willing to devote free afternoons to helping in the multifarious work always in progress.

There we first made acquaintance with the celebrated new deep-sea "oozes," learnt to distinguish them under the microscope, and how to demonstrate the silicious Radiolaria hidden in the calcareous Globigerina ooze; and there we first saw such wonders of the deep as *Holopus* and *Cephalodiscus,* and the extraordinary new abyssal Holothurians, afterwards known as Elasipoda. These—now the commonplaces of marine biology—were then revelations, and those of us who witnessed the discoveries in-the-making will always associate them with "Challenger Murray" as the archmagician of the laboratory—a sort of modern scientific alchemist, bringing mysterious unknown things out of store-bottles, and then showing us how to demonstrate their true nature. I am afraid that we who are trying to inspire students with the sacred fire at the present day have no such wonders to show as those first-fruits in the early days of deep-sea research. Then between times, while waiting for a reaction, or after work, Murray would tell us stories of the great expedition—how the first living *Globigerina (Hastigerina murrayi),* seen in all its glory of vesicular protoplasm expanded far beyond its tiny shell, was picked up in a teaspoon from a small boat during a dead calm in mid-ocean; and how the naval officers wrote their names with their fingers in letters of fire on the phosphorescing giant *Pyrosoma* (over four feet long) as it lay on the deck at night; how they "iced" their champagne in the tropics by plunging the bottles into the trawlful of ooze just brought up from the abyss, and still retaining its abyssal low temperature; and, finally, he would sing us a most amusing song—we never knew whether he had invented it or not—about a Chinaman eating a little white dog.

A few years later, after Sir Wyville Thomson's death in 1882, Murray had supreme control of both the collections and the editing of the reports; and of the "Office," by that time moved to more commodious quarters at 32 Queen Street, which was the scene of his labours for many years, and where I for a time held the post of "Assistant-Naturalist," and saw Murray practically every day.

When I first knew John Murray, although he was an older man, we were really in one respect fellow-students, as we attended together Professor Archibald Geikie's course on geology. One very pleasant and not the least instructive part of the course at that time was the series of geological walks personally conducted by the professor, not merely Saturday walks in the neighbourhood of Edinburgh, but also longer expeditions of a week or ten days at the end of the session, to localities of special geological interest farther afield, such as the Highlands or the Island of Arran. I well remember one such long excursion to the Grampian and the Cairngorm Mountains and Speyside, when we had, as somewhat senior members of the party—in addition to Professor Geikie—Dr. Benjamin Peach and Dr. John Horne of the Geological Survey, Dr. Aitken of the University Chemical Department, Joseph Thomson the African explorer, and John Murray of the "Challenger." The rest of us were ordinary students of science, and all will realize how we enjoyed and profited by the conversation of these senior men, how we dogged their steps and hung upon their every word. All who ever met John Murray will readily understand that in the frequent discussions that took place between these geologists and chemists, he always took a leading and forcible part—he was nothing if not original in his views and vigorous in his language.

The reader need not think that all this had nothing to do with oceanography. It was very much otherwise. These were all Edinburgh men deeplyinterested in the "Challenger" results. On the long tramps there were hot discussions, and wherever Murray was he was apt sooner or later to bring a discussion round to some fundamental problem of the ocean or the deposits forming on its floor, or to illustrate an argument by something he once saw in the Pacific, or the Antarctic—or elsewhere. And, moreover, on the tops of these ancient mountains of Scotland we could, and did, consider the changes of continents and the supposed permanence of ocean basins. I, for one, then came to realize that geology has a close bearing on oceanography; and I suspect that it was on occasions like these, in keen discussion with geologists and chemists, that Murray formulated some of the theories as to past history of land and sea that he afterwards published in the *Summary* volumes of the "Challenger" series.

Murray's first paper on his theory of coral reefs was read before the Royal Society of Edinburgh on April 5, 1880, and was published in the *Proceedings,* vol. x., p. 505. I well remember the occasion, and also the rehearsal which took place some days before in Sir Wyville Thomson's house of Bonsyde, when Murray read his MS. to a small but highly critical audience, consisting of Sir Wyville Thomson, Sir William Turner, and myself. For months before I had daily seen Murray preparing the paper in a large room at the "Challenger" Office, sitting at his notes in the centre of a multitude of charts showing all the reefs and coral islands of tropical seas—some of the charts spread out on tables, others carpeting the floor or stacked in piles and rolls—while he measured and drew sections of the contours so as to see which reefs supported his views and which presented difficulties. His coral-reef theory was a direct outcome of his "Challenger" work. The soundings had revealed the presence of volcanic elevations, and the distribution of the calcareous deposits showed how these might contribute to build up suitable platforms as the foundation of reefs which might grow to the surface independent of all sunken lands such as Darwin's theory had required. It may be said that Murray demolished the supposed need of vast oceanic subsidence, which had been felt to be a difficulty by many geologists, and showed that all types of coral reef could be accounted for without subsidence, and even in some cases along with elevation of land.

Some of Murray's friends were disappointed that his theory did not receive more serious and more immediate attention, and the then Duke of Argyll wrote a couple of articles with somewhat sensational titles—"A Great Lesson," in the *Nineteenth Century* for September, 1887, and "A Conspiracy of Silence," in *Nature* for November 17, 1887—which gave rise to answers from some of the leading men of science of the day, Huxley, Bonney, and Judd. Murray went on his way undisturbed, collecting further evidence and publishing at intervals further papers dealing with one or another part of the large subject—such as his paper on the structure and origin of coral reefs in the *Proceedings* of the Royal Institution for 1888, his account of the Balfour Shoal in the Coral Sea (1897), a submarine elevation in process of being built up by calcareous deposits, his "Distribution of Pelagic Foraminifera at the surface and on the floor of the Ocean" (1897), and a series of reports upon bottom deposits from the "Blake" (1885) and many other expeditions.

Later on (1896–8) Murray took a lively interest in the investigation, by a Committee of the British Association and the Royal Society, of a selected typical case, the atoll of Funafuti, one of the Ellice Group, in the South Pacific. A first expedition was sent out from this country under Professor Sollas, and then two others from Australia, under Professor Edgeworth David, of Sydney, and borings were eventually obtained reaching an extreme depth of over 1,100 feet. The core was brought home and subjected to detailed microscopic examination, with the extraordinary result that the supporters of both rival theories find that it can be interpreted so as to support their views. The Funafuti boring cannot be said to have settled the matter. I believe the verdict at the present time of most zoologists and geologists would be that whereas Darwin's beautiful theory would certainly hold good for coral reefs growing on a sinking area, Murray's explanation, based upon observations and ascertained facts, probably applies to many of the "atolls" and "barrier reefs" of tropical seas.

But I have been led on to these more recent times by his paper of 1880. Let us now return to his work at the "Challenger" Office. During the last couple of years of Sir Wyville Thomson's life, when he was more or less of an invalid, Mr. John Murray (as he then was) came gradually to take over more and more the complete charge of affairs at the "Challenger" Office, including the distribution of the groups of animals to specialists and the editing of the volumes of reports. It was very fortunate for zoological science that such a man was on the staff, ready to take up and carry out to a successful issue the work that Sir Wyville Thomson was no longer able to continue. Murray brought to the task a complete knowledge of all that had to be done and how best to do it, along with an extraordinary amount of zeal and energy. During the years that followed, until the completion of the work, he seemed to be doing several men's work. He was in constant communication, both by correspondence and personal visits, with the authors of reports in various parts of Europe and America; he had frequent dealings with the Government departments concerned in the production of the work; and all the time he was also himself investigating some of the great general problems of oceanography. It is difficult to imagine that any other man than John Murray could have carried through all this mass of detailed and difficult work and have produced the fifty thick quarto volumes within twenty years of the return of the expedition. About five of these large volumes are the result of Murray's own work. Along with Staff-Commander T. H. Tizard, the late Professor H. N. Moseley, and Mr. J. Y. Buchanan, he drew up the general *Narrative of the Expedition;* along with the late Professor Renard he wrote the very important report upon the *Deep-sea Deposits* (1891), generally recognized as the authoritative work on the subject; and finally, at the conclusion of the series, he produced two volumes entitled *Summary of Results* (1895), which give an elaborate historical account of our knowledge of the sea and the development of the science of oceanography from the earliest times to the present day, and also, in addition to complete lists of all the organisms at all the "Challenger" stations, includes a discussion of many important matters, geological as well as biological, relating to the origin of the present configuration of land and water and of the distribution of the marine fauna and flora of the globe.

It was characteristic of him to put forward, especially in these *Summary* volumes, views which were novel and even daring, which he believed he had evidence to support, but which a less courageous man might have kept back or expressed more cautiously. He always had the courage of his convictions. He admitted that he sometimes made mistakes, but held that the man who never made a mistake never made anything else. That was one of his *obiter dicta* which were flying about the "Challenger" Office, and stuck in my impressionable youth. Let me quote here a passage from one of his many letters that I have, and which refers to the kind of views he afterwards published in his *Summary.* It is dated September 13, 1894, and is evidently in answer to some question I had asked as to his views on the past history of life in the sea.

"... I gave two papers to the R.S.E. and also said something about distribution at the British Association, but I have not yet published anything. I am now considering whether or not I will add a chapter to the last 'Challenger' volume, giving my views.

"I believe the continental areas are very permanent, and for instance Africa has separated marine faunas and floras longer than the time when there was a very nearly similar fauna at both poles. However, the faunas of the sea are now arranged more according to zones of temperature than by land barriers. The tropics extend polewards as we go down in the geological formations till just before the Chalk there was a universally warm sea—from equator to poles and from top to bottom—say 80°F. Coral reefs once flourished at the poles. These have now been driven to equatorial regions where the temperature has remained nearly the above. The animals which in the universal warm sea came to live in the mud at a little depth, remained behind when cooling of the poles commenced. These animals without pelagic free-swimming larvlegæ also descended to the deep sea as the waters cooled. When the sea was all 70°or 80°F. the deep sea was not inhabited. Polar animals and deep-sea animals have all a direct development (so also fresh-water animals, also derived from the deeper part of the shore estuarine universal fauna).

"It is nonsense to suppose that while the earth was developing the sun has always been the same as now. It has been contracting. In Chalk times it had a diameter seen from the earth equal to an angle of 10° in the heavens. This would give all the heat and *light* that is necessary for a great Carboniferous forest at the poles.

"You can tell me how much of this is d—d nonsense.

"Yours sincerely, JOHN MURRAY.

"Fresh water fauna is much more archaic than deep-sea."

The following, from his little book *The Ocean* (p. 226), is a good example of Murray's bold speculations: "We look back on a past when the crust of the earth was in a molten condition with a temperature of 400°F., when what is now the water of the ocean existed as water vapour in the atmosphere. We can imagine a future when the waters of the ocean will, because of the low temperature, have become solid rock, and over this will roll an ocean of liquid air about forty feet in depth."

One of the theories which he supported, and which is not now generally accepted, although he believed he had much evidence in favour of it from the "Challenger" results, was the theory of "Bipolarity," viz., that identical organisms were found in Arctic and Antarctic seas and not in intermediate waters, and that they represented the original marine fauna which at some earlier period of the earth's history inhabited all the oceans. This bipolarity hypothesis has been vigorously controverted, and, like some other theories in science which have had to be abandoned, was most useful in its day as giving rise to much new investigation. A good deal of evidence against Murray's views on bipolarity has been accumulated as the result of recent Antarctic expeditions.

But whether all his views are accepted or not, they are all very stimulating and useful, and have given rise to much investigation and discussion in the history of oceanography. His five great volumes are a notable monument to his memory. They and the other "Challenger" reports which he edited record collectively the greatest advance in the knowledge of our planet since the great geographical discoveries of the fifteenth and sixteenth centuries.

I referred in the last chapter to the subsidiary expeditions (1880–2) for the purpose of investigating the very remarkable conditions of temperature and faunain the Faroe Channel. We saw how Carpenter and Wyville Thomson, during the preliminary investigations in the "Lightning" and "Porcupine," had found that the Faroe Channel was divided into two regions—a "cold" and a "warm" area. The temperature of the water to a depth of 200 fathoms is much the same in the two areas; but in the cold area to the N.E. the temperature is about 34° F. at 250 fathoms, and about 30° at the bottom in 640 fathoms, while in the warm area, which stretches S.W. from the line of demarcation, the temperature is 47° F. at 250 fathoms, and 42° at the bottom in 600 fathoms. A consideration of the "Challenger" temperatures led to the conclusion that the cold and warm areas of the Faroe Channel must be separated by a very considerable submarine ridge rising to within 200 or 300 fathoms of the surface. Sir Wyville Thomson induced the Admiralty to give the use of a surveying vessel for a few weeks for the purpose of sounding the Faroe Channel with a view of testing this opinion. That was the origin of the "Knight-Errant" expedition in the summer of 1880, conducted by Captain Tizard, R.N., and Mr. John Murray, under the general direction of Sir Wyville Thomson, who remained at Stornoway, in the Outer Hebrides, during the four traverses of the region in question. The results *(Proc. Roy. Soc. Edin.* for 1882, vol. xi) showed that a ridge rising to within 300 fathoms of the surface runs from the N.W. of Scotland by the island of N. Rona to the southern end of the Faroe fishing-bank.

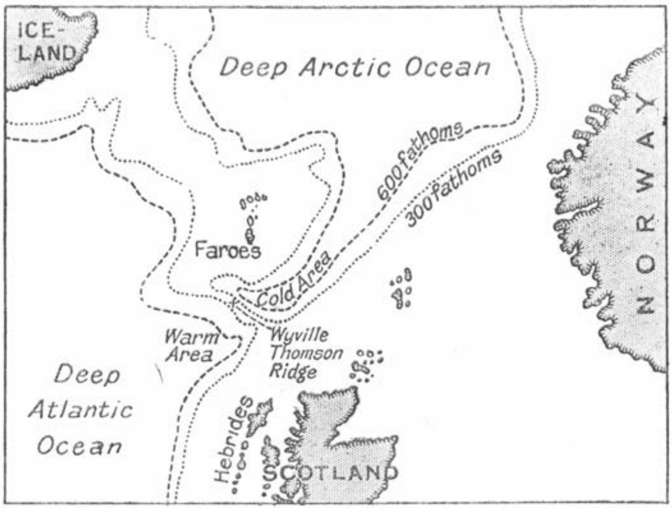


FIG. 3.—SKETCH-CHART SHOWING THE WYVILLE THOMSON RIDGE IN THE FAROE CHANNEL.

This was followed, after the death of Sir Wyville Thomson, by a further expedition in H.M.S. "Triton," in the summer of 1882, again under Murray and Tizard, which was very fruitful of zoological results. The discovery of two very different assemblages of animals living on the two sides of the Wyville Thomson ridge—Arctic forms to the North and Atlantic forms to the South—gives us a notable example of the effect of the environment on the distribution of marine forms of life. The results of the "Triton" expedition, written by a number of specialists, were published in the *Trans. Roy. Soc. Edin.* during the next few years, and attracted much attention to the subject.

Dr. Johan Hjort, the Norwegian oceanographer, referring some thirty years later to these expeditions, said *(The Depths of the Ocean,* 1912, p. 661): "In the history of oceanic research possibly nothing has contributed so much to the awakening of this interest as the discovery of entirely different animal communities living on either side of the Wyville Thomson Ridge. Atlantic forms occur to the south and Arctic forms to the north of the ridge, corresponding to the very different thermal conditions on either side."

During these few years after the "Triton" expedition, and when, in consequence of Sir Wyville Thomson's death, he was given complete charge of the "Challenger" Office, Murray came to occupy a more and more prominent position in the scientific world of the North. When we remember that his earlier fellow-workers and associates at the university were such men as Robertson Smith the theologian, Dittmar the chemist, Sir John Jackson the great contractor, and Robert Louis Stevenson; and his later friends, after the return of the "Challenger," were such men as Agassiz, Turner, Crum-Brown, Tait, Renard, Haeckel, Geikie, Blackie, Masson, Buchan, and Lord McLaren, we can understand the stimulating intellectual atmosphere he lived and worked in, and to which he doubtless contributed as much as he received.

We now come to a period of great local scientific activity, when Murray exercised a notable influence in the university scientific circle and took a leading part in every new movement. He was a prominent member of the Royal Society of Edinburgh, and of the Scottish Meteorological and Geographical Societies; he helped to establish the Observatory on the summit of Ben Nevis; and in 1884, along with his friend, Robert Irvine, of Caroline Park, on the shores of the Firth of Forth, he acquired the lease of an old sandstone quarry near Granton, into which the sea had burst some thirty years before, drowning the quarry and leaving it as a land-locked sheet of sheltered deep water which rose and fell with every tide. Here he moored a large canal barge, upon which he had built a wooden house, divided into chemical and biological laboratories, and which, for obvious reasons, he named "The Ark." Two little Norwegian skiffs were attached to "The Ark," one for the chemists and the other for the biologists, and on the opening day Dr. Hugh Robert Mill and I were invited to name them. He called his "The Asymptote," and I named the other "Appendicularia." Murray ridiculed our pretentious names, and said that in a few days the one would probably be called "the Simmie," or "the Tottie," and the other "Dick."

This floating biological station, after some years' work at Granton, was towed through the Forth and Clyde Canal to Millport, on the Cumbrae island, and there it was beached and became an annex of the Millport biological station. During the period when "The Ark" was at Granton, and later, Murray and Irvine turned out a good deal of joint work on the chemistry of the secretion of carbonate of lime by marine organisms, on the solution of carbonate of lime by the carbondioxide in sea-water, and on the chemical changes taking place in muds and other deposits on the sea bottom.

But his chief scientific work at this time and for years afterwards was the joint investigation at the "Challenger" Office of the enormous series of deposits (said to be over 12,000) which he and the Abbé Renard had accumulated from many expeditions and all seas. When one entered the little laboratory on the top floor of 32 Queen Street, after penetrating the dense cloud of tobacco smoke, the first thing one heard, rather than saw, was John Murray issuing some order or announcing some result; the next was the figure of the portly Abbé waving a courteous greeting with his perpetual cigar. Then there were the two assistants, Mr. F. Pearcey, who had himself, as a boy, taken part in the great expedition, and had been retained as assistant curator of the collections at the "Challenger" Office; and Mr. James Chumley, the secretary. Murray and Renard were hard at work at the microscope or at chemical reactions in test-tubes over Bunsen burners, Pearcey was preparing fresh samples to be examined, and Chumley was noting down results. There has probably never been in recent years such a small laboratory, so poorly equipped, which has turned out such epoch-making results. Everything absolutely essential was there, but nothing in the least extravagant. The place looked, with its plain boards and deal tables and sinks, more like an overcrowded scullery than an oceanographic laboratory.

But even in his busiest years at the "Challenger" Office Murray never gave up wholly his work at sea. He was a good hand at "roughing it" and making the best of circumstances, and no one could have had a greater appreciation of the open-air life. The practical work that he did, more or less periodically all the year round, on the west coast of Scotland, from his little yacht "Medusa," is a good example of careful planning and resolute carrying out.

It seems that while working at the results of the "Challenger" and other deep-sea expeditions, it occurred to Murray that for the purpose of comparison a detailed examination of the physical and biological conditions in the fjord-like sea-lochs of the West of Scotland might yield valuable information. He accordingly built a small steam-yacht of about 38 tons, called the "Medusa," fitted up with all necessary apparatus for dredging and trawling and for taking deep-sea temperatures and other hydrographic observations. This little vessel was, in fact, fully equipped for oceanographical investigations in the neighbourhood of land, and during the years 1884 to 1892 she was almost continuously engaged in exploring the deep sea-lochs of the Western Highlands. Various younger scientific men, such as Dr. W. E. Hoyle and Dr. H. R. Mill, were associated with Murray in this work; considerable collections were made, some of which are now in the British Museum, and many scientific papers contributed to various journals have resulted from the periodic cruises of the "Medusa." One of the most notable of these is H. R. Mill's detailed description of the oceanographic characters of the Clyde sea-area (1891–4). Another result was the discovery in the deeper waters of Loch Etive and Upper Loch Fyne of the remnants of an Arctic fauna—"boreal outliers" of Edward Forbes.

From time to time during these researches in the sea-lochs the "Medusa" penetrated to the fresh-water lochs, such as Loch Lochie and Loch Ness, which are united by the Caledonian Canal, and Murray was greatly impressed by the differences in the physical and biological conditions between the salt and the fresh-water lochs. This observation seems to have led to another of Murray's scientific activities, namely, the bathymetrical survey of the fresh-water lochs of Scotland, undertaken between the years 1897 and 1909. It was already known that, like some of the salt-water fjords outside, certain of these fresh-water lochs are of surprising depth. For example, 175 fathoms had been recorded by Buchanan in Loch Morar, and Murray, subsequently running a line of soundings along this loch, found at one spot a depth of 180 fathoms. No such depth is found in the sea outside on the continental shelf.

The survey was undertaken at first in collaboration with his young friend, Mr. Frederick P. Pullar, who was drowned in a gallant attempt to save the lives of others in a skating accident on Loch Airthrey in 1901. The results of the Lake Survey were published in a series of six volumes (Edinburgh, 1910), edited by Sir John Murray and Mr. Lawrence Pullar, and dedicated to the memory of Mr. F. P. Pullar, who had done much to initiate and promote the investigation in its earlier stages.

The work dealt with the determination of the depths of the lakes and of the general form of the basins they occupy, along with observations in other branches of limnography from the topographical, geological, physical, chemical, and biological points of view. Some important novel investigations, such as those on the temperature seiche and variations in the viscosity of the water with temperature, help to throw light on some oceanographical problems. In fact, the whole investigation, comprising 60,000 soundings taken in 562 lakes, resulted in very substantial contributions to knowledge, and is probably the most complete account of the depths and other physical features of lakes that has been published in any country.

It cannot be said that Murray ever finished his work on the west coast of Scotland, and I have evidence in a letter that he wrote to me late in life that he still thought of returning to the work. The passage is worth quoting, both for its scientific interest and for the kindly consideration which it shows. It is dated May 20, 1913, less than a year before his death:—

"... I am seriously thinking of overhauling all the 'Medusa' work on the west coast, and repeating a lot of these old observations for two years or more; then publishing a book on the lochs of the west coast. Would that in any way interfere with your work? I am being pressed by the Clyde people to do something of the kind.

"Could I afford it at present, I would be off to the Pacific in a Diesel-engined ship!!"...

During the years when he was working at the "Challenger" results and subsequently Murray published many papers in the *Geographical Journal* and in the *Scottish Geographical Magazine* and elsewhere, which deal with world-wide questions in oceanography or in physical geography, such as the annual rainfall of the globe and its relation to the discharge of rivers, the effects of winds on the distribution of temperature in lochs, the annual range of temperature in the surface waters of the ocean, and the temperature of the floor of the ocean, on the height of the land and the depth of the ocean (1888), and on the depths, temperatures, and marine deposits of the South Pacific Ocean (1906).

In 1897 Dr. John Murray (as he then was) formally opened the present Biological Station at Millport and the associated Robertson Museum, and delivered an address on the marine biology of the Clyde district. He continued to take a lively interest in the affairs of this West Coast Biological Station, and frequently looked in there with scientific friends when on his cruises in the "Medusa." I recollect, for example, an occasion when, after dredging in Loch Fyne, we ran to Millport for the night, and the party included Canon Norman, old Dr. David Robertson, Professor Haeckel, and Mr. Isaac Thompson. He frequently had foreign men of science as his guests, and was, I think, especially friendly with the Scandinavians, such as Nansen, Hjort, Otto Pettersson the Swede, and C. G. Joh. Petersen the Dane.

Murray's oceanographic work was not limited to any particular region or special series of problems, but was worldwide, both in extent and subject-matter. He was a great traveller, and had probably personally explored more of the oceanic waters of the globe than any other man. He had ranged from Spitzbergen in the North to the Antarctic Ice-barrier, dredging, trawling, tow-netting, and sampling the waters and bottom deposits in every possible way. Even when travelling as an ordinary passenger on a liner, he would engage emigrants in the steerage to pump water daily from the sea through his silk nets, or would arrange with a bath-steward to let the sea-water tap run through his net day and night in order that he might have living plankton to examine.

Murray was not only an investigator of special problems, but we owe to him much synthetic work, in which he gathered together the results of many observations and put them in the form of short conclusions or statistical statements. Some of these were published in the form of useful maps and charts, such, for example, as the map showing the 57 “deeps,” or parts of the ocean in which soundings of over 3,000 fathoms have been obtained. Most of these deeps (32) are in the Pacific, including the deepest soundings of all, which extend down to over six English miles.

At the meeting of the British Association held at Ipswich in September, 1895, a meeting of contributors to the “Challenger” reports was held, at which the then President of the Zoological Section (W. A. Herdman) presided, and about fifty biologists or oceanographers either attended or wrote expressing their concurrence in the objects of the meeting. It was then proposed and resolved “that this meeting of those who have taken part in the production of the ‘Challenger’ reports agrees to signalize the completion of the series by offering congratulations in some appropriate form to Dr. John Murray.” Eventually this congratulatory offering took the form of an address in an album, containing the portraits and autographs of all the “Challenger” workers, with an illuminated cover and dedicatory design by Walter Crane. This book was afterwards reproduced for the contributors in the form of a thin quarto volume, which forms a very interesting record of the completion of the work connected with the “Challenger” expedition.

Dr. Murray himself provided a very pleasing memento of the conclusion of the great work by having a handsome medal designed and struck, an example of which was presented to each of the authors of “Challenger” reports. The medal, in a bronze alloy, measures 75 mm. in diameter, and shows on the obverse the head of Minerva encircled by mermaids, a dolphin, and Neptune holding in his left hand the trident, and in his right the naturalist’s dredge, with the legend, “Voyage of H.M.S. ‘Challenger,’ 1872–76”; and on the reverse an armoured knight casting down his gauntlet in challenge to the waters—being the crest of H.M.S. “Challenger"—with the legend, "Report on the scientific results of the 'Challenger' Expedition, 1886–95." The name of the recipient of the medal is engraved on the lower margin.

After Sir Wyville Thomson's death, when Murray came to be recognized by the scientific world as the moving spirit in connection with all the "Challenger" work, and especially when the great series of publications was completed, honours of all kinds came pouring in upon him—for which he probably cared little. He was an honorary doctor of many universities, he was awarded the "prix Cuvier" medal by the Paris Academy of Sciences, and he was created K.C.B. in 1898. He gave the Lowell lectures at Boston in 1899, and again in 1911. He was chief British delegate at the International Congress for the Exploration of the Sea, at Stockholm, in 1899. He was President of the Geographical Section of the British Association in the same year; and it is an open secret that he might have been President of the Association had he been able to undertake it. He was approached no less than three times in connection with three different meetings (two of them overseas meetings, at which it was felt that a man of worldwide associations, such as Murray, would be singularly appropriate), but after some hesitation and careful consideration, he felt that circumstances compelled him to decline the honour. Some of his letters to me, from which I quote a few passages, allude to these offers.

This is a letter from Mentone, on April 1, 1904, referring to the first of these occasions:—

"... At first, I said it was impossible to alter our family and other arrangements so as to go to South Africa.... To my astonishment, my wife seems taken with the idea of going to the Cape, and says it is by no means impossible to alter our arrangements. I've promised to think over the matter for a week. I'll let you know definitely a day or two after I reach Edinburgh.

"I feel that you are predisposed to honour me, but I also feel I have given the Association very little of my attention:

others have more claims on the honour. I don't care a bit about it. If I consult my own feelings, I would much rather have nothing to do with it. My wife suggests there may be some question of duty. Perhaps? I had not heard you had taken on the General Secretaryship." . . .

In a letter from Boston, U.S.A., he writes on March 20, 1911:—

"... On Saturday I received your letter of the 3rd March. By same post had letters from Geikie and Bonney. Had I been at home, I would of course have seen you before sending any reply, but I am not likely to be in England before June.

"... To-morrow I deliver the Agassiz address at Harvard. I came over for that address, but have been let in for the Lowell lectures (eight) and addresses here [Boston], Princeton, New York, and Washington. We go to Washington next month. . . .

"During the last two days I've had frequent deliberations with my wife and daughter, who are with me, and the only way out seemed to be to decline the nomination. For some time past I have been planning a cruise as far as the Pacific during 1912 and 1913, and I have made a good many business and domestic arrangements with that object in view. It must take place in these years or not at all, and if my health be good I cannot well withdraw.

"I know your enthusiastic nature and your too favourable opinion of my poor labours. I know you like to do me honour. For these reasons I very much regret the nature of the cables I have just sent off to you, Bonney, and Geikie. I am anxious to do anything to assist the progress of oceanography, but I fear my presidentship of the British Association would not do much in that direction. However, it is very good and nice of you to say you think it would. I find many enthusiastic young workers here, and I believe there will likely be a ship fitted out for a deep-sea expedition in 1912. They wish to consult me at Washington and New York about this.

Townsend is now away in the ‘Albatross,’ off the Pacific coast. They invited me to go with them, also to go to the Tortugas Station, where some very interesting work is going on.” . . .

This further letter refers to the same occasion. It is from Washington, D.C., April 19, 1911:—

“. . . I duly received your letter of the 20th. I have not replied at once, especially as I had written to you when I sent off my cable, and I had also cabled and written to Bonney and Geikie. I have not changed my mind about the presidency. I cannot see my way to accept. I am very sorry, for I would willingly do very much to please you and my other friends on the Council. I also believe that some scientific man less known locally would be more agreeable to the Dundee people.

“You will see from the enclosed cutting that they have been doing us much honour here. There was a dinner in our honour last week, about seventy-five scientific men here and their wives. The British Ambassador and his wife were present. Taft accepted, but sent an excuse at the last minute.

“. . . We go to Philadelphia to-morrow to meetings of Philadelphia Academy. Then to New York. Osborn is to have 14 millionaires to hear me at the Museum as to what they should do for the study of the Ocean!! May it have some effect!

“On the 26th we start for the West to see rocks and mines in Nevada. We sail from Boston on the 30th May.

“With my very best thanks to you for all your endeavours to honour me, and to cultivate an interest in oceanography.”

The following letter of November 12, 1912, refers to the final occasion. He was killed before the meeting in question took place:—

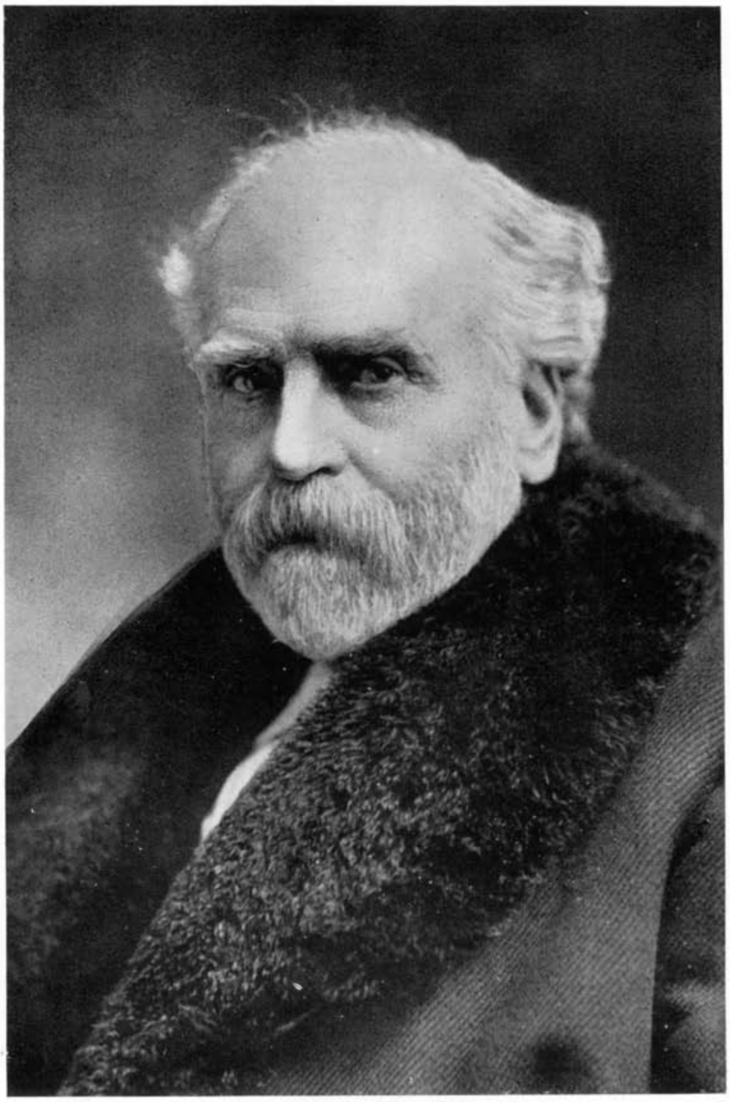
“. . . I shall not refuse at once. I’ll consult with my wife. All the same, I do not think it is the sort of thing for a man over seventy. I’m very well just now—have been for the past three months shooting over the moors nearly every day! Some people say even that I am a wonder! but who can tell what I'll be like in two years. Men over seventy years are likely to break down, then what a nuisance I would be to every one!

"I would, of course, appreciate the honour, but honours are not worth much to an old man. The only question would be, a real service to Science, and would it be a duty. At my age it can hardly be a duty. I have no message to give to the world! I honestly think some young scientific man would do the trick very much better. I'll consider it. I'll be in London, Piccadilly Hotel, the first ten days of December, and could perhaps see you.

"I really very much appreciate your desire to honour me. It is really very good of you. It is not quite out of the possible that I may be in the Pacific in 1914 in a boat of my own. I would have been there now had the cost not been much greater than I, at first, calculated."

At the inauguration of the new Zoological Laboratories of the University of Liverpool in November, 1905, Sir John Murray was one of the honoured guests of the university, and after the formal opening by the Earl of Onslow, Sir John gave a short address upon oceanography, the first lecture to be delivered in the zoology lecture theatre of the university. A few years later, in 1907, the university conferred upon him the honorary degree of Doctor of Science.

We now come to Sir John Murray's last great scientific expedition—a four months' cruise in the North Atlantic, in the summer of 1910—a very notable achievement for a man in his seventieth year. The investigating steamer "Michael Sars" was built by the Norwegian Government in 1900, on the lines of a large high-class trawler of about 226 tons, but specially fitted out for scientific work under the direction of Murray's friend, Dr. Johan Hjort. At Murray's request this vessel was lent, with her crew and equipment, by the



SIR JOHN MURRAY.

Norwegian Government for the North Atlantic cruise, Sir John Murray undertaking to pay all the expenses. The scientific reports on the expedition will be published in a series of volumes by the Bergen Museum; but the more general results have appeared in popular form in a volume entitled *The Depths of the Ocean* (Macmillan, 1912), by Murray and Hjort, with contributions by several other naturalists, which gives a condensed account of the modern science of oceanography, with special chapters on the latest discoveries, based largely upon the experiences of this North Atlantic cruise taken along with the previous cruises of the "Michael Sars" in the Norwegian seas.

Amongst noteworthy matters that are discussed in this volume we find:—

> "(1) Methods of plankton collecting, including the towing of as many as ten large horizontal nets, at various depths, simultaneously. The pelagic plants collected, either in the nets or by centrifuging the water, are discussed in a notable chapter by Gran.
>
> "(2) The "Mud-line," a favourite subject with Murray, as being the great feeding-ground of the ocean. He places it at an average depth of 100 fathoms, on the edge of the "Continental-shelf," at the top of the "Continental-slope," which descends more or less precipitately to the floor of the Atlantic at an average depth of 2,000 fathoms. We know from Murray's careful estimations that, if all the elevations of the globe were filled into the depressions, we should have a smooth sphere covered by an ocean 1,450 fathoms deep. The floor of this ocean is the "mean sphere level."
>
> "(3) Dr. Helland-Hansen, the physicist on board the "Michael Sars," had devised a new form of photometer, which registered light as far down as 500 fathoms in the Sargasso Sea. At between 800 and 900 fathoms, however, no trace of light was registered on the photographic plates, even after two hours' exposure. The observations show that light in considerable quantity penetrates to a depth of at

> least 1,000 metres (547 fathoms), which is much deeper than had been previously supposed. It was shown that the red rays of light are those that disappear first, and the ultra violet are those that penetrate most deeply.
>
> "(4) A special study was made on the "Michael Sars" of the characteristic colour of the fishes in various zones of depth. In the superficial layers of the ocean small colourless or transparent forms abound, forming a part of the wellknown pelagic fauna. Below this, at an average depth of about 200 fathoms, are found fishes of a silvery and greyish hue, along with red-coloured Crustaceans. At depths of from 500 fathoms downwards black fishes make their appearance, still associated with red Crustaceans and other strongly coloured red, brown, or black Invertebrates. This chapter is illustrated by some beautiful coloured plates of the fishes.
>
> "(5) Lastly, the "Michael Sars" got important evidence in support of the view that the fresh-water eel spawns south of the Azores, and that the larvæ are carried by currents back to the coasts of North-west Europe.

In 1913 Murray published in the Home University Library a small book of about 250 pages, entitled *The Ocean: A General Account of the Science of the Sea,* which is undoubtedly the most concise and accurate and, so far as is possible within its small compass, complete account that has yet appeared of all that pertains to the scientific investigation of the sea. It is written in simple language for the general reader, and is probably the best introduction to oceanography that can be recommended to the junior student or the intelligent non-specialist inquirer who desires information merely as a matter of general culture. It deals with the history, methods, and instruments of marine research, the depths and physical characters of the ocean, the circulation of the waters, life in the ocean, submarine deposits, and finally the nature and relations of the various "Geospheres" that constitute the globe. Coloured maps and plates illustrate depths, salinities, temperatures, currents, deposits, and many of the characteristic plants and animals of the plankton and of the "oozes." As Murray's final contribution to science it is an appropriate summary of his life-work, and will do much to spread the knowledge of his discoveries and to make his name widely known amongst intelligent readers of popular works on science.

If I try now to give a personal impression of John Murray as I remember him in earlier life, I picture him as a short, thick-set, broad-shouldered man, with a finely shaped head and very forcible-looking blue eyes under rather shaggy eyebrows. His hair was fair, somewhat reddish on the whiskers and moustache. Later in life, when his hair was turning white, he wore a closely-clipped beard. It was a strong, determined-looking face, with those arresting eyes, making him a noticeable and dominant figure in any assembly. But the eyes could dance with fun on occasions, and his good Scot's tongue was kindly as well as outspoken. He remained sturdy and energetic to the last, although he was seventy-three years of age a few days before the motor accident in which he was instantaneously killed on March 16, 1914.

John Murray was a man of upright character and of downright speech. He was apt to tell you what he thought of you, or anyone else, in plain and emphatic language without fear or favour. Some people of more conventional habits may have been shocked or offended at times; but the better one knew him the more one came to appreciate and admire his transparent honesty of thought and speech, his most uncommon "common sense," his purity of motive and directness of purpose, and his genuine kindness and good-heartedness, especially to all the young scientific men who worked with or under him, and whom he in large measure trained. He was absolutely free from all guile and humbug of any kind, and had no sympathy with intrigue or vacillation.

I may appropriately conclude this short account of John

Murray's life and work with a few sentences quoted from an appreciation *(Nature,* 1914, p. 89) by his old friend, and former teacher, Sir Archibald Geikie:—

"Sir John Murray's devotion to science and his sagacity in following out the branches of inquiry which he resolved to pursue, were not more conspicuous than his warm sympathy with every line of investigation that seemed to promise further discoveries. He was an eminently broad-minded naturalist to whom the whole wide domain of nature was of interest. Full of originality and suggestiveness, he not only struck out into new paths for himself, but pointed them out to others, especially to younger men, whom he encouraged and assisted. His genial nature, his sense of humour, his generous helpfulness, and a certain delightful boyishness which he retained to the last, endeared him to a wide circle of friends, who will long miss his kindly and cheery presence."

CHAPTER V
LOUIS AND ALEXANDER AGASSIZ AND AMERICAN EXPLORATIONS

The “Challenger” expedition was a national undertaking, and it was followed in the last quarter of the nineteenth century by a number of other less extensive but still important national explorations, such as the “Tuscarora” (United States), “Travailleur” and “Talisman” (French), “National” and “Valdivia” (German), “Vettor Pisani” (Italian), “Ingolf” (Danish), and “Siboga” (Dutch), all of which supplemented in one direction or another the fundamental discoveries of the British expedition.

In addition to these, various unofficial explorations, due to the enterprise of private oceanographers, began to make notable contributions to science, and of these men two may be selected as outstanding examples, on account of the extent and importance of their work and of their personal devotion to the subject; these two are Alexander Agassiz, of the United States, and H.S.H. Albert I, Prince of Monaco.

There are two Agassizs well known in the history of science, Louis and Alexander, father and son, and both made contributions to our knowledge of the sea. It is true that Louis Agassiz is better known from his other work in zoology and from his fame as a teacher of natural science at Harvard; but in addition to his pioneer marine work on the eastern coasts of the United States, we must remember the influence he exercised upon his assistants and students, including his distinguished son, and the inspiration and direction he gave to marine biological exploration in the land of his adoption. Consequently, I have no hesitation in claiming him also as a pioneer of oceanography.

It has been said of the two Agassizs that the father and son were very unlike in character and essential nature, and that is no doubt true to some extent. Louis was an enthusiast and was pre-eminently a great teacher and public expositor. Alexander was a quiet, reserved man, the typical student and investigator, who did not care for teaching and avoided publicity. But still, in considering their lives and the work they did, it is possible to trace some common characteristics. Both were great collectors all their lives, and between them they built up at Harvard a notable museum of an original character. Both also were indefatigable in seeking out the truths of nature, in accumulating facts rather than in spinning theories. Louis, in speaking of Oken and the nature-philosophers of his student days in Germany, who were “constructing the universe out of their own brains,” said, “He is the truest student of nature who, while seeking the solution of these great problems, admits that the only true scientific system must be one in which the thought, the intellectual structure, rises out of and is based upon facts”; while Alexander, half a century later, speaking of theories of coral reefs, said, “I am glad that I always stuck to writing what I saw in each group and explaining what I saw as best I could, without trying all the time to have an all-embracing theory”; and Murray, in the same connection, remarks of him, “He professed never to engage in discussions except where it was possible to verify one’s conclusions by an appeal to observation or experiment.” Thus we see the same dependence upon facts and avoidance of theories in both men.

Louis Agassiz, a Swiss, was born in 1807 in a small village, near Neuchâtel, in the Canton de Vaud. His education consisted first of a school at Lausanne, then at the Medical School of Zurich, and finally the universities of Heidelberg and Munich, where, like Edward Forbes at Edinburgh, he became a leader of a body, called the "Small Academy," of the more intellectual of his fellow-students, several of whom became distinguished scientific men afterwards, but who at that time were known in their own society by nicknames such as "Molluscus," "Cyprinus," "Rhubarb," etc. While still a student he started original investigations on the fresh-water fishes of Central Europe and on the fishes collected by Martius and Spix in Brazil; and before he was twenty years of age he had already engaged two young artists to draw his specimens and another assistant to help him in dissecting them, and he kept up that practice throughout all his earlier struggling years as a student and a young scientific man in Europe. One of his artists, called Dinkel, who remained with him for about sixteen years, generally shared his room, and we are told that they used the same vessel to make their coffee in the morning, to contain specimens in process of maceration as skeletons during the remainder of the day, and then, being temporarily emptied of its scientific contents, to make tea in for their evening meal. Professor Agassiz's widow, writing of these early days, says:[1] "He was of frugal personal habits; at this very time, when he was keeping two or three artists on his slender means, he made his own breakfast in his room, and dined for a few cents a day at the cheapest eating-houses. But where science was concerned, the only economy he recognized, either in youth or old age, was that of an expenditure as bold as it was carefully considered." On one vacation, when he proposed to come home to the small Swiss parsonage, at that time much overcrowded because of the impending marriage of one of his sisters, he wrote telling them of all the things he was going to bring with him for work during the vacation, collections and so on, including one of his artists, to which his father writes back: "By all means bring them all *except your painter.*" But when he arrived the painter was with him, and had to be accommodated somehow.

[1] *Louis Agassiz,* edited by Elizabeth Cary Agassiz, London, 1885.

Agassiz himself, talking of these days, said: “I kept always one and sometimes two artists in my pay; it was not easy, with an allowance of $250 (£50) a year, but they were even poorer than I, and so we managed to get along together. My microscope I had earned by writing.” In this way he took both a Ph.D. and an M.D. degree, and at the same time produced important treatises on both fresh-water and fossil fishes, which brought him into correspondence with the great French comparative anatomist Cuvier, with Humboldt and others.

In 1832, when twenty-five years of age, he was appointed to a newly established Chair of Natural History at Neuchâtel, the salary of which was about $64 a year! On this, the following year he married the sister of one of his fellow- students, and his wife, we are told, made some of the best drawings which illustrate his celebrated work on fossil fishes. His grandson, G. R. Agassiz,[1] writes: “The salary of Louis Agassiz was entirely insufficient to support his family and publish his scientific works. By 1846 he had exhausted the resources of his relatives, friends, and, indeed, the entire little community of Neuchâtel, who came generously to his assistance. He gladly, therefore, accepted a subsidy from the Prussian Crown, obtained through the influence of Humboldt, to make a scientific exploration in the United States.” This was the turning-point of his life, and opened up a career of extraordinary success. Previous to migrating to the United States, he had, however, made important visits to Paris, where he was befriended by the great comparative anatomist, Cuvier, then nearing the end of his career, and Humboldt, the great traveller; and to England, where he met Lyell, Buckland, Sedgwick, and other geologists, and incidentally received a grant from the British Association towards the expenses of the interesting work which he, with some of his friends and students, had started on the nature,

[1] *Letters and Recollections of Alexander Agassiz,* edited by G. R. Agassiz, London, 1913.

movements, and former extension of the glaciers in Switzerland.

In 1846 he went to America, leaving his son Alexander at school in Switzerland, and his wife and two young daughters with her brother, who was then a professor at Karlsruhe. He gave a course of Lowell lectures at Boston, and became at once a tremendous success as a popular expositor of all the natural history sciences and a great influence, not merely in the university circle at Harvard and amongst the intellectuals of Boston, but even amongst the hard-headed New England business men. He was extraordinarily enthusiastic and energetic, not merely in giving courses of lectures at various centres in the Eastern States, but also in making important scientific investigations wherever he went, beginning with the study of successive upheavals of the coast near Boston, the geographical distribution of marine animals and their relation to the Tertiary fossils, and the investigation of many groups of animals both on land and sea.

From 1847 onwards the hospitality of the U.S. Coast Survey vessels seems to have been constantly open to him, and thus his influence on oceanography began. Under no other Government probably could he have had opportunities so valuable to a naturalist, and probably no Government ever got a better return for friendly co-operation with men of science. Louis Agassiz had intended merely to pay a visit to the States, give his Lowell lectures, and then return to Switzerland, but one engagement at Boston led to another, to delay his return. The following year, 1848, he was offered a newly established Chair of Natural History at Harvard, at a salary of £300, and in that post he remained to the end of his days. He began to accumulate what is now the celebrated Museum of Comparative Zoology, housed at first in an old wooden shanty set on piles on the bank of the Charles river, and it was not until ten or twelve years later that the university commenced to build for him the present great University Museum at Cambridge, Massachusetts, which displays the wonderful collections made by both Louis and Alexander Agassiz as the result of their many expeditions.

In the meantime his wife in Switzerland had died, and shortly afterwards he brought his son Alexander, then a youth of thirteen, to join him at Boston. His grandson, writing of this time, says: “Professor Agassiz’s little house in Oxford Street must surely have seemed a strange home to the small foreigner. The household, besides the father, consisted of a dear old artist, Mr. Burkhardt, a young Harvard student, Mr. Edward King, an old Swiss minister called ‘Papa Christinat,’ who was supposed to look after the housekeeping, a bear, some eagles, a crocodile, a few snakes, and sundry other live stock. These last enlivened the home life in various ways. Sometimes there was a wild chase to capture the eagles, or a hunt to discover in what corner of the house the snakes had hidden themselves. Once, when there was a large party at dinner, an uncertain and heavy tread was heard upon the cellar stairs, and Bruin, having broken his chain, and broached a cask of wine, lurched into the room.” A year afterwards, however, Agassiz married Elizabeth Cary, of Boston, who seems to have reduced chaos to order and taken charge of the erratic professor and his children and eventually the grandchildren, in the most admirable and loving manner, which Alexander Agassiz repaid by taking affectionate care of her for many years after his father’s death.

Louis Agassiz now became an oceanographer. His important investigation of the Florida Reefs and Keys on behalf of the Coast Survey took place in 1851. The peninsula of Florida he made out to be formed by a succession of concentric reefs, separated by deep channels, the older of which have become silted up to form the well-known “Everglades”; while the Tortugas show a real atoll, but formed without the remotest indication of subsidence. He remarks further in his report that “one of the most remarkable peculiarities of the rocks in the reefs of the

Tortugas consists in their composition; they are chiefly made up of corallines, limestone algæ, and, to a small extent only, of real corals." This is a matter which has been rediscovered since by many investigators of coral reefs in various parts of the world, but Louis Agassiz was, I think, the first to notice the important fact that so-called coral reefs are not always formed of coral.

At this time, about 1855, we are told *(Letters, &c., of Alexander Agassiz)* that "his father's affairs, notwithstanding the fostering care of the son, were in a more than usually deplorable muddle shortly after Alexander Agassiz left college. Louis Agassiz possessed but a hazy idea of the value of a dollar, and the modest funds of the household budget had an alarming way of converting themselves into alcoholic specimens at the most inopportune moments." So in order to retrieve the family fortunes, Mrs. Agassiz and her stepson Alexander resolved to start a school for girls in the upper part of their house at Harvard, which at once became an unqualified success. "It became *the* girls' school of its day; special omnibuses brought the pupils out from Boston; while parents in other parts of the country made arrangements for their daughters to live in the neighbourhood, that they might enjoy its special advantages." Agassiz himself gave a daily lecture to some sixty or seventy girls, and remarked enthusiastically: "We will teach the girls everything but mathematics, and the poor things can learn that almost anywhere else." His son, however, who was an excellent mathematician, attended efficiently, no doubt, to that branch of their education. This school flourished for about eight years and was then closed, as the improved finances of the family made it no longer necessary.

About 1860 Harvard commenced the building of what is now the magnificent Museum of Comparative Zoology, for the purpose of containing Professor Agassiz's rapidly increasing collections. In the first endowment given for this purpose it was stated as a condition that the museum was to be called by no other name than the "Museum of Comparative Zoology," but this decision, although officially adhered to, has been defeated by popular acclaim, as the museum is known in Harvard, and probably amongst most scientific men all over the world, as the "Agassiz" museum.

In 1865 Louis Agassiz organized an important expedition to Brazil, largely in the interests of the museum, and in 1870, along with his friend Count de Pourtalès, who had followed him from Europe, he undertook his last cruise in the Coast Survey steamer "Bibb," on which he conducted important deep-sea surveying and dredging in the region of the West Indies, and amongst other oceanographic results pronounced in favour of the permanence of the great ocean basins. In the following year, 1871–2, he conducted an extensive dredging cruise on the "Hassler" round the whole of the South American coast from Florida to San Francisco. Incidentally, it may be remarked that some of their deepest and possibly most interesting hauls were lost, it is said, through the rottenness of the towing-ropes due to damp. Alexander Agassiz, in the many expeditions in which he continued and extended the work of his father, avoided this difficulty by introducing the use of wire rope for dredging purposes.

We now come to the last episode in the life of the old professor. In 1873 a New York merchant, Mr. John Anderson, reading accidentally a report in an evening paper of an address by Agassiz setting forth the advantages that would result in the training of young biologists from the establishment of a marine laboratory, wrote offering for the purpose the island of Penikese, at the mouth of Buzzard's Bay, off the New England coast, with its existing buildings, and a sum of $50,000 for the purpose of converting these and equipping them for the required purpose. This offer was made in the early summer, and by July 8, as the result of strenuous endeavour and a combined effort on the part of the professor, his students and the workmen, the buildings were converted, furnished and equipped, and were opened for the

PLATE VII.

PROFESSOR LOUIS AGASSIZ.

accommodation of a summer school of marine biology, attended by about fifty students, many of whom were teachers of science in various parts of the country. Agassiz lectured, assisted by several other younger biologists, throughout the summer, and conducted all the operations with great enthusiasm. But it was his last effort. His health was failing rapidly, and he died towards the close of that year (1873).

Now we must turn attention more closely to the son, Alexander Agassiz, who may truly be said to have devoted his life and fortune to marine exploring expeditions.

Shortly after the time when Alexander Agassiz arrived as a boy in the United States, he was taken by his father for a voyage in the "Bibb," one of the Coast Survey vessels. This was his first, and we are told that it seemed very likely to be his last, experience of oceanic exploration, for after coming on board he fell down a hatchway and was laid out apparently dead in the saloon. However, he soon recovered, and afterwards made many successive voyages in Coast Survey vessels, notably the "Blake" and the "Albatross," and also in other special steamers which he chartered for his expeditions. His voyages covered more than 100,000 miles in tropical seas, and it has been said that he personally has run more lines of investigation across the great oceans and has made more deep-sea soundings than all other oceanographers taken together. His first expedition in the "Blake" was in 1877, when he had with him, as commander, Captain C. D. Sigsbee, who was afterwards in charge of the ill-fated "Maine," the exciting cause of the outbreak of the war with Spain.

Agassiz's knowledge and experience as a mining engineer were of the greatest value on board the "Blake" in devising improvements in the apparatus for deep-sea work. He substituted steel-wire rope for dredging in place of hemp, and invented mechanical contrivances for equalizing the strain and facilitating the hoisting in of the apparatus. He and Captain Sigsbee together devised a new form of double-edged dredge, generally known as the “Agassiz” or the “Blake” dredge or trawl, which will work equally well whichever way it falls on the bottom; and also a very ingenious closing tow-net (called the “gravitating trap ”), which could be lowered to any depth, opened and towed, and then closed again, so that it was possible to strain the plankton or minute organisms from a column of water of any given length at a particular depth. As the result of experiments with this apparatus, they were unable to find any planktonic organisms in the region investigated below 100 fathoms from the surface. These, and other later investigations with the “Tanner” closing tow-net in the “Albatross,” led Agassiz to believe that, between the plankton fauna living at or near the surface, say down to 200 fathoms, and that on or near the bottom, there was a vast region where practically no life existed. This theory (the non-existence of a mesoplankton), with some modifications as to the extent of the upper zone of life (he defined it later on, after experiments with the “Tanner” net in the “Albatross,” as “a marked falling off below 200 fathoms”), Agassiz maintained to the end of his days in opposition to most other oceanographers, including his friend Sir John Murray. It was during the successive voyages in the “Blake” that Agassiz was able to add to our knowledge of that great warm current the Gulf Stream, from the Strait of Florida to the Newfoundland Banks, and, as the result of this and later work, to show the connection between ocean currents and an abundant surface plankton and the dependence of the bottom fauna upon the plankton.

It is interesting to note as the climax of Alexander Agassiz’s connection with the Coast Survey that in 1885 President Cleveland offered him the position of superintendent of the whole of that work and Scientific Adviser to the Government. However, considerations of health and of the probable sacrifice of his own scientific work which would be necessary, caused him to refuse what must have been in some ways a very tempting offer. There is no doubt that he gave much scientific service in hydrographic work for the U.S. Coast Survey, in charting the seas of both the Atlantic and Pacific shores of his adopted land.

Although trained as an engineer, there is no doubt that even in his younger days, when working at his profession, his heart was really in marine biology, and he made notable contributions to embryology and morphology quite apart from his constant museum work at Harvard and his later oceanographic expeditions. His memoirs on the *North American Acalephæ,* on the *Embryology of the Star-Fish* and his *Revision of the Echini* established his position as a firs-trate zoologist. He discovered the relation of the "Tornaria" larva to the chordate *Balanoglossus,* the larval stages of various Annelids, the pelagic young of certain fishes, the fact that the pincer-like pedicellariæ of Echinids are modified spines, and many new deep-sea animals, all before his fortieth year.

Upon the death of his father in 1873 he undertook the direction of the marine biological laboratory which had just been established on Penikese Island, but after running it, with the valued assistance of Packard and Putnam, for one succeeding year, he found that the strain was more than his health could stand, and, consequently, as that isolated island was in many ways inconvenient for the purpose, he was led to abandon that first American marine station and erect a private laboratory beside his house at Castle Hill, near Newport, Rhode Island, which, for the next quarter of a century, was an active centre for a small body of the leading younger biologists of America. The Newport laboratory was finally closed to students in 1898, when its place was taken by the now celebrated marine laboratory and the Fish Commission Hatchery at Woods Hole, near the junction of Buzzard's Bay and Vineyard Sound.

Another piece of work which Alexander Agassiz took over on the death of his father in 1873 was the direction of what is now one of the great museums of the world, and to which during his life time he gave a million and a half of dollars and devoted nearly fifty years of service. As a boy he had seen it housed in a ramshackle wooden shed and then grow in his father's hands to something like what it eventually became, and as an old man he left it after one of his last endowments practically complete as to the scheme and arrangement and exhibiting, as no other museum in the world does, the geographical and oceanographical distribution of animal life. At the time of his death, in 1910, the museum had published fifty-four volumes of its *Bulletin* and forty volumes of the larger *Memoirs,* for the most part at the expense of Mr. Agassiz.

In addition to all his scientific work it must be remembered that Alexander Agassiz was a highly successful man of business. He had been trained at the university as a mining engineer, and as a young man he took over the management of the Calumet and Hecla copper-mines, on the southern shore of Lake Superior, which were then in a desperate state. These are remarkable mines in this respect, that the metal occurs not as an ore, but in the form of native copper. By his engineering knowledge, his business ability and his indomitable perseverance he managed to overcome great difficulties and convert an enterprise that seemed doomed to failure into a great financial success. He was president of this very important mining company up to the time of his death in 1910.

The hardships he endured during many winter months in the wilds, while seeing his mines through their early troubles, brought on a severe illness (1868) from which, it is said, he never completely recovered. In his convalescence the liberality of a Boston friend enabled him to realize a long-wished-for opportunity of visiting and examining the collections of Echinoderms in European museums, and of becoming personally acquainted with the British naturalists then engaged in oceanographical work, and especially in deep-sea exploration. He visited Wyville Thomson in Belfast in order to see and hear about the results of the "Lightning" and "Porcupine" expeditions. After this visit, it seems that Wyville Thomson "had written to Agassiz complaining that he had lost or mislaid some deep-sea specimen, and Agassiz jocularly replied from London assuring him that he had 'taken nothing away from Ireland except a bad cold.'"

Returning now to the consideration of his oceanographical work, his book *The Three Cruises of the "Blake"* gives in popular form the general results of all his voyages in the "Blake" from 1877 to 1880, illustrated by 545 maps and figures of the remarkable inhabitants of the cold dark floor of the deep sea and of many of the most interesting forms of the surface plankton of the Gulf Stream and the West Indies. The value to science of the 355 deep-sea observations made on the Atlantic coasts of the United States may be gathered from the following statement by Sir John Murray:

"If we can say that we now know the physical and biological conditions of the great ocean basins in their broad general outlines—and I believe we can do so—the present state of our knowledge is due to the combined work and observations of a great many men belonging to many nationalities, but most probably more to the work and inspiration of Alexander Agassiz than to any other single man. Agassiz's researches in the Atlantic resulted in very definite knowledge concerning the submarine topography of the West Indian region and of the animals inhabiting these seas at all depths—probably we know more of this submarine area than of any other area of equal extent in the world because of his explorations. He arrived at the general result that the deep-sea animals of the Gulf of Panama were more closely allied to those in the deep waters of the Caribbean Sea than the Caribbean forms were to those of the deep Atlantic. Hence he concluded that the Caribbean Sea was at one time a bay of the Pacific Ocean, and that since Cretaceous times it had been cut off from the Pacific by the uprise of the Isthmus of Panama."

This conclusion, it may be added, is in close agreement with the later discoveries of geologists as to the movements of land and sea in Central America.

His later, and more specially oceanographic, expeditions were primarily devoted to the exploration of coral reef problems. After the death of his father, closely followed by that of his young wife, in 1873, he spent much time in travel abroad, and it was apparently during a visit to the "Challenger" Office at Edinburgh, in 1876 or 1877 (when I, then a young student of zoology, first saw him), that he became interested in Murray's work on the building up and the breaking down of calcareous deposits in tropical seas, and especially in relation to the mode of formation of coral reefs. The situation at that time, or at any rate the views held at the "Challenger" Office and which excited Agassiz's interest, are summarized in the following quotation from Murray's obituary notice of his friend, published in the *Bulletin of the Museum of Comparative Zoology,* vol. 54, 1911.

I shall discuss the various theories as to the growth of coral reefs and islands more fully in a later chapter, but this will be sufficient to indicate the object and the bearing of Agassiz's contributions to the subject as the result of his many expeditions in coral seas. Murray says:—

"One of the most striking results of the 'Challenger' expedition was the discovery of enormous numbers of pelagic calcareous Algæ, pelagic Foraminifera, and pelagic Mollusca in the surface and sub-surface waters everywhere within tropical and sub-tropical regions, but the dead calcareous shells of these pelagic organisms were not distributed with similar uniformity over the floor of the ocean. In some places they formed pteropod and globigerina oozes, but in the very greatest depths not a trace of these shells could be found in the red clays which covered the bed of the ocean. It was observed that the thinner and more delicate shells disappeared first from the marine deposits with increasing depth, and only the thicker and more compact shells or their fragments reached the greater depths. These conclusions were verified again and again during the cruise of the 'Challenger,' and subsequently by Agassiz in his expeditions. Evidently the calcareous shells were removed by the solvent action of sea water as they fell towards, or shortly after they reached, the bottom of the ocean. In the shallower depths the majority of the shells reached the bottom before being completely dissolved, and there accumulated. The solvent action was also retarded, in these lesser depths, through the sea water in direct contact with the deposit becoming saturated, and therefore unable to take up more lime. The explanations thus given to account for the disappearance of carbonate of lime from deep-sea deposits were then applied to the interpretation of the phenomena of coral atolls and barrier reefs. It was argued that all the characteristic features of atolls and barrier reefs could be explained by a reference to the biological, mechanical, and chemical processes everywhere going on in the ocean without calling in the extensive subsidences demanded by the theories of Darwin and Dana."

Alexander Agassiz's examination of the coral growths on the coast of Florida in his first cruise in the "Blake," supported by what he had seen of the "Challenger" results, excited an interest which lasted during the remainder of his life, and gave rise to many special expeditions for the purpose of exploring reefs in all parts of the tropical seas. It may be said that the last thirty years of his life were given over to the investigation of coral reef problems. He devoted himself to accumulating facts, and was on all occasions averse to committing himself to theoretical views. He certainly held that the explanations given by Darwin and Dana of the formation of an atoll could only be of limited application, if even that. And there is no doubt that, as the result of his unrivalled experience, he is to be reckoned as a supporter in the main of Murray's theory. When he first heard of it he said, "This new view is founded on observation and can be verified, and I'll attempt to do it, and will visit the coral-reef regions for the purpose "; and he certainly explored and described and illustrated with much photographic detail every important coral-reef region in the tropical Atlantic, Pacific and Indian Oceans. When, in 1903, he gave an address to the Royal Society of London on the subject, he stated in the discussion that in all his investigations and voyages he had not seen one single atoll or barrier reef which could be said to be an illustration of the Darwinian theory of coral reefs.

According to Sir John Murray[1] Agassiz claimed to have shown (1) that existing atolls and barrier reefs in no way indicate the former position of shore-lines around islands now deeply submerged; (2) that the platforms or banks from which atolls and reefs arise have been built up or levelled down in a variety of ways and at different times, each coral-reef region requiring to have its special conditions studied, as no general law applies to all; (3) that the characteristic features of the atoll, the single shallow lagoon and the surrounding rim of living coral with deep water outside, can be explained by biological, chemical and mechanical activities continuously in operation at the present time, and that therefore the atoll and the barrier reef cannot be accepted as evidence of subsidence; the characteristic features of these reefs might bedeveloped in a stationary, and in a slowly rising, as well as in a slowly sinking area; (4) that the coral atoll on reaching the surface would, under certain conditions, advance seawards on a talus of its own debris, expanding like a "fairy ring" in grass, and his interpretation of the Funafuti boring was that it was driven down through such a talus with an underlying tertiary base.

As he returned from each of his expeditions with the result

[1] *Bull. Mus. Comp. Zool.* Harvard, vol. 54, 3, 1911.

that he had been unable to find any traces of subsidence, his opponents retorted that the region he had been investigating must be an exceptional one. This occurred so frequently that his long-continued exploration of the tropical seas may be described as an exhaustive and fruitless search for a *typical* coral reef. After his visit to the Maldives in the Indian Ocean in 1901, his son writes: "Agassiz had now visited practically all the important coral-reef regions of the world, and in no single instance had he seen an atoll or barrier reef whose formation he thought could be satisfactorily explained by subsidence. It naturally followed that his final conclusion was a total dissent from Darwin's theory on the subject."

Professor Stanley Gardiner had visited the Maldives just before Agassiz, and it is important to note that in all essential respects they are in accord, and both have decided that "Darwin's theory is not applicable to the Maldives."

The late Dr. A. G. Mayer, formerly Director of the Carnegie Institute Research Laboratory on the Tortugas, who had been with Agassiz on several of his expeditions, writing of his coral-reef explorations, says: "I believe science will come to see that he succeeded in showing that Darwin's simple explanation of the formation of atolls does not hold in any part of the world."

It was during Agassiz's Maldive trip in the winter of 1901–2 that I had a most interesting interview with him. I had met him before that in Edinburgh, had visited him in his Newport laboratory, and, again since at Harvard, but at Colombo in Ceylon in January, 1902, we spent a long day and evening together. He had just returned from his Maldive expedition and I was just starting on mine to the pearl banks in the Gulf of Manaar. Our two steamers, both chartered from the British India Co., lay at anchor side by side in the harbour, and we dined on shore that evening and discussed coral reefs, tropical seas and marine biology in general. My expedition profited greatly by that chance encounter, for next morning, before I sailed, Agassiz had shipped from his vessel to mine some 600 fathoms of steel dredging wire and an odd assortment of store bottles and tubes left over from his expedition.

I had thought of him before as a quiet, reserved man of great determination and ability. It has been said of him in America: "He was a colossal leader of great enterprises fully as much as he was a man of science." But at that time at Colombo, and also since, I have felt that he was also very thoughtful for others and of a kindly and generous disposition.

When the "Challenger" expedition carried her explorations down through the central Southern Pacific, she found a rather puzzling state of things. In deep water relatively very few animals were captured on the bottom of the ocean when compared with those taken in the Great Southern Ocean or nearer continental shores; those obtained were, however, of rather pronounced archaic types. The deposits in the same area were of surpassing interest; large quantities of a deep-brown clay were hauled up, in which were imbedded enormous numbers of manganese nodules and concretions, some of them being formed around sharks' teeth, ear-bones and other bones of whales, and others around volcanic fragments mostly converted into the mineral palagonite. Sometimes hundreds of sharks' teeth and dozens of whales' ear-bones were captured in a single haul, and most of them belonged to extinct species; some of the teeth were of such size that the sharks must have been 100 feet in length. Small zeolitic crystals and crystal balls were also mixed up in these red-brown clays, evidently formed *in situ.* More extraordinary still were the minute spherules, having a hard black coating and an interior of pure iron and nickel, as well as other minute spherules, called chondres, found hitherto only in meteorites. These spherules are believed to have an extra-terrestrial origin, and to have formed at one time the tails of meteorites or falling stars. This was a strange assemblage of things, and some scientific men argued that such a condition of matters must be regarded as local and accidental.

Now, Alexander Agassiz, on his last expedition, to the Eastern Pacific, in 1904–5, explored anew this region of the earth's surface the furthest removed from the shores of continental land, and he found that this same condition of things extended over vast areas of the Pacific Ocean. Here we have almost certainly the region of minimum accumulation on the sea-floor, and recent investigations indicate that there is in these deep deposits more radio-active matter than anywhere else in the solid crust of our planet. A satisfactory and clear understanding of the chemical phenomena taking place on the floor of the ocean in this region has not yet been obtained, but Agassiz's researches take us a long way on the road to a solution of some exceedingly interesting and important oceanic problems. Take, for example, his conclusion that the bottom fauna depends upon the surface plankton, and that depends upon the presence of strong currents, which may be expressed briefly as—no currents, no plankton, no bottom fauna. This was one of his last contributions to oceanography; and Prof. C. A. Kofoid, who was with him on the occasion, has kindly given me the use of a photograph (Pl. VIII.) he took of Agassiz watching the arrival of the deep-sea trawl on the deck of the "Albatross." He passed his seventieth birthday at sea on this Pacific expedition, and he actually died at sea in mid-ocean five years later, while returning from a visit to Europe.

The following list of his more notable expeditions may be of interest:—

" Blake "	Caribbean Sea	1877–80
" Albatross "	South Seas and Pacific	1899–1900
Coral Reef Expeditions	Bahamas and Cuba	1892
	Bermuda and Florida	1894
	Barrier Reef, Australia	1896
	Fiji Islands	1897–8
	Maldives	1902
" Albatross "	Eastern Tropical Pacific	1904–5

Professor Kofoid, of the University of California, who acted as one of his scientific assistants on his last great Pacific expedition, writes: “The oceanographer of the future will acknowledge his great debt to this the greatest of explorers of the sea. His explorations carried him over 100,000 miles of voyaging in tropical seas, principally in the Caribbean and about its adjacent islands, in the Indian Ocean, and especially in the tropical Pacific. It is safe to say that his expeditions mapped more lines across deep-sea basins and made more deep-sea soundings than all other scientific expeditions combined.”

[*Photo by* C. A. KOFOID.

ALEXANDER AGASSIZ ON U.S.S. "ALBATROSS" IN TROPICAL PACIFIC, WATCHING ARRIVAL ON DECK OF DEEP-SEA TRAWL.

CHAPTER VI

THE PRINCE OF MONACO AND THE OCEANOGRAPHIC MUSEUM

Not infrequently in the past have princes and nobles been munificent patrons of science and done much for the advancement of knowledge; but it must be rare, indeed, for a reigning prince to attain recognition and distinction as a practical working man of science. The late Prince of Monaco was both. He has given to France and the world of science at least three research institutions of first-rate importance; and throughout many years of his life, during the last half-century, since on one of his early expeditions his little yacht lay alongside the "Challenger" in the Tagus, in January, 1873, he has himself planned and carried out many notable investigations in oceanography.

His Serene Highness Prince Albert Honoré Charles, a descendant of the ancient house of Grimaldi, was born in 1848, and succeeded his father, Prince Charles III, as sovereign ruler of Monaco in 1889. He died in 1922.

In his early youth he served as lieutenant in the Spanish Navy, and since then has shown a lifelong devotion to the sea and its exploration, and consequently both nature and training conspired to make him an accomplished navigator, competent to take command of his own ship. Probably the most characteristic representation of the Prince is the statue in the Oceanographic Museum at Monaco, showing him in plain sailor's uniform standing at the rail on the bridge of his yacht. (See also the photograph on Plate IX.)

He must have spent a large portion of his life, and much of the ample funds fortune placed at his disposal, in the many expeditions which he conducted in his successively larger and more perfectly equipped yachts, from the 200-ton schooner "Hirondelle" up to the second "Princesse Alice" (1898), a magnificent ocean-going steam vessel of 1,420 tons, and about 240 feet in length, fitted and manned for every kind of exploring work at sea. The Gulf Stream, the Azores, Spitzbergen, the Mediterranean, and much of the Atlantic from the Equator to the Arctic Circle, were systematically investigated in both their physical and their biological characters. His companions and assistants on these expeditions have included the Baron de Guerne, Dr. Jules Richard, and our countrymen, Mr. J. Y. Buchanan (of the "Challenger") and Dr. W. S. Bruce, the Antarctic explorer; and the results, both in general oceanography and on the zoology of various groups of animals, have been made known to science first by the Prince's preliminary reports of over thirty annual cruises in the *Comptes-Rendus* of the Paris Academy, and later in full detail in those beautifully illustrated publications, *Résultats des Champagnes Scientifiques,* etc. (over 50 parts), and the later series of octavo *Bulletins* (upwards of 400 parts) and the quarto *Annales de l'Institut Oceanogr.,* all issued by the Monaco Press, with the co-operation of Dr. Jules Richard, Director of the Museum.

It is chiefly in connection with the devising of apparatus for deep-sea research and in introducing new methods of investigation that the Prince's expeditions differ from others. Amongst other new appliances which have yielded notable results may be mentioned his huge baited traps (the "nasse"), his "stirrup-trawl" and other types of trawls and nets for various depths of water, and his use of submarine electric lights to attract fishes and crustacea. There can be no doubt that his practical knowledge as a seaman and as a mechanical engineer added greatly to the efficiency and success of all his work on the yacht. His chief assistant, Dr. Richard, gave full descriptions and useful illustrations of many of these appliances for oceanographical investigation in *Bulletin* No. 162, published from Monaco in 1910.

All the Prince's successive voyages were very fruitful of scientific results, and biology owes the knowledge of many new deep-sea Atlantic animals to the special memoirs issued from the Monaco Press. But none of these have been more novel, and almost sensational, than the results of the Prince's whale-fishing expeditions in the Mediterranean and the Atlantic, when he obtained the more or less perfect remains of various new and, in some cases, gigantic cuttle-fishes (such as *Lepidoteuthis grimaldii* and *Cucioteuthis unguiculata*) from the stomachs of the toothed sperm-whales, or "cachalot." These huge and previously unknown "squids," or cuttle-fish, seem to be the principal, if not the sole, food of these toothed whales.

In the various reports of the expeditions from about 1896 onwards we have interesting accounts of Homeric fights with these monsters of the sea, of which the following sentences—in part quotations from a letter of the Prince to Mr. J. Y. Buchanan, who had accompanied him on many of his expeditions—may be taken as a sample. Mr. Buchanan prefaces[1] the letter by telling us that in 1895, while they were pursuing deep-sea research near the Azores, a native crew in their neighbourhood killed a sperm-whale which died under the bottom of the Prince's yacht, having charged the ship in its death-agony as its apparent enemy. On floating up at the other side it emitted from its widely-opened mouth the remains of its last meal, which proved to be fragments of gigantic cuttle-fishes hitherto unknown to science. These were in such good condition that they could be examined zoologically, and were afterwards described and figured in communications to the Paris Academy of Sciences. As soon as the yacht returned after this experience from the Azores, the Prince equipped her for the whale fishery, and engaged

[1] *Accounts Rendered,* Cambridge University Press, 1919, p. 259.

a Dundee whaler called Wedderburn as his mate. Extracts from the Prince's letter are as follows:

"The trial of our whaling business has given splendid results... in twenty-four hours we harpooned and secured three big cetaceans and lost a whale. Each of these cases was very dramatic; the whale... was one of those who dive very deep and straight towards the bottom. She pulled out the 400 metres of line that we had, in three minutes or less, with such a powerful speed that the fore part of the boat took fire. We had to cut just when a few fathoms were left, and then our boat was full of water. Then the animal reappeared on the surface, about half an hour later and at a distance of three miles; we steamed after it, and the run lasted the whole day without loss or gain, but after all, without the possibility for us to shoot the rocket to cause an end, the whale having got the harpoon in some part which was not deadly and losing no blood at all. At night I had, of course, to abandon the pursuit." He then proceeds to describe a fight they had with three huge specimens of *Orca gladiator,* the killer-whale, which is described as the tiger of the ocean, carrying jaws filled with formidable teeth for attack and animated with dauntless courage. They succeeded in killing one at once. Then the two others attacked the boat and worked so as to squeeze it between them, which did not succeed because the dead one, which had been hauled up close, served as a protection on one side, and also because the rounded shape of the boat and of the animals produced the effect of lifting the boat out of the water. Other boats were immediately launched from the yacht and sent to the battlefield. Meanwhile Wedderburn succeeded in killing with one stroke of his harpoon the biggest of the two enemies. The incident was a real battle, which lasted an hour, and in which four boats and seventeen men were engaged. As the result of these and similar occurrences, the Prince tells us, in the letter, that the beach at Monaco was now being turned into a whaling station, where the skeletons were being prepared for the museum.

These were only the first experiences of a series of investigations which the Prince has since made into the occurrence, habits, and structure of both the whales and their food, the cuttle-fishes. Professor Joubin, in a paper on the zoological details, tells us that when the stomach of the sperm-whale caught in 1895 was opened, it was found filled with a quantity, estimated at over 100 kilograms, of partially digested remains of these Cephalopods, all of them of enormous size. He describes some of the muscular arms, though much shrunken and contracted, as being as thick as those of a man and covered with more than a hundred great suckers, each armed with a short claw as powerful as those of a lion or a tiger. The stomachs of the sperm-whales usually contain in addition a large number of the horny beaks and other harder parts of cuttle-fishes, the more indigestible residue of former repasts.

Another case reported is where a whale contained a single arm or tentacle which, "though incomplete from having been partially digested, still measured 27 feet in length," and this seems to justify the common saying of the sailors that "the squids are the biggest fish in the sea."

It is well known that the sperm-whale is valuable, not merely on account of its blubber, from which oil is obtained, but also because of two very important commercial products, the one being the spermaceti, a wax which occurs in liquid condition in a large cavity of the head, and the other being the still more valuable material, ambergris, which occurs in the form of lumps or concretions in the animal's intestine. It seems probable that this ambergris, which is not found in all sperm-whales, but only, it is said, in those that seem torpid and sickly, is really a pathological product, and it is suggested that it may be produced as a result of the irritation caused by the cuttle-fish beaks and other hard parts, which are frequently found embedded in the concretions. Lumps of ambergris, which is used in the arts both as a drug and also as the basis of many of the finest perfumes, may be found on occasions weighing up to 100 or even, exceptionally, close on 200 b., and may be of the value of anything up to £1,000 sterling.

It seems probable that the huge cuttle-fish, upon which the sperm-whale feeds, are inhabitants neither of the surface nor of the bottom, but of the deep intermediate waters, the region of the sea which is least known. They apparently never come to the surface, nor are they caught in our trawls. They are powerful swimmers and very muscular, and up to the present, as Mr. Buchanan says,[1] "the only means of capturing these interesting and gigantic animals is to engage a bigger giant to undertake the task, and to kill him in his turn when he has performed the service."

It seems probable that the whale usually brings its captured prey to the surface in order to devour it, and the combat of the "thresher" and the whale, or the supposed sea-serpent and the whale, which occurs in so many sailors' stories, seems to be explainable as the violent and desperate resistance of the giant cuttle-fish to being swallowed when brought to the surface by the cachalot. Whales have been found with wounds, scratches, and impressions on their skin, which are clearly due to the claws and suckers of the cuttlefish, and there is one specimen described from the Monaco Museum which has an impress of gigantic suckers round the lips of the whale—as if the prey had resisted to the last being swallowed by its captor.

As an example of a totally different kind of oceanographic research conducted by the Prince, we may take the cruise of the summer of 1902, when, just outside the mouth of the Mediterranean, at a depth of 800 fathoms, he found the bottom water to have the remarkably high temperature of 9.4° C. Now, the temperature of the bottom water of that region of the Atlantic at a depth of 800 fathoms ought not to be higher than 4.5° C. "It was evident, therefore," says Mr. Buchanan in discussing this result, "that we had here

[1] *Accounts Rendered,* p. 274.

struck one of the main drains of overflow from the abysmal regions of the Mediterranean," where the water at the bottom is a good deal warmer than in the Atlantic. The Mediterranean is so situated that it loses more water by evaporation from its surface than is supplied to it during the year by rain and rivers. If the Straits of Gibraltar were closed, it is calculated that the Mediterranean would shrink in size and increase in saltness till it attained a condition similar to that of the Dead Sea. The deficiency due to over-evaporation is compensated by the surface current of Atlantic water which it is well known enters at the Straits, and every gallon of this Atlantic water brings with it about six ounces of salt, which remains in the sea when the water evaporates, and would tend to accumulate as water of high density at the bottom were it not that it is discharged in a deep current into the Atlantic. This outflow, after passing between Capes Spartel and Trafalgar, naturally follows the deepest channels outwards until it is lost in the ocean. Mr. Buchanan argues that the high temperature obtained outside the Straits at a depth of 800 fathoms on this occasion was due to one of these local rivers of relatively warm and salt water, and he calculates, from a comparison of temperatures, that at that point it consisted roughly of 50 per cent. of Mediterranean and 50 per cent. of Atlantic water.

As another example of the Prince's oceanographical work in the neighbourhood of the Azores, we may take the discovery in 1902 of the existence of an enclosed basin, appropriately known as the "Monaco" deep, in which the temperature at a depth of 1,645 fathoms was 5° C. Now, in the open water of the North Atlantic of the neighbourhood the temperature at such a depth ought not to be higher than 3° C. It was evident, then, that the sounding had been taken in an enclosed basin shut off from the water of the surrounding ocean by a lip situated at such a depth below the surface that the minimum temperature of the water which can gain access to it is 5°C. This result was confirmed by a number of subsequent soundings and temperature determinations. The depth of the barrier separating the "Monaco" deep from the ocean outside, it is calculated by Mr. Buchanan, must be between 850 and 900 fathoms. This feature of enclosed basins, cut off by submarine barriers from the ocean around, and containing warmer water than their depth warrants, seems to be one that is common to many archipelagos, and examples are known from the West Indies, the Sulu Seas, Celebes, the Mediterranean, and the Red Sea. In a previous chapter we have seen a somewhat similar case in the Faroe Channel, where the Wyville Thomson ridge prevents the cold bottom Arctic water from flowing into the area of warmer Atlantic water.

There is another investigation which will always be connected with the Prince of Monaco's name, and that is his distribution, commenced as far back as 1885, of floats or drift bottles over wide areas of the Atlantic starting from the Azores as a centre, in order to determine the set of the currents. These floats, in some cases bottles, in others blocks of wood, but in the later development of the work spherical copper vessels so weighted as to float just below the surface in order to avoid the direct action of the wind, contained in sealed tubes a paper printed in nine languages, requesting the finder to fill up certain details and return it to the office at Monaco. In his first experiments, out of 931 floats so distributed on certain lines across the ocean, 226 have been found and returned, and the results of their wanderings have yielded a considerable amount of valuable information in regard to the movements of currents in the North Atlantic and especially of the Gulf Stream water. These and other later observations, resulting from the distribution of about 2,000 floats in all, have enabled the Prince to draw up a valuable chart showing the surface circulation of the Atlantic water, upon which he was undoubtedly at the time of his death the leading authority.

It is of interest to notice in this connection a recent paper by the Prince, communicated to the French Academy of Sciences in 1919, dealing with the future of the floating mines which have gone adrift as a result of operations in the recent war, and showing that some of them may be a danger to navigation in certain parts of the North Atlantic for at least four years from that date. He showed that those from mine-fields in the North Sea will eventually find their way to the fjords of Norway, while those from the western shores of Europe will enter into the great Atlantic circulation determined by the influence of the Gulf Stream, and will be carried south towards the Cape Verde Islands, and will then work westward in the equatorial current towards America, visiting the Antilles and Bahamas. They will then fall into the current of the Gulf Stream, which will enable them to reach Bermuda on the way to the Azores, so circulating round the Sargasso Sea between the fiftieth latitude to the north and the fifteenth to the south. Some may continue to circulate in this great cycle, while others may be carried north-east towards the western coasts of the British Isles. Those that take this latter course will eventually reach the Norwegian fjords, and probably, in the end, the Arctic Ocean by the North Cape, and be, no doubt, ultimately destroyed in their encounter with the ice. The Prince calculates that the rate of wandering of these mines in the great Atlantic circulation will be about five miles per twenty-four hours. He gives some useful advice to navigators as to the safest routes and the lines of greatest danger in crossing the Atlantic, and adds that the coasts of the United States will be protected against this danger of mines coming from Europe by the cold Labrador current which descends from the north to the coasts of Florida.

As a further contribution to oceanography the Prince has had prepared, and has published at Monaco, a very valuable "Carte Générale Bathymétrique des Océans," on which are collected all the really accurate deep-water soundings of the various expeditions. Shortly before his death he had appointed a commission of experts to revise the chart and issue a new and improved edition.

In July, 1891, the Prince of Monaco, accompanied by his collaborator, Baron Jules de Guerne (then President of the Zoological Society of France), attended a special meeting of the Royal Society of Edinburgh for the purpose of delivering an address[1] upon the arrangements he had adopted in his new yacht ("Princesse Alice I") for the adequate study of problems of the ocean. In speaking of his earlier work on the schooner "Hirondelle," after some remarks on the importance of work at sea and the difficulty of finding scientific men who can carry it out, he said: "It was consequent on such reflections that, some seven or eight years ago, I undertook the mission that lay before me because I was at once a sailor and devoted to science." He then describes his soundings, temperature observations and dredgings in the Gulf of Gascony down to a depth of 500 metres, and his arrangements on the new yacht for similar work in any depths up to 8,000 metres. He gave an account also of the results of his "drift-floats" up to that time in regard to the directions and mean velocity of the currents in the North Atlantic. Incidentally, in answer to the question, "What is oceanography?" he says it will soon appear as strange as the question would be, "What is geography?" and he divides physiography into these two departments of knowledge, geography and oceanography.

The magnificent oceanographical museum, which the Prince has built on the southern face of the ancient rock of Monaco rising steeply from the edge of the Mediterranean, was inaugurated by a series of impressive functions lasting for four days at the end of March, 1910. Oceanographers and other scientific men representative of many countries were present on the invitation of the Prince, and France, Italy and Germany at least had sent ships of their navy, which were thrown open to the scientific visitors along with the Prince's yacht. In his inaugural address the Prince gave

[1] *Proc. Roy. Soc. Edin.,* vol. xviii, p. 295.

THE PRINCE ON THE BRIDGE OF HIS YACHT.

THE MONACO MUSEUM OF OCEANOGRAPHY.

a generous recognition of British pre-eminence in oceanographical research. It is, therefore, little short of a deplorable omission that the British Government failed to send any ship of the navy and was not officially represented at the inauguration, although several of us from this country were present as the Prince's guests.

This museum of oceanography demonstrates the methods of investigation and the results obtained. It contains the extensive collections made on the Prince's expeditions, and also shows the various types of dredges, trawls, tow-nets, deep-sea thermometers, water-bottles, current meters and other apparatus used by the different nations in their explorations.

It may perhaps serve to give an impression of the circumstances surrounding the very striking inauguration of this Musée Océanographique de Monaco if I quote a few sentences written in 1910 when returning home from that great meeting. As the Prince had been recognized for the previous quarter of a century, by men of science, as an ardent and successful explorer of the sea, it is not surprising that, when he built and endowed this unique museum, it was visited at the opening celebration by such a gathering of scientific men interested in the sea as had probably never been seen before or since. "Official representatives of France, Italy, Germany, Spain, Portugal, Russia and other countries, delegates from the leading academies of the world—the Academy of Sciences of Paris, the Royal Society of London, the Academy 'dei Lincei' of Rome, and the corresponding scientific societies of Berlin, Vienna, Madrid, and St. Petersburg—along with many other scientific men invited personally by the Prince, were united in celebrating the progress of oceanography, and in launching an institution unique in character and of first-rate importance for science. . . .

"The museum building is a mass of white masonry, about 100 metres in length and over 70 metres high, planted actually on the face of the cliff, on the seaward side of the rock of Monaco. It rises sheer from the sea, and its lower three storeys are below the level of the top of the rock on which the old town and palace stand, so that the main entrance from the streets of the town is half-way up the building. Its appearance architecturally is fine from every point of view, but is especially striking from the sea, where the masonry appears to be almost a part of the rock, and to grow up in a series of arches from the ledges of the cliff itself. . . . (That aspect is shown in Fig. 2, on Pl. IX.)

"The Prince's inaugural address, in which he set forth his aims in founding the museum, was followed by congratulatory speeches from M. Loubet, M. Pichon, Admiral von Koester, and other representatives of the Great Powers present, and the formal proceedings terminated with brief discourses on departments of oceanography by the three professors attached to the institution—Joubin, Poirier and Berget—after which the company was conducted round the museum by the Prince and his scientific staff. . . .

"It is unnecessary to recount all the ceremonies and fêtes of the four days. It will suffice to mention that on one of the days the Prince gave a banquet to his 300 guests, followed by congratulatory speeches from the representatives of the great academies present and other scientific men; on one evening he entertained us to a gala representation at the opera. A second evening was devoted to a 'Fête Vénitienne' on the bay, on a scale which even our southern friends, who are accustomed to such displays in the open air, on a smooth sea, under a serene sky, and in a balmy atmosphere, told us had never in their experience been equalled. The pageant, performed after dark, represented the legend of Monaco—to the effect that Hercules, in his wanderings, entered the ancient port (still known as the Port of Hercules), lying between the rock of Monaco and the modern Monte Carlo, and, struck by the wonderful natural features of the situation, chanted a hymn in praise of beauty and knowledge (art and science), and, notwithstanding the savage assaults of the primitive inhabitants, half human, half beasts, took possession of the rock, which he named Monaco (from his own title Monœchos), and dedicated it to the advancement of knowledge—all very appropriate to the Prince's new institution. The whole story was represented in that evening fête by brilliant illuminations on the dark waters of the bay. First, huge brightly-coloured monsters of the deep, Behemoths and Chimæras (I suppose really motor-boats with erections of lath and canvas painted and illuminated inside), were seen approaching the mouth of the harbour, followed by three gorgeous barges, on the foremost of which stood Hercules, played by a gigantic Italian singer, Titta Ruffo, whose magnificent baritone voice filled the huge natural amphitheatre, extending from the rock of Monaco to the casino of Monte Carlo, as he chanted his hymn of dedication. The primitive inhabitants were there in numerous boats filled with coloured lanterns. The fierce battle was represented by volleys of rockets and other fireworks, and by explosions of coloured fire. Finally, the triumph of Hercules was celebrated by the bursting into light in the centre of the bay of three large set-pieces, showing in the centre the arms of the Grimaldi (the Monaco family, said to be the most ancient in Europe), supported on the one side by Art and on the other by Science—all three with mottoes and appropriate devices.

"The Prince's yacht and other visiting yachts, and the three or four French and Italian gunboats and torpedo-destroyers that had been sent in honour of the occasion, were also illuminated at night, and the latter gave searchlight displays, and were open for inspection during the day. A reception at the palace, various other entertainments and scientific meetings in the museum, a visit to the prehistoric caves of Grimaldi (where the remains of early Mediterranean man have been found), and other interesting excursions in the neighbourhood filled up the rest of what was certainly a most notable occasion in the history both of the principality of Monaco and of the science of the sea."

That is what I wrote at the time. On reading it over now, I only desire to add that our time was not wholly, nor even mostly, taken up with these festivities, magnificent and worthy of the occasion though they were. These were evening functions, but the days were largely occupied with serious scientific conferences, as they were called, committees of oceanographers discussing physical and biological problems of the sea and plans for future work—all of which were put an end to a few years later by the outbreak of war.

The establishment at Monaco, which serves as a centre of oceanographic research for the southern nations of Europe, is to be congratulated on the fact that work at sea—so far as the Mediterranean is concerned—is now being resumed. A meeting of the "Commission Internationale pour l'Exploration Scientifique de la Mer Méditerranée" took place at Madrid in November, 1919, under the presidency of the Prince of Monaco, when a programme of work was drawn up, and spheres of operations were allocated to different countries.

The oceanographical museum at Monaco is, however, only one part of the foundation which the Prince has laid for the study of the sea. With the object of arousing interest in scientific marine studies in France, the Prince started a series of lectures at the Sorbonne in 1903, and in 1906 he gave permanence to these studies by endowing them and presenting to the French nation a building specially devoted to university instruction in oceanography. In connection with this "Institut" at Paris three professorships have been established, one of physical oceanography, one of biological oceanography and the third of the physiology of marine life. As one of the inaugural addresses stated:—

"By his researches the Prince of Monaco has won for himself a place in the foremost rank of men of science, and by enshrining the results in the monumental buildings at Monaco and Paris he has invested his labours with permanent value for all time."

It has been said in France of the two oceanographic institutions that, "the factory is at Monaco, the sale-room at

Paris." But it is a *distribution* of knowledge rather than a sale, as all is given gratuitously.

The third great scientific benefaction of the Prince has no relation to oceanography, but may be mentioned briefly in order to complete the record. It is the "Institut de Paléontologie Humaine" at Paris, where again, as at Monaco, there is a museum and a laboratory with a staff of professors devoted entirely to the investigation of one subject—the early history of man. The Prince's personal interest in prehistoric archæology has been shown for many years by the explorations he has conducted or promoted at the Grimaldi caves near Monaco, and at other caverns and important sites in France and Spain, along with Professor Boule, the Abbé Breuil and others, and the results, as in the case of the oceanography investigations, have been published at his expense in princely style. It has been reported in the daily press since his death that he has bequeathed a million francs as further endowment to each of these research institutions.

Of recent years, since the war, he has played a prominent and most helpful part in promoting international co-operation for oceanographic work. He formed a natural centre in organization and leader in work, and was appointed president at various international conferences, such as that held recently at Rome. In his independent position he stood apart from all international rivalries and showed only a single-minded devotion to the pursuit of truth. His death in Paris in June, 1922, is a great loss to the cause he did so much to promote—the advancement of the science of the sea.

No one who has worked with him at a conference or been his guest at Monaco will be likely to forget his constant courteous hospitality, his evident interest in all the scientific questions raised and his desire to secure co-operation between the different nations in the further exploration of the oceans. And he did it all because he loved it, and modestly disclaimed praise—"Je n'y ai aucun mérite. Je n'aurais pas été heureux sans cela," he said.

CHAPTER VII
MARINE BIOLOGICAL STATIONS FOR RESEARCH

In addition to actual expeditions at sea, the science of oceanography has gained much during the last half-century from observations made on shore by many biologists of all kinds working at what have come to be called "Biological Stations." In order to give some account of the scale on which the best of such institutions have been organized and equipped, and of the facilities that are offered for investigations, I have rewritten with some necessary alterations and additions an article founded on notes taken during a visit of some weeks to the celebrated zoological station at Naples and printed in the *Popular Science Monthly* for September, 1901.[1] I have added at the end a short account of the founder, Dr. Anton Dohrn, from personal recollections of that remarkable man.

It is interesting to remember that the movement to establish institutions for the investigation of marine problems on shore, in which Anton Dohrn was a pioneer, took definite shape just at the time (1872) when the "Challenger" was starting on her memorable voyage round the world.

Biological, zoological, marine stations are all of them merely the seaside workshops of the modern naturalist "writ large." But they offer wonderful facilities for the most advanced and best kinds of biological work, and it is almost impossible to overestimate the influence they have had in the advancement of our knowledge of living nature. The field-naturalist of old, before the days of university laboratories, studied his animals and plants alive in the open, or

[1] Made use of with the courteous permission of the Editor.

collected and arranged them in his cabinets and museums. The work was interesting and necessary, but to some extent superficial. We see its importance enhanced in these later days in the light of Darwinism. It was an enormous gain to science when zoological and botanical laboratories were equipped in the universities, and when every student came to examine everything for himself and to probe as deeply as possible into structure and function. It is no wonder if for a time, in some quarters, in the fascinations of microscopic dissection and section-cutting and mounting, there was perhaps a tendency to lose sight of living nature, and to convert refinement of method and beauty of preparation into the end, in place of being only the means of the investigation.

The biological station came to put all that right. It presented a happy union of the observational work of the field-naturalist with the minute investigations of the laboratory student. It brought the laboratory to the seashore, and the sea, in the form of well-equipped healthy tanks, within the walls of the laboratory. It enabled the living organisms to be studied almost in their native haunts by the most refined laboratory methods.

Fifty years ago the biological station was almost unknown; now there are, I suppose, about fifty or possibly more, large and small, scattered along the shores of the civilized world from the Arctic Circle to the tropics and Australia, from western California to far Japan in the East—and of these the parent institution, and by far the finest and most important, is the world-renowned "Stazione Zoologica" at Naples.

It is almost impossible to think of the Naples station apart from Anton Dohrn. He was the founder, benefactor, director, the centre of all its activities, the source of its inspiration. He established the first building in 1872, and, although he has had support from the German and Italian Governments and from scientific institutions all over the world, still I believe it is no secret that his own private fortune, used unsparingly, has contributed much to the permanence and success of the undertaking. He fostered and directed it continuously for over thirty years: the twenty-fifth anniversary of the foundation was celebrated on April 14, 1897, by a remarkable memorial in which all the leading biologists of the world were united.

The international character of the institution is a most interesting and important feature. Situated in the south of Italy, founded and directed by a German, subsidized (in an excellent manner described below) by most European governments, including even those of Switzerland, Hungary, Holland, Belgium and Spain, the members of the staff and the naturalists at work in the institution may be of any nation and usually are of many; and at any hour of the day at least the four languages, French, German, English and Italian, may be heard among the busy groups in the laboratory and the library. I am describing it as it was before the war. It is now, no doubt, changed to some extent. On the outbreak of war it was taken over by the Italian Government and put in the control of a Commission of three Italian professors. Its future is still somewhat uncertain.

But the Naples Zoological Station is not wholly for the scientific man—in fact, many sight-seeing visitors to Naples do not know that science has anything to do with it. The more public department of the institution, the celebrated "Acquario," is one of the sights of Naples, and is well known to and highly appreciated by the more intelligent of the tourists you meet at the hotels. The whole institution is usually known to the English-speaking tourist as "The Aquarium," and few, even of those who visit and enjoy it, seem to know or wonder anything about the remainder of the great white edifice into the ground floor alone of which they are allowed to penetrate.

The zoological station of Naples in its present condition (it was once smaller, and will probably some day be larger) consists of three great white flat-topped buildings of imposing appearance, connected by a central yard and large iron galleries, placed in the Villa Nazionale, the beautiful public garden which occupies that part of the shore of the wonderful Bay of Naples. Surrounded by palms, cacti, aloes, with groups of statuary, fountains and minor temples, looking out upon the incomparable panorama from Vesuvius by Sorrento and Capri to Procida and Ischia, there is probably no finer situation in the world than that occupied by what is unquestionably one of the most important of zoological institutions.

As to this importance, no university laboratory approaches it. There is no other laboratory where the work-places are occupied by some forty or fifty doctors of science and professors and investigators of established reputation from all parts of Europe and America, who have come there to do original work, attracted by the fame of the institution and its director; no laboratory where forty such workers can be kept supplied with abundance of fresh material for their researches (of the most diverse description) brought from the sea at least twice a day; no laboratory where there are such excellent facilities for work and such charming opportunities for scientific intercourse.

The staff of the institution a few years before the war, when I last visited it, consisted of:

> “(1) Professor Dr. Anton Dohrn, the founder and director.
>
> “(2) Seven Scientific Assistants or heads of departments, one of the most interesting of whom was the late Dr. Lo Bianco, the administrator of the fisheries and préparateur.
>
> “(3) In addition to these scientific heads of departments there were:—the business secretary, two painters, and the chief engineer; and, finally, about thirty attendants, collectors and others employed in the laboratories, in the collecting and preserving departments, in the aquarium and elsewhere.

This may seem at the first thought a very large staff, but the activities of the institution are most varied and far-reaching, and everything that is undertaken is carried to a high standard of perfection. Whether it be in the exposition of living animals to the public in the wonderful tanks of the

“Acquario,” in the collection and preparation of choice specimens for museums, in the supply of laboratory material and mounted microscopic objects to universities, in the facilities afforded for research, or in the educational influence and inspiration which all young workers in the laboratory feel—in each and all of these directions the Naples station has a world-wide renown. And the best proof of this reputation for excellence is seen in the long list of biologists from all civilized countries who year after year obtain material from the station or enroll as workers in the laboratory. Close on 1,500 naturalists have now, since the opening of the zoological station in 1873, occupied work-tables, and, as these men have come from and gone back to practically all the important laboratories of the world, Naples may fairly claim to have been for the last half-century a great international meeting-ground of biologists, and so to have exercised a stimulating and co-ordinating influence upon marine biological and oceanographical research which it would be difficult to overestimate.

The success of the institution has caused constant additions and has stimulated the staff to fresh undertakings. To the original aquarium and zoological laboratories a second building mainly for botany and physiology and the preparation of specimens was soon added; and a third has since been completed. Additional accommodation has also been obtained by a rearrangement of the roof of the main building. This gives space for a second large zoological laboratory, a supplementary library and various smaller rooms, used as chemical and physiological laboratories, for photography and for bacteriology. A good deal of the research in recent years, both on the part of those occupying work-tables and of the permanent staff, has been in the direction of comparative physiology, experimental embryology and the bacteriology of sea-water, and all necessary facilities for such work are now provided.

The laboratories contain accommodation for over fifty scientific men to work, and each such work-place, known

Dr. Anton Dohrn.

Zoological Station at Naples.

technically as a "table," consists either of a small room or of an alcove or a portion screened off from a larger room. Such tables are rented at £100 a year, not to individuals, but to states or universities or committees, and of the fifty-five tables available before the war, about thirty-four were permanently engaged—thus bringing in a considerable annual subsidy to the administration. Germany used to take some ten of these tables, and Italy seven. There are, I believe, three American tables—one belonging to the Women's Association—and there are three English (rented by the Universities of Cambridge and Oxford and the British Association respectively), consequently there are generally about half a dozen English and American biologists at work in the station; but the director always interpreted in a most liberal spirit the rules as to the occupancy of a table, and, as a matter of fact, during a visit I made in 1901 there were, for a short time, no less than three of us on the books as occupying simultaneously the British Association table, but in reality all provided with separate rooms.

A work-table is then really a small laboratory fitted up with all that is necessary for ordinary biological research, and additional apparatus and reagents can be obtained as required. The investigator is supposed to bring his own microscope and dissecting instruments, but is supplied with alcohols, acids, stains and other chemicals, glass dishes and bottles of various kinds and sizes, drawing materials and mounting reagents. Requisition forms are placed beside the worker on which to notify his wishes in regard to material and reagents; he is visited at frequent intervals by members of the scientific staff; he has an attendant to look after his room and help in other ways, and in fact all his reasonable wants are supplied in the most perfect manner. A scientific man, or woman, then, wishing to do a special research at the Naples station must be appointed to a particular table for a definite time by his government, university, or the controlling committee of that "table," and this is the system which has worked so well for nearly fifty years and which has given a certain stamp and tradition to some at least of the tables.

The opportunities for taking part in collecting expeditions at sea are most valuable to the young naturalist, and especially to such as have not had previous experience of the rich Mediterranean fauna. Dredging, "plankton" collection and fishing are carried on daily in the Bay of Naples by means of the two little steamers (the "Johannes Müller" and the "Francis Balfour" —both classic names in biology) belonging to the station, and by a flotilla of fishing and other smaller boats which start for work in the very early morning and return laden with treasure in time to supply the workers in the laboratory for the day. Many of the Neapolitan fishermen are more or less in the employ of the station and bring to the laboratory such rare specimens as they may chance to find in their day's work.

The late Dr. S. Lo Bianco, for many years the genial chief of the collecting and preserving department, had a phenomenal knowledge of the marine fauna, and of where, when and how to catch any particular thing—and, moreover, of how best to preserve it when caught. Each afternoon he visited the laboratories and ascertained the wants of the workers, each night he gave his orders to his crews of fishermen, with various hints as to likely haunts and the best tactics to pursue; and the following morning sees a procession of tubs and baskets filled with glass jars, containing the specimens rich and rare, being conveyed from the little dock to the laboratory—generally balanced in wonderful piles on the heads of the stalwart and picturesque boatmen. Dredging expeditions during the day along the shores or to the neighbouring bay of Pozzuoli take place in the steam launch, and workers who wish to search for some special animal or who are studying the fauna can join such trips. Then about once a fortnight or so a longer excursion is organized, say to Ischia or to Capri, occupying the whole day, and to this all in the laboratory who care for it are invited. It was on these occasions that Lo Bianco was seen in his glory; directing all proceedings, the centre of all activities, full of geniality and information, he was the life and soul of the party. Speaking to us in any language, and knowing everything we catch on land or sea, patting the fishermen on the back, talking seriously with the strictly scientific, joking with the more versatile, sympathizing if necessary with the seasick and helping every one to enjoy the day and profit by the experience, he was an ideal leader of the marine biological picnic.

The finest specimens caught or those not required for immediate investigation are either most skilfully preserved for museums or pass into the tanks of the aquarium. And it is possible, without ever going to sea, to gain a very fair idea of the local Mediterranean fauna from that last-named part of the institution. The beauty and interest of the aquarium are due, of course, in great measure to the brilliancy and abundance of the rich fauna in the neighbouring waters, but also in part to scientific knowledge and skill. The tanks are most carefully watched and governed, and their exact condition is always known—the temperature, specific gravity, number of bacteria present, and other particulars of the water, are constantly tested and considered. The public admiring the tanks on the ground floor little know of the "council of war" occasionally summoned in the laboratory upstairs consisting of experts in the subjects concerned, chemistry, biology, bacteriology, to examine some unusual sample or settle some delicate question. And so, by much care and thought, results and effects are produced which we admire greatly in the aquarium and which, although no doubt in part due to the latitude, are also dependent upon the scientific knowledge and manipulative skill behind the scenes.

Amongst the fishes, we see in one tank fine specimens of the Muræna—the real old Roman eel—coiling their snake-like bodies through the necks of broken jars just as their ancestors no doubt did two thousand years ago with the same pots and jars—for those in the tanks are antiques—in the neighbouring Bay of Baiæ. We can see the Torpedo or electric ray in an open shallow tank, and by putting the thumb above and the fingers under the animal's flat shoulders, whilst we pull or squeeze the tail with the other hand, an electric shock can be obtained. Octopus, squids and other cuttle-fish are present in abundance; crabs that mimic their surroundings, those with anemones and with sponges on their backs, animals that look like plants, corals and sea-fans of many kinds, worms that live in leathery tubes a foot long and expand out of the top, like gorgeous flowers six inches across with innumerable spirally-arranged petals—these seem to be the favourites with visitors. But probably the most interesting tanks to the scientific man are those containing the recently caught "plankton," the Medusæ and other delicate and gelatinous surface organisms. There is one marvellous creature that can be seen almost nowhere else, the *Cestus veneris,* "Venus's girdle," which is like an undulating, pulsating band of light, in some positions absolutely transparent, in others flashing iridescent fire like a diamond from its sides. So much for the public aquarium, which, at an admission fee of two francs, brings in to the institution a revenue of about £1,000 a year. Now a word as to the publications of the station before the war.

Workers at Naples are free to publish the results of their investigations where they like, and records of the good work in all departments of biology which has been done at this station are to be found in all civilized countries in the form of memoirs and articles contributed to the scientific periodicals of the world. But still a considerable amount of the whole, including a number of the more extended, more solid and more noteworthy contributions, has been published at Naples as a noble series of monographs on the *Fauna and Flora of the Gulf of Naples*—each monograph being one or more quarto volumes, richly illustrated, and dealing with one particular group of animals or a section thereof. This great series, of which over thirty monographs have now appeared, is amongst the most cherished possessions of every zoological library. Besides these monographs many volumes of a smaller annual octavo journal have been published containing shorter but still important papers, and one of the staff also edited a yearly summary or record of the advances made in all departments of zoology in all parts of the world.

But although the work of the Naples Zoological Station is thus many-sided, the leading idea is certainly original research. An investigator usually goes to Naples to make some particular discovery, and he goes there because he knows he will find material, facilities and environment such as exist nowhere else in the same favourable combination. As a result of the splendid pioneer work which the "Stazione Zoologica" has done at Naples, every civilized country has now established its own biological stations, some larger, some smaller; but although these are of prime importance amongst scientific institutions in their own countries, as enabling the young investigator to commence research in living material without leaving home, it must not be thought that they detract from the advantages of a visit to the Naples station, or affect the commanding position of that unique University of Natural History. Notwithstanding Woods Hole, in the United States, Roscoff in France, Plymouth and others at home—aye, and the many others that are likely to follow—Naples is still, or was before the war, the Mecca of the young biologist, and will probably long remain the greatest biological station in the world.

Anton Dohrn, who was born in 1840 and died in 1909, used to tell that his early studies in marine biology at Messina in the sixties first inspired him with the idea of a great international zoological station at some favoured spot on the shores of the Mediterranean—and he wisely chose Naples. There were many difficulties to be overcome. He received support in some quarters, opposition from others, and amongst his friends who gave encouragement it is pleasant to think there were two young Englishmen—Francis Maitland Balfour, the great Cambridge embryologist, and the gifted Charles Grant, the author of *Stories of Naples and the Camorra.*

Dohrn was a man of great determination and self-reliance, and when finally the official support he had expected to receive from Germany failed him he had the courage of his convictions and showed his faith in the project by devoting his personal fortune to the establishment of the Stazione Zoologica—the first part of which was opened in 1873, to be followed by a second building in 1890, and a third devoted to physiology in 1907. The upper figure on Plate X gives a characteristic representation of Dohrn in later life.

In addition to being a man of ideas and initiative and a great organizer and administrator, he was an eminent zoologist and produced a large amount of first-rate original research. The great work of his life was to prove that Vertebrates were derived from Chætopod worms, and that their characteristic features were not newly acquired but were modifications of other organs which had in the ancestral worms some different function to perform. He regarded Amphioxus and the Tunicata as degenerate back-sliders which threw no light on the problem of early ancestry.

I have a vivid recollection of an occurrence during my first meeting with Dohrn which emphasizes the point. It was about 1880, when he visited Edinburgh to see the "Challenger" collections, and, being at that time Demonstrator of Zoology in the university, I was deputed by my chief, Sir Wyville Thomson, who was then in poor health, to take his distinguished visitor round the department and especially to see the large lecture theatre in the museum. Dohrn, who had been told by Thomson that I was working at the "Challenger" Tunicata, said he would like to try his voice from the platform, and sending me up to the back benches of the theatre, improved the occasion by hurling at me in stentorian tones a few emphatic sentences on the degeneracy of Tunicates, ending up with: "And so your Ascidia is a humbug!"

CHAPTER VIII
HYDROGRAPHY

We pass now to a consideration of the chief physical characteristics of the oceans—the Earth is supposed to be the only planet in our solar system which *has* oceans. These physical characteristics may all be grouped under the general term Hydrography, and the following may serve as a convenient list of the more important subdivisions:—Size, Depth, Temperature, Salinity, Density, Pressure, Colour, Penetration of Light, Viscosity, and Alkalinity. There are a few other physical phenomena of the ocean which for various reasons are omitted from this brief summary of the subject.

SIZE OF THE OCEAN.

First, as to the extent of the oceans relatively to the land, it is known that water covers more than two-thirds of the surface of the globe, and it has been calculated that the volume of the dry land above sea-level is 23 millions of cubic miles, while the volume of the ocean is many times more, about 300 to 320 millions of cubic miles according to different estimates. The mean height of the land is 2,300 feet and the average depth of the sea 11,500 feet; but the greatest height of the land (Mount Everest, 29,002 feet) and the greatest known depth of the sea (5,348 fathoms = 32,089 feet) are nearly the same, the mountain being over 5½ and the sounding a little over 6 miles. The disproportion between land and sea is constantly increasing in consequence of the wearing down of the land. It is supposed that the material carried from the land to the oceans is about 3.7 cubic miles per annum, and Sir John Murray has calculated that at this rate the whole of the land would be transferred to the sea in 6,340,000 years, and the "hydrosphere" would then completely cover the "lithosphere" to a depth of about 1,450 fathoms. The whole area of the sea bottom is estimated at nearly 140 million square miles.

DEPTHS OF THE OCEANS.

Our knowledge of the main outlines of the contours of the ocean floor was gained by the "Challenger" expedition half a century ago; and the many expeditions since, although they have taken thousands of soundings and have filled in many blanks and made known a few deeper holes, have left the picture very much as it was drawn by Sir Wyville Thomson and his colleagues in 1876. The deepest sounding then was 4,475 fathoms; the deepest known now is 5,348 fathoms, over six English statute miles.

If the floor of the ocean be divided into 1,000-fathom zones of depth (0–1,000; 1,000–2,000; etc.), by far the largest area is that which lies at depths of from 2,000 to 3,000 fathoms. The smallest area (only about 6 per cent. of the whole) is that at depths over 3,000 fathoms. These "Deeps," as they are called, of over 3,000 fathoms, are relatively small depressions scattered over various parts of the oceans, and it is appropriate that we should owe most of the numerical statements and maps dealing with such matters to one of the "Challenger" naturalists, Sir John Murray, who continued his oceanographic investigations almost to the present day—his last cruise was in the summer of 1910 and his last publication appeared in 1913. He died early in 1914.

Murray has defined and named 57 "Deeps," the greater number (32) of which are in the Pacific, the deepest of the oceans; and the largest and one of the deepest of them is the "Tuscarora Deep," a depression running nearly north and south in the North Pacific to the east of Japan. The "Aldrich Deep" in the South Pacific contains several of the deepest soundings of over 5,000 fathoms.

With the exception of these abyssal "Deeps," the floor of the oceans far from land is a flat or very slightly undulating plain, the contours being distant and the gradients so slight as to be scarcely noticeable, like those on most good railway tracks on land. On approaching the continents, however, the slope usually becomes steeper to form what Murray called the "Continental Slope." (Fig. 4). Working out from the land, the shore of the continent extends as a shallow "Continental Shelf" to about the 100-fathom line, where, at this "Continental Edge," the steeper gradient (the "Continental Slope") begins and descends, almost abruptly in places, to the

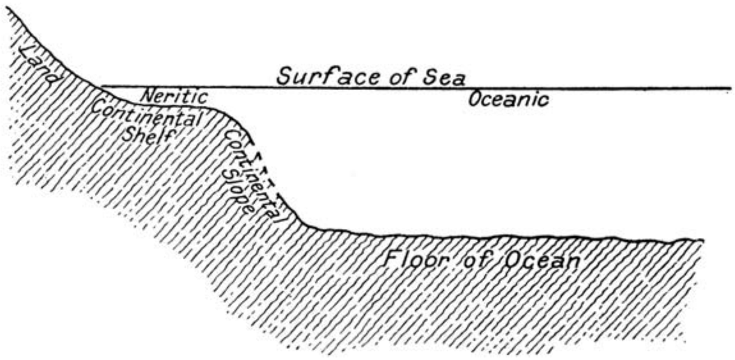


FIG. 4.—DIAGRAMMATIC SECTION OF THE SEA-BOTTOM.

great abyssal undulating plain—the floor of the ocean.

In taking a series of oceanographical observations at sea, the first requisite is to determine the locality and the depth—where you are, and exactly how much water is below you. If you know the exact locality, the depth may perhaps be obtained approximately from the chart, but it is well to verify it by direct observation with a sounding apparatus, such as the "lead," the Lucas self-recording machine, or the Kelvin sounder, which indicates the distance up a tube that the water is forced by the pressure at that depth.

There have been many types of sounding machines used in the history of oceanography—some have a detachable weight which is left at the sea bottom to avoid delay in winding in the wire; in some the wire runs out over a measuring wheel connected with a dial from which the depth (said to be correct to 1 fathom in great depths) can be read off as the weight touches bottom.

In some cases the sounding machine brings up in a tube or other receptacle a small sample of the bottom deposit, which may be sufficient to show the nature of the bottom for charting. The distribution of the submarine deposits on the floor of the ocean in relation to depth will be considered further on (Chapter X).

The floor of the deep sea is icy-cold, receives no light from the sun, and is under a pressure of several tons to the square inch—over a ton for each thousand fathoms of depth.

TEMPERATURE.

Quite apart from seasonal variations in temperature (which are only of large amount in the temperate zones), some parts of the ocean are naturally much warmer than others. The surface of the sea in the tropics may be over 80°F. (the highest record is 96°F. in the Persian Gulf), and in the polar regions is at or below freezing-point (the lowest known being 26°F.—making the extreme recorded range 70°F.). The freezing-point of sea-water is 28°F. (–2.22°C.).

The range of seasonal variation in the year in the surface temperature of the sea is least in Arctic and Antarctic waters and in the tropics, where it (the range) is less than 10°F. In the southern temperate zone the range is from 10°to 30°F., and in the northern temperate zone from 10°to 50°F. The range is seen at its greatest about latitude 40°in both north and south hemispheres.

These surface temperatures are determined primarily by the latitude, and secondarily modified by cold and warm currents and other influences. The surface isotherms, then, are rarely found running with much regularity east and west, as would be the case if the temperatures depended solely on the latitude, but are frequently diverted somewhat to the north or south by the influence of currents, distribution of land and water, and prevailing winds. For example, in the North Atlantic the corresponding isotherms are much lower on the American than on the European coast, as a result of the influence of the Labrador cold current flowing south from Davis Strait and the warm Gulf Stream flowing north and east towards Europe.

Throughout the oceans the surface water is generally warmer than that below, and, as a rule, deep water is cold water. In the tropics the temperature may be over 80°F. at the surface, and at or about freezing-point (28°F.) at the bottom. As a general rule, the temperature decreases continuously as the depth increases, as is shown in the following series, extracted from Murray's table of the "Challenger" results, of mean temperatures for the whole ocean:— There may, however, be variations from this rule due to layers of warmer water between

100 fathoms	= 60·7° F.	1,000 fathoms	= 36·5° F.
200 ,,	= 50·1° F.	1,500 ,,	= 35·3° F.
500 ,,	= 40·1° F.	2,200 ,,	= 35·2° F.

colder, or the reverse.

In some cases the temperature of the deeper water does not bear the same relation to that of the surface at all times of year. For example, off the Norwegian coast the surface of the sea is coldest in February and warmest in August, while at a depth of 200 fathoms in the same locality the water is at its lowest temperature in August and at its highest in February; and Murray (in 1888) found the same seasonal reversal of conditions in Upper Loch Fyne on the west coast of Scotland.

The bottom temperatures are below 30°F. in the polar seas; they are between 30°and 35°F. over much of the Antarctic and the Southern Ocean, the Indian Ocean, and parts of the Atlantic and Pacific; between 35°and 40°F. in the North Atlantic and parts of the Pacific. In the open oceans there is, then, very cold water in the deep sea all over the bottom, and this cold water is derived from the polar regions, more especially from the Antarctic by a slow circulation of that cold bottom water along the floor of the oceans towards the equatorial regions.

There are, however, certain exceptional areas with higher temperatures in deep water. The Sargasso Sea and between the Azores and Madeira and the Canary Isles have a higher mean temperature down to 1,000 fathoms than any other part of the ocean at corresponding depths. Where a barrier to free circulation exists, such as a submarine ridge cutting off an enclosed area from the ocean outside, the temperature of the deeper water

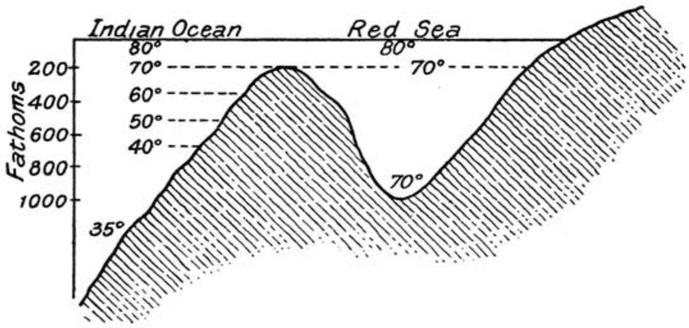


FIG. 5.—DIAGRAM SHOWING RED SEA BARRIER.

inside the barrier may be much higher than that at a corresponding depth outside. For example, the Red Sea is cut off from the Indian Ocean by a barrier at about 200 fathoms. Down to that level it shows the same temperatures as those of the ocean, 80°F. at 100 fathoms and 70°F. at 200 fathoms, but at greater depths the Red Sea maintains that temperature down to the bottom at 1,000 fathoms, while outside the barrier in the open ocean the temperature decreases with the depths to 40°F. at 700 fathoms and about 35°F. at 1,000 fathoms. The same conditions are found in more or less enclosed areas in various parts of the oceans, such as the Sulu Sea, at Celebes, the Azores, and

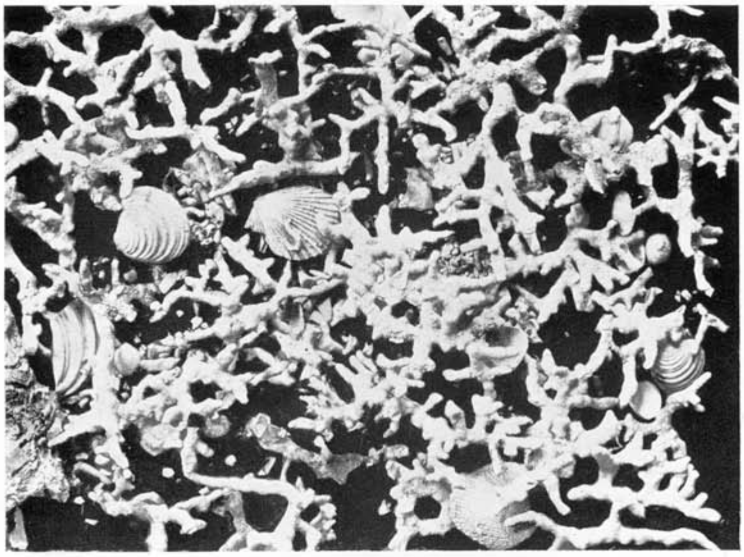
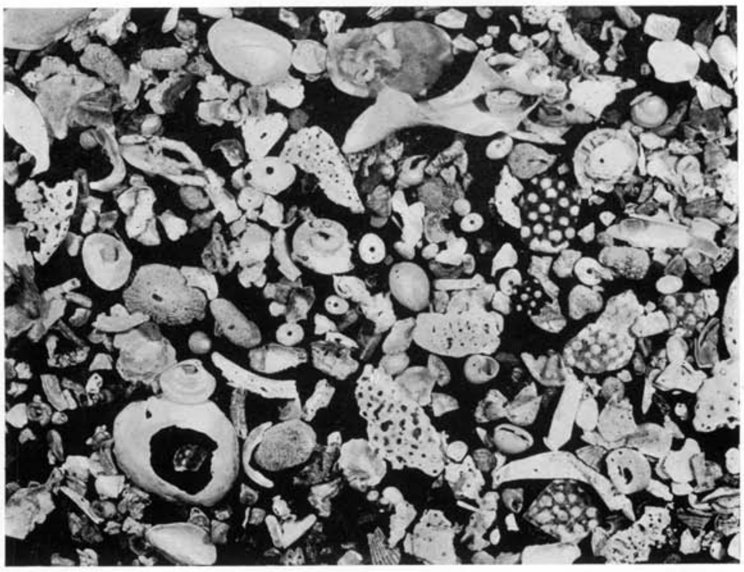


FIG. 1.—Plant Neritic deposit from the Irish Sea, composed of the Nullipore *Lithothamnion polymorphum*; natural size.



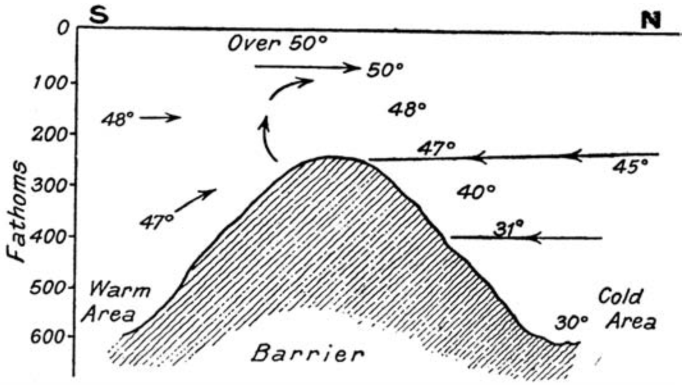
[*Photographs by* A. FLEMING.

FIG. 2.—Animal Neritic deposit from the Irish Sea, composed of remains of Molluscs, Echinoderms, Polyzoa, etc.; natural size.

FIG. 5.—DIAGRAM SHOWING RED SEA BARRIER.

the Faroe Channel, where the "Wyville Thomson" ridge prevents the cold Arctic water from invading the warm area to the south of the barrier (see Fig. 6).

Quite apart from the effect of such barriers, there are other variations in the distribution of temperatures according to depth, due to the circulation of special currents of different temperature which mix very slowly with the surrounding water. Some temperature sections through the ocean are very regular in arrangement, the isotherms being horizontal and arranged in order, the temperature decreasing with the depth—a section through the Atlantic for some distance west of the Canaries shows that normal condition; while other sections



are very irregular, the isothermal lines being far from horizontal and curving up and down according as masses of warmer or colder water are encountered. Examples of such very irregular temperature sections are seen in various parts of the North Atlantic. In a section from the Sargasso Sea northwards towards the banks of Newfoundland the isotherms, at first quite regular, rise rapidly towards the surface as colder water is reached, and then spread rapidly downwards in the warm Gulf Stream, to rise once more in the colder coastal waters. A little way off the Newfoundland Bank the isotherms, which are practically horizontal over the

Bank, turn steeply downwards to form a cold wall against which the warmer waters of the Gulf Stream run eastwards.

Layers of water—both surface and deeper—of different temperatures, and having also other distinguishing characteristics, can be traced for considerable distances in the ocean, by means of hydrographic observations, and their source determined and ultimate destiny predicted; and in that way the distribution of various pelagic animals which are affected by the temperature and other characteristics of the water can be explained. Murray and Hjort have in this way shown how the spread of the Pteropod *Clione limacina* from the sea about Newfoundland towards the west coast of Ireland depends upon the temperature of the water met with.

If we take the temperatures in another direction through the North Atlantic from the work of the "Michael Sars," we find in a section from the Sargasso Sea to the Norwegian coast at Lofoten that the isotherm of, say, 50°F. can be traced rising from a depth of about 400 fathoms to the surface, showing the gradual cooling of the upper waters in going north. A more complicated case, where waters from three different sources, each having characteristics which are recognizable, occur in the same section, is seen to the west of Norway. Proceeding towards Jan Mayen, after passing through a belt of coastal water, there is an area of warmer and salter Atlantic water at a temperature of about 7°C. overlying the mass of cold Arctic water which occupies the greater part of the deep channel and has a temperature of 3°C. in its upper part, 0°C. in the intermediate depths, and —1°C. at the bottom. This is an example of cold polar water creeping along the sea bottom towards the equator; and, as a rule, in the open sea, the bottom isotherms are quite independent of those on the surface. The surface isotherms run generally in an easterly and westerly direction roughly parallel to the equator (though they may be diverted from this course), while the bottom isotherms run more or less north and south, following the contours of the continents and of the floor of the ocean.

These are some of the more important results in regard to the distribution of temperature in the sea discovered by the “Challenger” expedition and by other oceanographers since; but it must be pointed out that there are also exceptional cases, or variations from the normal arrangement, due to unusual causes, probably in some cases of periodic occurrence. These give rise to occasional increase or diminution of known oceanic currents, and the consequent inflow of water of unusual character into an area—and this is generally first recognized from the strange organisms accompanying the water.

As an example of another occasional influence affecting the temperature of the water, there is the effect of wind. Sir John Murray, and others since, have shown the well-marked effect of prevalent winds upon the distribution of temperatures in the Scottish lochs or in narrow fjord-like arms of the sea. Murray, for example, showed that in Loch Lochy, in April, 1887, after a south-west gale, the warmer surface water was driven away from the south end of the loch and was piled up at the north end, displacing colder water down to a depth of 10 fathoms. Water of intermediate temperature was also carried away from the south end and accumulated farther north down to a depth of 25 fathoms, so as to allow colder bottom water to come to the surface at the south end of the loch. In Loch Ness, on the same occasion, he found even a more extreme condition, where the bodies of water of three temperatures formed almost vertical columns, the warmer at the leeward (north) end, the colder at the windward (south), and the water of intermediate temperature in the middle of the loch (see Fig. 7.).

A similar effect may be produced on the sea coast where a strong off-shore wind will carry out the surface water, with its contained organisms, and so allow deeper water to well up close inshore (Fig. 8). Even in the open ocean, in places and under special conditions, vertical currents may be formed, causing deeper layers of colder water, with their contained organisms, to rise to the surface.

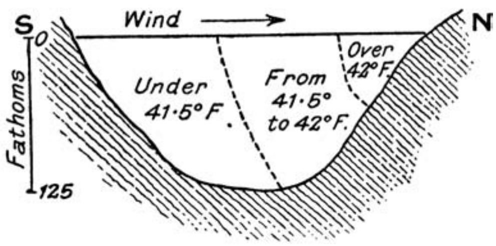


FIG. 7.—DIAGRAM SHOWING EFFECT OF WIND ON DISTRIBUTION OF TEMPERATURES IN LOCH NESS. *(After Murray.)*

SALINITY.

As all the water running off the land into the sea dissolves and carries with it materials from the rocks and the soil, it is probable that the ocean contains samples, even if only minute traces, of every mineral substance found on earth. Over thirty of the known elements have been found in sea-water, and more than a dozen of these are in such quantity as to be of real importance. These contained "salts" of sea-water amount on the average to

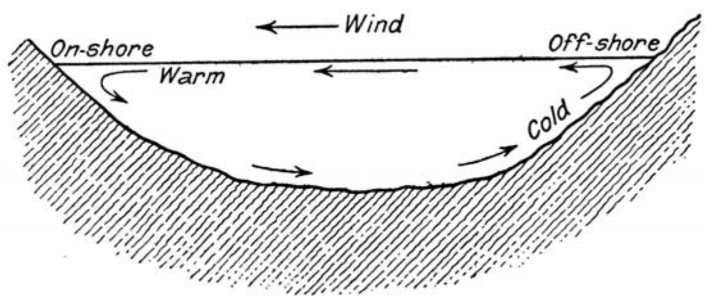


FIG. 8.—DIAGRAM SHOWING EFFECT OF OFF- AND ON-SHORE WINDS AT SEA.

thirty-five parts in a thousand parts of water, and are chiefly chlorides and sulphates of sodium, magnesium, potassium and calcium. Chloride of sodium (common salt) makes up more than three-fourths of the whole, whereas in the water of rivers bearing material from the land to the sea it only amounts on the average to about 2 per cent. of the dissolved salts. On the other hand, carbonates, of which only minute quantities are present in the sea, make up over half the total in the case of river-water. It is these and other differences that have given rise to the view that the saltness of the sea is not due merely to the dissolved salts now being conveyed from the land to the sea, and accumulated there throughout the ages as the result of the constant evaporation of pure fresh water from the surface, but may be due also in part to salts present in the primeval ocean when condensation first took place on the globe. We know little or nothing, however, of the proportions in which such salts may have been present in the earliest oceans, and as little of the chemical changes which may have taken place in the dissolved salts accumulating in the sea during geological ages.

The volume of the total salts in the sea has been calculated to be 4,800,000 cubic miles; and one of the most recent estimates of the age of oceans on the earth (not necessarily the present ones) is nearly a hundred million years.

The principal salts present in average sea-water are usually stated (from Dittmar's "Challenger" results) to be as follows:— It is, however, probable that by far the greater part of these materials are not present in the above

Sodium chloride	27·213	parts	per 1,000.
Magnesium chloride . . .	3·807	,,	,,
Magnesium sulphate . . .	1·658	,,	,,
Calcium sulphate . . .	1·260	,,	,,
Potassium sulphate . . .	0·863	,,	,,
Calcium carbonate . . .	0·123	,,	,,
Magnesium bromide . . .	0·076	,,	,,
	35·000	,,	,,

form combined as salts, but are dissociated as "ions," and therefore a more correct statement of the constitution of the thirty-five parts contained in the thousand of sea-water is the following list given by Murray and others:— In addition to these

Na	10·722	parts in 1,000	of sea-water.
Mg	1·316	,,	,,
Ca	0·420	,,	,,
K	0·382	,,	,,
Cl	19·324	,,	,,
SO_4	2·696	,,	,,
CO_3	0·074	,,	,,
Br	0·066	,,	,,
	35·000	,,	,,

principal constituents of sea-salt, there are a few other elements (such as silicon and phosphorus) present in smaller quantity, but still of great importance in connection with living organisms and the general metabolism of the ocean. It is obvious, when we consider the life of animals and plants in the sea, that some of these salts are constantly being withdrawn from the water to form shells and skeletons and other hard parts, and are again later on being returned to the sea by solution. There is thus a perpetual interchange or circulation of such materials as calcium and silica, and there may also be vast accumulations formed of, for example, carbonate of lime in the deposits forming on the floor of the ocean. These are by no means the only materials withdrawn from the water by the action of living organisms and by chemical reactions at the sea bottom.

Three gases dissolved in sea-water—oxygen, nitrogen, and carbon dioxide—are of primary importance in connection with living organisms. The sea absorbs air from the atmosphere, but dissolves a larger proportion (about 34 per cent.) of oxygen than of nitrogen. Moreover, as water at a lower temperature absorbs more gas, the cold polar waters may contain nearly twice as much of the dissolved gases as the warm tropical water. As oxygen is constantly being used up by animals, it must constantly be renewed, and as it is present in the water at all depths (except in the case of enclosed deep basins like the Black Sea where in the bottom waters there is a marked deficiency of oxygen and a large production of sulphuretted hydrogen), there must be sufficient circulation of the bottom waters to convey the oxygen into the abysses.

In addition to what is present in combination, carbon dioxide is found free in small and variable quantities in sea-water. There is a free interchange of carbon dioxide between the surface of the sea and the atmosphere, and this tends to regulate the amount in the water, which, however, varies considerably from time to time, as there are great differences in the amounts used and produced by plants and animals respectively in different parts of the sea and at different times of year.

Various methods have been employed to determine the salinity of sea-water, such as evaporating, drying, and weighing the salts; ascertaining the specific gravity or weight relatively to fresh water, at a definite temperature, such as 60°F.; or estimating the amount of chlorine by titration and calculating from that the total salts present, as the ratio of the salts to each other is practically constant although the total quantity may vary from as much as 39 parts in 1,000 down to 31—or any amount less close to land or in estuaries. Even in the North Atlantic (an ocean of relatively high salinity) regions differ greatly. For example, in the Sargasso Sea the salinity may be from 37 to 38 parts per thousand, at the Azores 36, off the west of Ireland 35, and from 34 down to 31 close to Newfoundland. The highest records known (over 39‰) are in the Eastern Mediterranean and the Northern Red Sea, where the evaporation is great and the rainfall small in amount.

In the open sea, as a general rule, the salinity diminishes from the surface downwards to about 1,000 fathoms, but in still greater depths there is generally salter water at the bottom. Near land, however, there may in places be a layer of fresh, or almost fresh, water on the surface. This is well marked at the upper ends of fjords in Norway and in some of the Scottish sea-lochs, where the water from a stream may lie on the surface of the salter sea-water, without mixing, to such an extent that it is drinkable as fresh water.

Currents may be traced in the sea for considerable distances by their salinity. At the Strait of Gibraltar a strong surface current of colder and less saline water flows in from the Atlantic to make up for the large amount of evaporation in the Mediterranean, and a return current of warmer and salter water flows out along the bottom, over the barrier at a depth of about 100 fathoms, into the Atlantic, where it can be traced for some distance. Similar interchanges are known in other parts of the world, and the presence of these currents of different temperatures and salinity has a profound effect upon the distribution of many pelagic animals.

In brief, it may be stated that the distribution of marine organisms depends mainly upon the temperature of the water, the temperature in any region depends largely upon the existence of currents of different salinities and temperatures, these currents are caused mainly by prevalent winds, the winds are due to differences of barometric pressure, and these pressures depend finally upon the action of the sun's rays.

The origin, course, and effect of a typical warm current of high salinity (the Gulf Stream) will be dealt with in more detail in the next chapter.

DENSITY.

A salinity of 35 parts per thousand corresponds to a density or specific gravity of 1.026 (fresh water being taken as 1), and the increase in density (and reduction in temperature) with increasing depth in the ocean is seen in the following series:— A familiar effect of difference in specific gravity is seen in the increased buoyancy

Surface	density	= 1·025.	
100 fathoms	,,	= 1·026 (temp.	= 60·7° F.).
300 ,,	,,	= 1·027 (,,	= 44·7° F.).
2,000 ,,	,,	= 1·028 (,,	= 35·2° F.).

of a loaded vessel on entering the

sea from a river. A submarine is less buoyant, when passing from the sea at a density of 1.026 into fresh water, by 26 tons in a thousand, and *vice versa.* So that when a submarine of 1,000 tons leaves a river for the sea, she must take in an extra 26 tons of ballast to keep her down, and when she returns she must get rid of 26 tons, or she will sink deeper in the fresh water.

It has been pointed out by Buchanan that coastal waters are areas of minimum density, while the areas of maximum surface density are in the centres of the five tropical oceans, North and South Atlantic, North and South Pacific, and Indian Ocean. From these areas the denser surface water flows outwards in all directions.

Where layers of water of different densities and temperatures lie one upon another, the "discontinuity" line is often the boundary between two very different assemblages of organisms. It may also be the layer along which submarine waves are formed, as has been shown by Dr. Otto Pettersson on the west coast of Sweden, where these submarine waves of inflowing salter "Bank" water from the North Sea, underneath the surface fresher coastal water, bring shoals of herrings to constitute the important winter fisheries of the Skagerak.

PRESSURE.

We exist at the sea-level under the pressure of one atmosphere, which amounts to nearly 15 lb. on the square inch. At any depth in the sea there is the added weight of the water above, so the pressure increases greatly with the depth. A cubic foot of sea-water weighs 64 lb., and the pressure increases by one additional atmosphere for each 10 metres (or 33 feet) in depth—at 1,000 metres the pressure is that of 100 atmospheres. A diver at a depth of 30 fathoms sustains a pressure of 80 lb. per square inch, and at the greatest depths of over six miles the pressure is about 6½ tons on every square inch.

Water is almost incompressible—under one additional atmosphere it is compressed to the extent of only one-twenty-thousandth of its bulk, and this very slight compressibility decreases with increase of pressure. At 4,000 metres (2,187 fathoms) water becomes only 1.75 per cent. heavier, and a solid mass of iron of 1,000 grams shows at 4,000 metres only the insignificant difference of 0.3 per cent. in weight. Substances are thus seen to be practically as heavy in deep water as in shallow, and will sink as rapidly. A brass weight "messenger" sent down a line to close some apparatus takes just four times as long to reach its objective at 2,000 metres as it does to arrive at 500 metres. Any object that sinks in a foot of water will go to the bottom whatever the depth is; and the floor of the ocean at great depths is covered with delicate shells, which are very light and yet have sunk from the surface to the bottom. Solid objects, or those that are freely permeable to the water, so that the pressure can be equalised throughout, such as the body of an animal, remain practically unchanged; but substances with internal cavities containing air are strongly compressed and distorted under the enormous pressure of tons on the square inch at great depths, and may collapse into fragments. For example, the beam of the "Challenger" trawl came up from its first deep-sea trip with the wood so much compressed that the denser knots stood out from the surface, and Mr. Buchanan tells how a hollow brass cylinder with closed ends had been squeezed flat, and thermometers and closed glass tubes, wrapped up in cloth and protected by a copper case, came up crushed to powder, from a depth of 3,000 fathoms. Sir Wyville Thomson called this collapse under pressure an "implosion."

These facts completely dispose of the popular delusion that, on account of the great and increasing pressure, water in the sea becomes denser and denser with increase of depth, and that all objects which sink at the surface—ships and men, iron, lead, and gold—"find their level" and there remain suspended at the various depths. Sir John Murray, writing in 1913 *(The Ocean,* p. 96) in regard to this myth, said:—

"Within the past year the writer has often been asked if the 'Titanic' really reached the bottom in a depth of three miles. During the 'Challenger' expedition, after a funeral at sea, the bluejackets sent a deputation aft to ask if 'Bill' would go right to the bottom when committed to the deep with a shot attached to his feet, or would he 'find his level' and there float about for evermore ? Another question was, if 'Bill' really did go to the bottom, what would he be like on reaching bottom at four or five miles ?

"A living rabbit was on one occasion sent down to over 500 fathoms on a line. The body came up very little altered to all appearance, the bones were all intact, and the lungs were the only viscera that seemed to be affected by the pressure. Even at 3,000 fathoms a human body would be little altered in outward appearance.

"The 'Titanic' is probably now lying on the bottom in a very little altered condition: only those parts of the structure would be burst inwards ('imploded') into which water could not enter rapidly enough to equalize the pressure on the two sides, say, of an iron plate. As the vessel sank deeper and deeper, the corks in all the wine and beer bottles would be driven in if not quite full, and ultimately every hermetically closed chamber or recess would be imploded."

One interesting effect of the pressure is that if deep-sea animals are brought up too rapidly to the surface, they are killed by the disorganization of their tissues, due to the release from pressure, and if deep-sea fishes accidentally get out of their accustomed depth, and pressure, the expansion of the air in their swim-bladders renders them so buoyant that they continue to tumble upwards to the surface, helpless, and eventually killed by the distension of their bodies and the disorganization of their tissues, due to the diminished pressure. They die a violent death from falling upwards.

COLOUR AND LIGHT IN THE SEA.

Some of the varied colours of the sea can be explained, but we probably do not yet fully understand them all. Pure water has in bulk a clear blue colour, which is an optical effect due to the blue rays of the sun's light being less absorbed than the red rays, and therefore the characteristic colour of the open ocean, where there is no disturbing influence, is blue. Variations in the tint of blue and the occurrence of other colours, such as green, yellow, and grey, are due to impurities in the water or minute organisms present in great quantity. Green and yellow tints of different intensities occur near land, the olive-green of the Antarctic is caused by enormous quantities of Diatoms suspended in the water, and the deep blue round coral reefs is said to be due to carbonate of lime in solution. Other local or temporary conditions may affect the colour profoundly—for example, a plague of minute Dinoflagellates *(Gonyaulax,* etc.) may discolour the sea red for miles.

The light rays from the sun penetrate the sea to varying depths, according to their nature and the clearness of the water, the red rays being absorbed first and the blue penetrating more deeply. The effects of the light upon a photographic plate have been traced down to 300 fathoms off Capri, in the Mediterranean; and, in the Atlantic, Helland-Hansen's light-recording apparatus showed light-rays affecting the plate on an exposure of eighty minutes at 1,000 metres (547 fms.), but at 1,700 metres the plates were not affected after an exposure of two hours. Sir John Murray therefore considers the "photic zone" to be in general the upper 500 fathoms in the open sea. Near land and in oceanic water containing impurities or many minute organisms the light penetrates to lesser depths.

The degree of penetration of the light-rays has a profound effect upon the plants and animals of the sea. Green Algæ, which are only found near the surface, assimilate their necessary food matters only in yellow light, which does not penetrate far, while Red Algæ, which live in deeper water, assimilate better in the blue light, which reaches lower depths.

The colours of some animals seem to be related to the amount of light at the depths in which they live. On Sir John Murray's cruise in the "Michael Sars," in 1910, Dr. Hjort made a detailed investigation of the colours of the Atlantic pelagic fishes in relation to their distribution in depth, and his results show that the surface fishes down to about 150 metres are colourless; from 300 to 500 metres the fishes are silvery or grey; and at depths of 1,000 to 2,000 metres they are black or dark-coloured, and are associated with red-coloured Crustaceans, which at that depth would lose their colour and appear black. These prawn-like Crustacea, found in various parts of the oceans at depths of 300 fathoms and more, only look red when red light-rays fall upon them, and as no red rays penetrate so far through the water, these and other brightly coloured deep-sea animals in their natural habitat must appear dark, and probably quite inconspicuous, and only show up in their bright colours when brought to the surface.

Many of the surface animals, apart from fishes, are blue or violet, and tone in with the sea around them, while others down to 50 fathoms or so are gelatinous and quite transparent. Some of the surface animals—fish, crabs, and others—of the Sargasso Sea are coloured, and even shaped, so as to resemble parts of the "Gulf-weed" on which they live, and so become inconspicuous in their natural surroundings.

Many pelagic animals respond to different degrees of intensity of sunlight. Some Radiolaria in tropical seas flourish on the surface, others at varying depths below in what may be regarded as a subdued twilight, and one section of the group, the Phaeodaria (Challengerida) live only at a considerable depth, over 400 fathoms, probably for the most part below the photic zone. Other members of the plankton with some power of locomotion (such as *Sagitta)* descend to a moderate depth, under twilight conditions, during bright daylight, and come to the surface at night. Michael, and also Esterley and others working on the Californian coast, have demonstrated this diurnal migration in relation to light for many of the larger and more active members of the plankton, and the general principle of avoiding bright sunlight probably holds true for most, if not all, of the zoo-plankton. The largest catches of plankton are obtained, in most seas, not on the surface, but at a depth of 5 to 10 fathoms. Moreover, some of the bottom-living animals, such as Amphipods, Cumacea, and other higher Crustacea, are known to come to the surface at night.

Many of the "bathypelagic" animals which remain below the photic zone show peculiar adaptations to the absence of sunlight, such as the characteristic red colour, modification or loss of eyes, presence of special light-producing organs, and the development of tactile appendages.

VISCOSITY.

The viscosity of sea-water—the resistance it offers to a body falling through it—varies greatly with the temperature, and is much greater in cold than in warm water. Consequently, in polar seas, where the viscosity is great, there is little or no change in the amount in passing from the surface to the bottom, while in the tropics the small degree of viscosity in the warm surface water rapidly increases in passing to deeper and colder layers—as the temperature falls the viscosity increases.

Taking the value of the viscosity of pure water at freezing-point as being 100, then in sea-water having a salinity of 35‰ (per mille) the viscosity at a few temperatures such as would be met with in the tropics between surface water of over 80°F. and the cold bottom water would increase, as shown in this table (adapted from Murray):—

Temp. C.	Viscosity at 35°/oo sal.	Specific gravity at 35°/oo sal.
30°	47	21·76
20°	59	24·79
10°	76	26·98
0°	103	28·13

In falling a little over 20 centigrade degrees the viscosity is nearly doubled. At, say, 500 fathoms (the lower limit of the photic zone) in the tropics, where the temperature is, say, 40°F., the viscosity is twice as great as at the surface, where the temperature is, say, 80°F. Therefore planktonic organisms would sink twice as fast at the surface as at 500 fathoms, and consequently, to meet this difficulty, some of them have developed devices to increase their surface resistance, or others to diminish their specific gravity, such as oil globules and gas bubbles, and increase of branched or flattened appendages, along with a general reduction in size and weight. Polar animals obviously do not require these adaptations to rapid variations in viscosity so much as those inhabiting the warmer seas, and consequently "suspension organs" are more characteristic of the latter.

It will be noticed from the table above that the specific gravity of the water also increases somewhat with the decrease of temperature in deeper water. This, along with the increase of viscosity may be a help to a slowly sinking organism in delaying its progress downwards.

ALKALINITY.

The general alkalinity of sea-water is due to the presence of the hydroxides of magnesium and calcium, but the degree of alkalinity varies greatly from time to time and from place to place, and depends to some extent at least upon the amount of free carbon dioxide present in the water. Our knowledge of the variations in alkalinity throughout the year has been increased greatly of late years by the work of the Scandinavians, Palitzsch, Witting, and Sörensen, of the late A. G. Mayer at the Carnegie Institute in the United States, and of the late Benjamin Moore and others working in the Irish Sea. The sea around the Isle of Man was noticed more than ten years ago (in the course of our plankton work at Port Erin) to be a good deal more alkaline in spring (say April) than it is in summer (say July); and consequently, during the years 1912 to 1914, Professor B. Moore and his assistants undertook a detailed investigation at the Port Erin Biological Station, and by examining samples of the sea-water periodically, were able to show that there were marked variations in the hydrogen-ion concentration, as indicated by the relative degree of alkalinity, which gets low in summer increases somewhat in autumn, and then decreases rapidly to disappear practically during the winter; and then, after several months of a minimum, begins to come into evidence again in March, and rapidly rises to its maximum in April or May. This periodic change in alkalinity is seen to correspond roughly with the changes in the living microscopic contents of the sea represented by the phyto-plankton annual curve, and the connection between the two phenomena is seen when we realize that these changes in the alkalinity of the water are due to the relative absence of carbon dioxide. In early spring the rapidly developing myriads of Diatoms in their metabolic processes use up the store of carbon dioxide accumulated during the winter, or derived from the bicarbonates of calcium and magnesium, and so increase the alkalinity of the water, until the maximum of alkalinity, due to the fixation of the carbon and the reduction in the amount of carbon dioxide present, corresponds with the crest of the phyto-plankton curve in, say, April or May.

Testing the alkalinity of the sea-water may therefore be said to be merely ascertaining and measuring the results of the photosynthetic activity of the great phyto-plankton rise in spring due probably to the daily increase of sunlight.

The marine biologists of the Carnegie Institute at Washington have made some recent contributions to the subject by taking observations on the alkalinity of the open sea (determined by hydrogen-ion concentration), during which they found in tropical mid-Pacific a sudden change to acidity in a current running eastwards. Now in the Atlantic, the Gulf Stream and tropical Atlantic waters generally are much more alkaline than the colder coastal water running south from the Gulf of St. Lawrence. That is, the colder Arctic water has more carbon dioxide. This suggests that the Pacific easterly set may be due to deeper water containing more carbon dioxide (= acidity), coming to the surface at that point. The alkalinity of the sea-water can be determined rapidly by mixing the sample with a few drops of an indicator and observing the change of colour; and this method of detecting ocean currents by observing the hydrogen-ion concentration of the water might be useful to navigators as showing the time of entrance to a known current.

OTHER PHYSICAL CHARACTERS.

The phenomena of tides, due primarily to astronomical causes, the formation of waves, the presence and movements of seiches (tidal, temperature, etc.), and the circulation of the atmosphere and other meteorological changes, although all of some oceanographic importance, need not be dealt with in this outline of hydrography. To discuss all these subjects adequately would require far more space than is available in the present book.

SOME EFFECTS UPON LIFE IN THE SEA.

I may conclude this chapter with a brief statement as to the bearing of some of these physical characters of the sea upon the distribution and habits of some living organisms.

1. *Depth* is a prime factor in the distribution of marine plants and animals. There are littoral, shallow-water, and

deep-sea forms, and comparatively few species have a wide bathymetrical range.

2. *Temperature* has a profound effect upon the distribution of most marine organisms. As notable examples on a large scale may be given the distribution of coral reefs, which are only found in tropical seas, where the temperature throughout the year is not lower than 68°F.; and the case of sea-fisheries, many of which are determined by the temperature of the water in which the fishes live. Rise of temperature increases the rate of metabolism in an organism, and this probably has far-reaching effects in the sea. Then, again, the secretion of carbonate of lime by marine animals is greatly increased by a rise of temperature.

3. *Salinity,* etc. Some animals can only exist in water of a certain density, some only deposit their eggs under certain conditions of salinity, and the flotation and further development of the eggs and later stages of many of our food-fishes depends upon the specific gravity of the water. Moore, Roaf, and others, in their work at the Port Erin Biological Station, have shown that the chemical characteristics (hydrogen-ion concentration or alkalinity) of the sea have a profound effect upon the development of embryos and larvæ. The shoaling movements of the herring, which give rise to important fisheries, take place successively farther and farther south on the east coast of Britain during summer and autumn, and this is associated with the salinity of the sea, as Atlantic water of 35‰ and temperature 13°to 15°C. moves south from the Shetlands towards the English Channel. The winter herring of the Skager-Rack do not frequent Atlantic water, but are found in the "Bank" water of 32‰ to 33‰. Consequently, when there is too much Atlantic water entering the Skager-Rack, no winter herring fishery takes place.

4. *Pressure* is obviously an important factor in the life of deep-sea animals, and probably in varying degree determines the distribution of many others at lesser depths.

5. *Sunlight* is all-important in connection with photosynthesis by Diatoms and other plants in the sea. Its effect is also evident in the heliotropic movements of Copepoda and many other free-swimming animals, and in the vertical rise and fall of plankton. All the energy made use of by organisms is ultimately derived from the energy of solar radiation. There appears to be some connection between the periodic changes in solar energy indicated by "sunspots" and variations in the strength of oceanic currents, and these in their turn affect some of the periodic fisheries, such as the great Norwegian cod fisheries at Lofoten.

6. In addition to these large and obvious factors affecting the distribution of marine organisms, it seems probable that some very slight modifications in the physical condition of sea-water may have a curious effect upon their life and prosperity. Some animals will live healthily in one tank in a biological station and not in another; the proximity of other animals may in some cases be an advantage and in others the reverse; it is even possible that meteorological conditions may exercise some subtle influence upon animals on the sea bottom through several fathoms of water, as in the following case, which seems well established:—Crabs and lobsters at Port Erin are never caught in quantity during northerly to easterly winds and in cold dry weather, but if the wind goes round to the south-west and it becomes warmer and damper, the crabs "travel," as the fishermen say, and are then caught in the creels in abundance.

CHAPTER IX

OCEAN CURRENTS—THE GULF STREAM

There are several distinct types of movement of the water in the oceans:—

1. *The Tidal Wave* (caused by the attraction of the sun and moon), which rises and falls every 12¼ hours, and is only seen in its unmodified form in the great Southern Ocean, where it has a free and uninterrupted course around the globe. This gives rise to branch waves that extend up the oceans between the continents, and may become very much complicated where they meet with obstruction. The rise and fall of the tidal wave gives origin to tidal currents in shallow water near land, or over oceanic shoals. Such tidal currents have been detected down to the considerable depth of 400 fathoms in the open ocean. Higher tides (" spring tides ") occur at the time of full moon and new moon, and less high (" neap tides ") at the time of the first and third quarters of the moon. Further details are more a matter for the astronomer than the oceanographer.
2. *Waves and Storms* and drift of surface water are caused by the wind. As proof of the existence of surface drifts for great distances, we have the evidence of golf-balls from Scotland found at the Lofoten islands in the north of Norway, and Siberian drift-wood carried into the Norwegian seas. The waves of the open sea may give rise to a current on approaching a shore. As a general rule, what Murray has called the "mud-line," at a depth of about 100 fathoms on the coast of a continent facing the open sea, is the region where the finest particles are undisturbed by wave action, but it is said that there is evidence of waves affecting

the bottom deposit down to a depth of about 200 fathoms.

3. *Seiches* are oscillations in a body of water in an enclosed basin or bay, or even in the open ocean, where the water is caused to swing to and fro round one or more pivots or "nodes." Temperature seiches and density seiches may also occur beneath the surface in a body of water where there is a "discontinuity layer" causing an abrupt change in temperature or density of the water above and below. The lower layer may then swing backwards and forwards without causing movements at the surface.

4. *Currents.* True ocean currents are bodies of water of definite constitution, often differing markedly from the surrounding water, through which they flow like a river without much mixing and retaining a clearly defined border (as in the case of the Gulf Stream). Ocean currents are all in the long run due to the energy derived from the sun, but the more immediate causes may be stated as—

   > "(1) The sun's heat causing differences of temperature,
   >
   > "(2) Differences in amount of evaporation and of rainfall, and hence of density of the water.
   >
   > "(3) Prevalent winds. The direct frictional action of the wind is a prime factor in oceanic circulation.

As these causes have much the same action in each of the three great oceanic areas—the Atlantic, the Pacific, and the Indian Ocean—they give rise to comparable systems of currents, modified in each case by local factors, such as the shape of the land. In the Atlantic, for example, the chief oceanic currents describe a figure of eight (8) moving, as a result of the rotation of the earth, clockwise to the north— east—south in the North Atlantic, and counter-clockwise to the south—east—north in the South Atlantic, the central crossing being in the interval between the great North and South Equatorial currents which flow westwards before the trade-winds. In this interval lies the Counter-Equatorial current flowing eastwards to the African coast, where it becomes the Guinea current. (See Fig. 9.)

The Gulf Stream, which has its origin in these great equatorial currents, may be taken for more detailed description, as it is certainly the most celebrated and best known of all oceanic currents. The trade-winds blowing across the North Atlantic from the west coast of Africa carry the North Equatorial current from about Cape Verde towards the West Indies and the Caribbean Sea, where it is reinforced by a branch from the

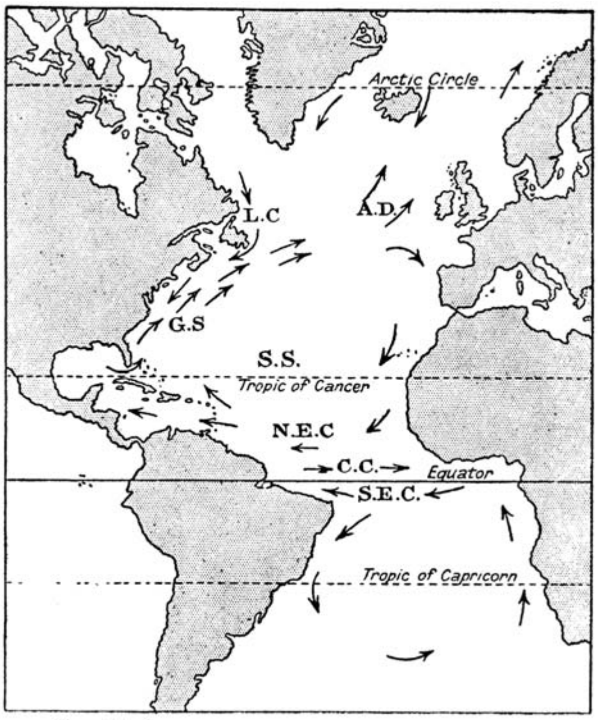


FIG. 9.—Simplified Map of Currents of the North Atlantic.—A.D. Atlantic Drift, C.C. Counter Equatorial Current, G.S. Gulf Stream, L.C. Labrador Current, N.E.C. North Equatorial Current, S.E.C. South Equatorial Current, S.S. Sargasso Sea.

South Equatorial current. This equatorial water, heated by the tropical sun and rendered salter by evaporation, becomes heaped up against the Central American coast. The levels of the Caribbean Sea and the Gulf of Mexico are thus raised, and this hot, salt water pouring in from the south-east escapes through the Strait of Florida as a river 50 miles wide, 350 fathoms deep, flowing at five miles an hour. This is the celebrated "Gulf Stream," to which, directly or indirectly, we owe the genial climate of North-west Europe as compared with corresponding latitudes in North America. In latitude 58°N. off the Hebrides, in July the temperature of the sea is 13°C. (55.4°F.), while at the same latitude off the coast of Labrador, in the same month, the temperature is 4.5°C. (40.1°F.). Since the advantages in climate enjoyed by the eastern borders of the North Atlantic are due, even if indirectly, to the Gulf Stream, the origin, extent, and distribution of that great current must be matters not only of scientific but of surpassing popular interest.

The Gulf Stream has been recognized by navigators since very early times. It is indicated on a seventeenth-century map, and Benjamin Franklin, in 1770, published a well-known representation of it, which has been reproduced in many books. "There is a river in the ocean" are the words with which Captain M. F. Maury commenced the chapter on the Gulf Stream in his *Physical Geography of the Sea* (1860), and he goes on to tell us that its banks and its bottom are of cold water, while its current is warm, and it is more rapid than the Mississippi or the Amazon, and its volume more than a thousand times greater. Its waters are not only warmer but are salter and of a bluer colour than those of the sea through which they flow. It arises, as a "gulf stream," in the Gulf of Mexico, flows out to the Atlantic by the Florida Pass, and runs in a northerly course past Cape Hatteras towards the Banks of Newfoundland, where it turns more to the east, gradually widening and losing speed and heat as it goes. It is 32 miles wide where it emerges from the Narrows of Bemini, between Florida and the Bahamas, and flows with a velocity of 4 knots; off Cape Hatteras it has widened to 75 miles and slackened to 3 knots, while to the south of the Great Bank of Newfoundland its rate is only 1½ miles an hour. Though thus changing in cross-section and speed, it is said to preserve its individuality and distinctive character for over 3,000 miles. Off the coast of North Carolina the edge of the stream is still sharply marked, the clear indigo blue of the warmer water abutting against the dull green of the coastal water of the United States and forming a line that is visible to the eye of the passing sailor. Even as far north as the Banks of Newfoundland the temperature of the Gulf Stream water is from 20°to 30°F. higher than that of the surrounding sea.

The Gulf Stream, however, is not constant in volume and in position. It shows seasonal and even annual variations. Petermann (1870) insisted on the seasonal variations in the strength of the Gulf Stream, and this has been fully established since by H. N. Dickson. The limit of its northern edge off Cape Race, Newfoundland, is in March about latitude 40°to 41°, and in September about latitude 45°to 46°. It is pushed down to the south by the colder water in winter, and then expands to the north in summer. Its drift eastward across the Atlantic towards Europe is strongest in summer. It shows, moreover, pulsations extending over periods of years, the effects of which in the north of Europe can be traced, according to the Scandinavian investigators, in their weather, their harvests and their sea-fisheries.

Benjamin Franklin attributed the Gulf Stream to the action of the trade-winds, and this was the prevalent view amongst seafaring men until Captain Maury in 1860 put forward the view that the winds were insufficient to produce the effect, and that the true cause of the strong current of tropical water of high salinity was to be found in the difference of specific gravity and of temperature between the water in the Gulf of Mexico and in the Atlantic outside. But the high salinity would render the Gulf water heavier and the high temperature causes it to be lighter, so these two characteristics would tend to counteract, and the resulting effect could only be due to whatever difference remained.

James Croll (1870), the Scottish geologist, was the first to criticize Maury's theory and to show that his causes were inadequate and contradictory. W. B. Carpenter in 1870 advanced the view that the Gulf Stream was only a special case of the general oceanic circulation due to cooling and sinking at the poles and heating at the tropics. Wyville Thomson, in the *Depths of the Sea* (1872), disputes this, and reverts to Sir John Herschel's opinion (1846) that the heat-distribution of the North Atlantic is due to the Gulf Stream, and that that current is mainly caused by the trade and anti-trade winds.

It is now known, however, that the Gulf Stream is not an independent phenomenon, but is a part of the general system of surface circulation of the ocean, a system in which the currents (diverted to the east, as a result of the rotation of the earth, in their course northwards from the equator) flow clockwise in the North Atlantic around a central relatively calm area, the Sargasso Sea, in which sea-weeds and other floating objects accumulate.

We have seen that the cause of the Gulf Stream can be traced back to the great north equatorial current which flows from east to west and forms the southern boundary of the Sargasso Sea. This magnificent equatorial stream, driven across the Atlantic by the trade-winds, conveys such an enormous body of warm and relatively salt water into the Caribbean Sea and the Gulf of Mexico as to raise the level of these seas by several inches above that of the Atlantic, before emerging as the Gulf Stream through the narrow Strait of Florida at a temperature of 86°F.

The officers of the United States Coast Survey have made many hydrographic sections across the Gulf Stream area from Havana, in the Gulf of Mexico, to Cape Cod, Massachusetts, and we owe the most detailed modern information to their work. When followed on its easterly course it is found that the Gulf Stream as a definite current or "river in the ocean" gradually dies away and is finally lost about latitude 45°opposite the Newfoundland banks, and it is generally considered that the surface drift which continues its influence farther to the north and east is due to the anti-trade southwest winds.

The Labrador cold current passes down south inside the Gulf Stream along the New England coasts to Carolina, forming a "cold wall" which dips under the Gulf Stream as it issues from the Strait of Florida. This "cold wall" of the oceanographers, as seen, for example, near the Newfoundland banks, is a remarkable phenomenon. The bottom water over the banks at the latitude of Paris is as cold as in polar seas (say, –1.5°C.), while outside the banks the warm salt Gulf Stream water has a temperature of over 16°C. Where the waters adjoin the curves of temperature and salinity are closely placed and run at a high angle.

What is left of the Gulf Stream when it reaches mid-Atlantic is no longer a continuous body of water, but is composed of separate bands and swirls, expanding fan-like and changing from time to time. Nansen and Helland-Hansen found great variations from year to year in the temperature of what they recognize as Gulf Stream water in the Norwegian Sea, and these cause variations in the temperature of the air, in the year's harvest, in the growth of trees, and in the presence of shoals of fishes on the Norwegian coast. There is even said to be a correspondence from year to year between the temperature of the sea in February and the flowering of the Coltsfoot (Tussilago farfara) in April.

Some hydrographers state that no Gulf Stream water reaches Europe; that in March it attains the Azores at farthest, and in November nearly to Spain, but always curves round to the south to surround the Sargasso Sea; and that north of the true Gulf Stream the "Atlantic Drift" arises, due in part no doubt to prevalent south-west winds, and so brings warmer and denser water to our seas from the sub-tropical Atlantic; while Le Danois, in France, has recently stated that the Gulf Stream does not extend beyond the Sargasso Sea, and that beyond that there is merely a permeation of the North Atlantic by salter and warmer water expanded as the effect of the tropical sun on the equatorial waters—but the effect upon European seas is the same whichever view we adopt, and it matters little whether we call the water that reaches our western shores "Gulf Stream" or "Atlantic Drift." We are indebted directly or indirectly for the amenities we enjoy on the eastern shores of the Atlantic to that mighty river which issues from the Gulf of Mexico and spreads its beneficent influence over the North Atlantic, and is certainly one of the greatest of oceanographic phenomena.

We have seen that the Gulf Stream does not reach mid-Atlantic as a continuous body of water. It is when off the Banks of Newfoundland that it first appears to break up and form several main divisions: a northern branch which runs towards Davis Strait, partly as an under-current; an eastern branch running towards the Azores and, spreading out like a fan, merges finally into the Canary Stream and the great whirlpool of the Sargasso Sea; and a third or North European branch which runs towards the British Isles and is then continued up the Norwegian coast and also into the North Sea.

Dr. Otto Petterssen, writing of its general influence, says that this flow of warm surface water from tropical and subtropical regions continues like a wave through the North Atlantic Ocean, and is felt in the most distant parts of the Atlantic-stream system—as a rise in ocean level, highest in October to December and lowest in March, and a quickening of the warm under-currents; and these fluctuations of the Gulf Stream correspond with other phenomena, atmospheric, planktonic and in the migration of fishes. It is estimated that the Gulf Stream in the Atlantic gives off enough heat to warm the air all over North Europe, and oceanographic researches give hope that we may be able to predict winter temperatures in advance from observations on the temperatures of the sea. A fuller knowledge of the ocean currents ought to enable us to predict not merely the weather in general, but such details as the distribution of ice in the North Atlantic and the prospects of sea-fisheries for perhaps a year in advance.

The oceans of the globe perform a great equalizing function. All the movements of the sea are ultimately due to solar energy. The sea distributes the heat of the sun, conveying about half of that received in the tropics to higher latitudes, and it also tempers tropical climates by means of cold currents from the polar regions. By interchange of carbon dioxide with the overlying air it helps to maintain a uniform composition in the atmosphere, and by its slow changes of temperature it to some extent regulates climates. It supplies water-vapour to the atmosphere and rain for the land. It receives and redistributes materials from the land and maintains a huge population of organisms which form an all-important part of the cycle of organic and inorganic nature.

THE TILE-FISH

A very striking case of the possible influence of the occasional shifting of warm and cold currents upon the population of a portion of the sea is seen in the discovery and subsequent disappearance of the tile-fish in the North American Gulf Stream area.

A new and valuable food-fish was found off the coast of New England, between Cape Hatteras and Nantucket, in 1879, and was described under the name of "Tile-fish" (Lopholatilus chamœleonticeps). (See Plate XVIII, Fig. 1.) It is about the size of a cod, weighing up to about 50 lb., and occurred in great abundance at depths of from 50 to 100 fathoms, at 80 to 100 miles from the coast. For a couple of years it was fished by the cod-fishery schooners from Gloucester and other New England ports. It belongs to a group of fishes that inhabit warmer seas, and this tile-fish apparently frequents the western edge of the Gulf Stream in moderately deep water at a temperature of about 50°F. Specimens caught and examined were found to be gorged with a large species of Amphipod *(Themisto bispinosus).*

In the spring of 1882 incoming vessels reported that tile-fish were seen in countless millions floating upon the surface of the ocean, in a dead or dying condition, and covering thousands of square miles. A full account of the matter, as then known, was given in a report by Captain J. W. Collins, published by the United States Commission of Fish and Fisheries for 1882.

The dead fish were found over an area measuring 170 miles in a north-easterly and south-westerly direction, with an average width of at least 25 miles. Captain Collins estimated the area occupied at from 5,000 to 7,000 square miles, and that the number of dead fish must have exceeded a billion. The fishing schooner "Navarino," in March, 1882, reported having sailed through the sea, thickly scattered over with the dead fish as far as the eye could reach, for two days and a night, for a distance of at least 150 miles. Thousands of the fish were seen close together near to the vessel, and these were from 2 to 4 feet in length. The general opinion among the fishermen and others at the time seemed to be that the fish were killed by some submarine volcanic eruption or other great convulsion of nature. Captain Collins estimated from reports of the various fishing boats that there must have been about 256,000 dead fish in the square mile, and that at a low estimate about a thousand million pounds weight of edible fish were destroyed on that occasion.

The opinion is expressed in this official report that the tile-fish encountered a layer of unusually cold water, which paralysed and rendered them helpless to such an extent that they floated to the surface dead or in a dying condition. It is known that in that spring there were furious northerly gales, and an unusual quantity of ice off the coast of Newfoundland, and the cold Arctic current flowing south-west inside the Gulf Stream is said to have been unusually strong.

Professor Verrill had made known, from his extensive dredgings on the New England coast, that there is, on the continental shelf south of Cape Cod, a broad belt (which he called the Gulf Stream Slope) along the inner border of the Gulf Stream at from about 65 to 150 fathoms, where the temperature of the bottom water is decidedly higher than it is either inside or farther out, and on this broad belt he had found many animals which were only previously known from the Gulf of Mexico or off the coast of Florida. There is, in fact, a continuation upwards of the West Indian gulf-stream fauna, and probably the tile-fish is a member of that community.

In a dredging expedition after the destruction of the tile-fish Professor Verrill reported the scarcity or total absence of many of these sub-tropical species which had been taken in abundance in the two previous seasons at the same localities and depths. He found that the invertebrate bottom fauna of southern origin was practically obliterated on his Gulf Stream Slope.

The Fish Commission also sent a fishing vessel to go over the ground and fish systematically for the tile-fish in their former haunts. That boat worked for three days at the localities where they had been so abundant in the previous two years, but did not catch a single tile-fish.

From all the evidence there seems to have been a wholesale destruction of life at the bottom on this Gulf Stream Slope, caused by a lateral shifting of currents so as to bring colder water into the area where the tile-fish and the other sub-tropical animals had been formerly found in abundance. It was estimated by the Fish Commission investigators that the bottom of the ocean in this region must at the time have been covered to the depth of about 6 feet with the dead bodies of the tile-fish and other organisms.

The original presence and the subsequent destruction of the tile-fish may alike have been due to changes in the volume and consequent lateral shifting of the Gulf Stream and the Labrador current. That there are seasonal and other variations in the volume and temperature of the Gulf Stream waters in the North Atlantic was established and discussed in some detail by H. N. Dickson in 1901.[1]

I am indebted to Dr. C. H. Townsend, Director of the New York Aquarium, for some later information in regard to the reappearance in quantity of this valuable fish upon the old fishing-grounds off Nantucket and Long Island, at about 100 miles from the coast to the east and south-east of New York. It is believed that the tile-fish is now abundant enough in these waters to maintain an important fishery, which will add an excellent food-fish to the markets of the United States. It is easily caught with lines at all seasons of the year, and reaches a length of over 3 feet and a weight of 40 to 50 lb. During July, 1916, the product of the fishery was about two and a half million pounds weight, valued at $55,000, and in the first few months of 1917 the catch was four and a half million pounds, for which the fishermen received $247,000. Dr. Townsend, writing in March, 1920, says: "Since then (1915) we have had a regular fishery for tile-fish, the New York catch being made on tile-fish grounds about 100 miles south-east of New York. The Boston catch is taken a little farther to the eastward. Tile-fish are to be found in the New York markets plentifully enough in the summer, although fishing was much interrupted during the war."

It is no small matter to have introduced a new and important food-fish to the markets of the world, and the U.S. Fisheries Bureau deserve great credit for their success in investigating the fish, establishing the fishery and introducing this new food to the people.

[1] *Phil. Trans. Royal Soc., A.,* vol. 196, p. 61.

CHAPTER X
SUBMARINE DEPOSITS

The deposits which are forming on the floor of the ocean are derived partly from the wearing down of the land and partly from accumulations of the harder parts of the animals and plants that live in the water. The material from the land, forming "terrigenous" deposits, is partly carried to the sea by rain and rivers, and partly washed or worn off the coast by waves and currents. All such materials from the land may be either carried off in suspension or dissolved in the water. The greater part of this work which leads to the formation of terrigenous deposits is performed by rivers: they carry down thirty-three times as much sediment as is worn off the coasts by wave action. These sediments from the land are deposited in shallow water along the coasts of the continents as gravels, sands and muds of various grades and kinds, which farther from land become mixed with the remains of organisms either living on the bottom ("neritic") or floating on the surface ("pelagic"). Some continental shores have a much greater quantity of terrigenous deposits than others, on account of the larger amount of sediment brought to them by rain and rivers. For example, about half of the world is drained into the Atlantic Ocean, and most of this into the North Atlantic. More than half the total rainfall is on the Atlantic drainage area; and in consequence, the deposits of the Atlantic are more terrigenous than those of other oceans.

Marine plants and animals take up mineral substances in solution from the sea and build up their shells, skeletons and other hard parts, and these after death add to the deposits at the bottom. This takes place in shallow water as well as in the open ocean, but where there is much sediment from the land these organic deposits may be swamped and masked by the terrigenous gravels, sands and muds.

Chemical action may also take place in the sea-water, and so produce changes in the deposits in some localities or under some conditions, giving rise, for example, to glauconite, phosphatic concretions and manganese nodules.

Finally, there are contributions to the deposits made by submarine volcanic action, by the disintegration and decomposition of floating pumice into clay, by volcanic dust carried by the wind from the land, and by meteoric particles falling from space upon the oceans.

The leading authority on submarine deposits, and especially upon those of the deep sea, is the late Sir John Murray, who commenced the detailed study of the subject during the "Challenger" expedition, and continued it to the end of his life. It is safe to say that he has examined, classified and described more deep-sea deposits than any other man. The most comprehensive and authoritative work on the subject is the "Challenger" report by Murray and Renard on the deep-sea deposits of the Expedition, published in 1891.

Sir John Murray's primary classification of all deposits is into (1) Terrigenous, the gravels, sands and muds derived from adjacent land; and (2) Pelagic, the deep-sea "oozes" far removed from land and largely made up of the calcareous and siliceous remains of organisms which once lived in the surface waters of the open ocean, and after death sank to the bottom. It is convenient, however, to recognize and add a third category, which has been named Neritic, for those deposits, mainly calcareous, which are found in many shallow waters amongst terrigenous sands and muds, but are not themselves terrigenous in origin, being formed of the shells and other remains of Molluscs, Echinoderms, Crustaceans, Polyzoa, Sponges, Tunicata, and other bottom-living animals, and a few plants such as the calcareous Nullipores. I shall, therefore, classify the submarine deposits under these three primary divisions, which may be defined as follows:—

Terrigenous (Murray's term restricted), where the deposit is formed chiefly—say at least two-thirds, 66 per cent.—of mineral particles, characteristically quartz, derived from the waste of the land.

Neritic (Herdman, 1895), where the deposit is largely of organic origin, its calcareous matter being derived from the shells and other hard parts of the animals and plants living on the bottom (benthonic organisms).

Pelagic (Murray's term unaltered)—or better, planktonic—where the greater part of the deposit (except in the case of "Red Clay ") is formed of the remains of free-floating animals and plants which lived in the sea over the deposit. These pelagic deposits are produced by planktonic organisms, and are characteristic of the deep sea, where terrigenous materials do not penetrate, and where benthonic organisms are not present in sufficient quantity to cause neritic deposits.

The statement in brief form is:

Terrigenous, derived from the land;

Neritic, derived from benthonic organisms;

Pelagic, derived from planktonic organisms.

There are, however, transitional forms of deposit from the one group to another.

I. TERRIGENOUS. Deposits of varied mineral materials and many textures, but all derived from the waste of the land, and containing on the average about 68 per cent. of silica. The nature of the deposit depends chiefly upon the geological structure of the adjacent land and the agents of denudation and disintegration. There may be large boulders strewn upon the beach or in shallow water detached from a cliff or washed out of the Boulder Clay.

There may be all sizes of smaller stones forming various kinds and sizes of gravel, and grading down to coarse sand and then to fine sand, and finally mud. The nature of the sand and mud will depend upon the kind of rocks from which it is derived or the sediments brought down by the rivers; and as a rule in most places the terrigenous deposits become finer and finer the farther they are from the coast, until the mud-line is reached, where the finest particles suspended in the water are deposited. This is usually at a depth of about 100 fathoms on continental shores facing the open ocean.

In addition to these shallow-water sands and muds, obviously derived from the adjacent land, and usually characterized by quartz grains, Murray classifies under terrigenous certain deeper muds coloured blue or red by hydrated oxides of iron, or green by glauconite, and found around continental lands, farther out and deeper than the mud-line.

There are also volcanic muds round oceanic islands of volcanic origin and formed from the particles of volcanic rocks.

Around coral reefs and islands there may be coral-sands and coral-muds, calcareous deposits formed of the fragments of coral broken up and sometimes ground down to a very fine powder. It is possible that some of these coral muds are formed not mechanically but by bacterial action. The late G. Harold Drew, working at Tortugas, Florida, on the effect of *Bacillus calcis* in shallow tropical seas, found that this organism caused the precipitation of soluble calcium salts in the form of calcium carbonate ("drewite") on a large scale. He believed that his observations showed that the great calcareous deposits of Florida and the Bahamas, previously known as coral muds, are not, as was supposed by Murray and others, derived from broken-up corals, shells, nullipores, etc., but are minute particles of carbonate of lime which have been precipitated by the action of these bacteria. More recently, however, C. B. Lipman has repeated the observations both at Samoa and at Tortugas, and finds that Drew was mistaken in supposing that this precipitation was wholly due to the action of the organism (now known as *Pseudomonas calcis).* Further investigations on this matter are still (1923) in progress; but I have mentioned it as an example of the complications that may be present in the actions and interactions, mechanical, chemical and organic, in connection with such an apparently simple process as the grinding of coral fragments into coral mud. The bearing of these observations upon the formation of oolitic limestones and fine-grained unfossiliferous limestones must be of peculiar interest to geologists, and forms a notable instance of the annectent character of oceanography, bringing the metabolism of living organisms in the modern sea into relation with mesozoic and even palæozoic rocks.

The seaward limit of the terrigenous deposits is on the average about 200 miles from land, and these deposits cover in all about one-fifth of the area of the ocean.

II. NERITIC.—Amongst the shallow-water deposits there are some which are by no means "terrigenous," as they are not formed of particles derived from the land, but are constituted either wholly or in large part of the hard parts of the bottom ("benthonic") animals and plants living on the spot or close to. The shells of Molluscs, the exo-skeletons of Crustaceans, the tubes of some worms, the spines and plates of Echinoderms, the spicules of sponges, Alcyonarians and Tunicates, and also some calcareous algæ, such as corallines and nullipores, form such neritic deposits of organic origin, but not pelagic like the deep-sea oozes. These neritic deposits are very largely calcareous (up to 80 per cent. of carbonate of lime), and would form a highly fossiliferous limestone if consolidated.

In some places near land, at depths of 10 to 20 fathoms, the bottom may be covered with growing lumps and broken fragments, and water-worn particles of the branched nullipore *Lithothamnion polymorphum* (Plate XI, Fig. 1); in others there may be deposits almost wholly composed of the dead and broken shells of lamellibranchiate mollusca, such as mussels, cockles, and their allies; and on a bank off the south end of the Isle of Man, at a depth of 20 fathoms, there is a white shellsand (Plate XI, Fig. 2) composed of broken fragments of the mollusca *Pecten, Anomia, Pectunculus, Mactra, Venus, Mytilus, Cypræa, Buccinum, Emarginula, Purpura,* and *Trochus,* of various calcareous Polyzoa, such as *Cellaria fistulosa, Cellepora pumicosa,* and many Lepralids, of plates of *Balanus* and tubes of *Serpula,* and of plates and spines of several Echinoderms. Such a neritic deposit as this would form a rock almost wholly made up of fossils, and might be compared with some Tertiary deposits, such as the Coralline and Red Crag formations of Suffolk. In one of the neritic deposits south of the Isle of Man, close on sixty species of Polyzoa were recorded from one haul of the dredge.[1]

Although the neritic deposits are chiefly found on the continental shelf near land, they may also occur in shallow water on a submarine bank in the open ocean, surrounded by deep waters with their characteristic pelagic oozes. It may be argued that coral sands and muds are also neritic deposits, as they are formed of the remains of the hard parts of shallow-water organisms more or less *in situ.* But if the coral reef (which may be a large, inhabited island) be regarded as *land,* then the deposit derived from it may be called "terrigenous." As Murray has pointed out, hard-and-fast lines cannot always be drawn between some of the categories of deposits; they merge one into another by insensible gradations, as is only to be expected when we consider their mode of occurrence and origin.

III. PELAGIC (or Planktonic).—With the exception of the

[1] See Herdman and Dawson, *Fishes and Fisheries of the Irish Sea.* London, G. Philip & Son, 1902.

Red Clay, all these deep-sea oozes are formed mainly of the remains of planktonic animals (such as Foraminifera and Radiolaria) and plants (such as Diatoms and Coccolithophorida) which lived in the surface waters over the deposit. The following five distinct kinds of deposit were made known by Murray from the "Challenger" results: Pteropod ooze, Globigerina ooze, Red Clay, Radiolarian ooze, and Diatom ooze, and although typical representatives of each have very distinctive characters and localities, they may graduate one into another on their borders. Just as shallow-water coastal terrigenous deposits of gravel and sand may pass into neritic calcareous accumulations of shells or nullipores, so in deeper water in oceanic areas neritic assemblages of bottom organisms may be gradually replaced by the remains of pelagic molluscs to form a Pteropod ooze, and that in turn at a greater depth of, say, 1,000 fathoms by the disappearance of the delicate Pteropod shells becomes a Globigerina ooze, which at depths over 2,500 fathoms is gradually replaced by Red Clay, and that finally in certain abyssal areas acquires the characters of Radiolarian ooze.

The following short descriptions, summarized in the main from Murray's various writings on the subject, hold good, in general for these oceanic deposits, but do not indicate hard-and-fast boundaries:—

> "1. *Pteropod Ooze.*—A calcareous deposit occupying only about half a million of square miles and confined to the tropics, generally on submarine ridges, at depths of less than 1,000 fathoms. Its basis is a Globigerina ooze largely mixed with and masked by the large delicate shells of the pelagic mollusca, the Pteropods, and, to a less extent, Heteropods. As these thin Pteropod shells expose a large surface to the water as they sink through it, they become dissolved before reaching the bottom at greater depths. The rapidity of solution of the Pteropod shells is probably aided also by the carbonate of lime being in the form of aragonite, while the Globigerina shells are calcite. In the "Challenger"

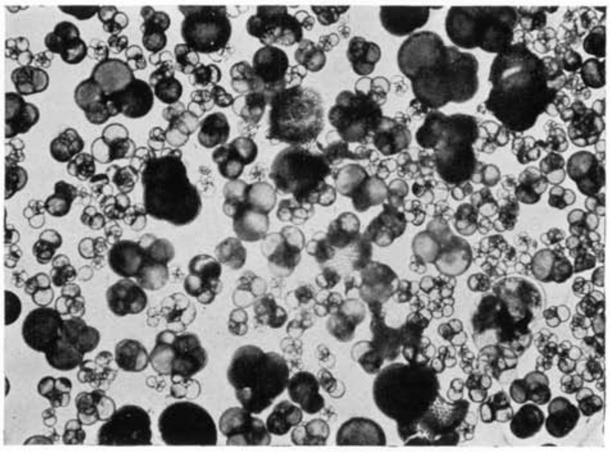


FIG. 1.—Globigerina ooze, from the floor of the Atlantic. × 25.

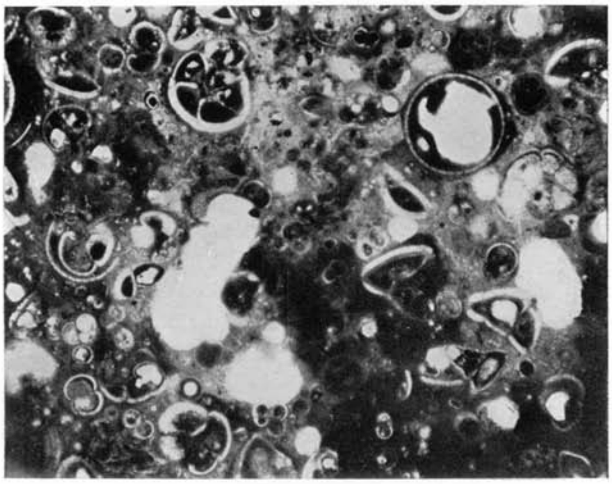


FIG. 2.—Section of consolidated Globigerina ooze from N. Atlantic, 1,675 fathoms. × 25.

[*Photo-micrographs by* E. NEAVERSON.

section through the Atlantic from Tristan d'Acunha to Ascension Island, wherever the depth is less than 1,000 fathoms Pteropod ooze is found capping the elevations, while the depressions between are occupied by Globigerina ooze. It occurs in similar manner on several isolated spots in the Pacific and Indian Oceans.

"2. *Globigerina Ooze.*—A calcareous deposit covering nearly 50 millions of square miles on the floor of the ocean in deep water, but not in the greatest depths. It is not found in cold seas, but elsewhere is widely distributed in depths of 1,000 to about 2,500 fathoms, and is especially characteristic of the North Atlantic, where it occupies 9 million square miles, nearly 40 per cent. of the area. It was first made known from the soundings of cable-laying steamers in the North Atlantic, described by Ehrenberg and Bailey (1853), and later by Wallich, Wyville Thomson, Carpenter, and others; and is carried far north into the Norwegian Sea by the effect of the Gulf Stream on the surface organisms. It is also found in the Indian Ocean, the South Pacific, and the Southern Ocean, but is almost absent from the North Pacific.

This deposit is formed mainly of the shells of Foraminifera which live in the surface waters, and of these the most abundant and characteristic is *Globigerina bulloides* (Fig. 10), although other allied species and genera are also commonly present, along with the calcareous Coccoliths and Rhabdoliths derived from minute surface algæ. Many other organisms are represented, but the relatively large and strong Globigerina shells mask the others and appropriately give their name to the deposit (see Plate XII, Fig. 1). Some idea of the kind of rock that might be formed from Globigerina ooze may be obtained by consolidating and sectioning a sample of the deposit (see Plate XII, Fig. 2).

The proportion of lime varies in samples of Globigerina ooze at different depths, from 30 to 90 per cent., the average being about 65. The deposit is in its most characteristic condition at depths of 1,200 to 2,200 fathoms. At lesser depths it may graduate into Pteropod ooze or coral deposits, and at greater depths it gradually loses the calcareous shells and passes into Red Clay at about 2,500 to 3,000 fathoms. During the "Challenger" expedition, Murray calculated,

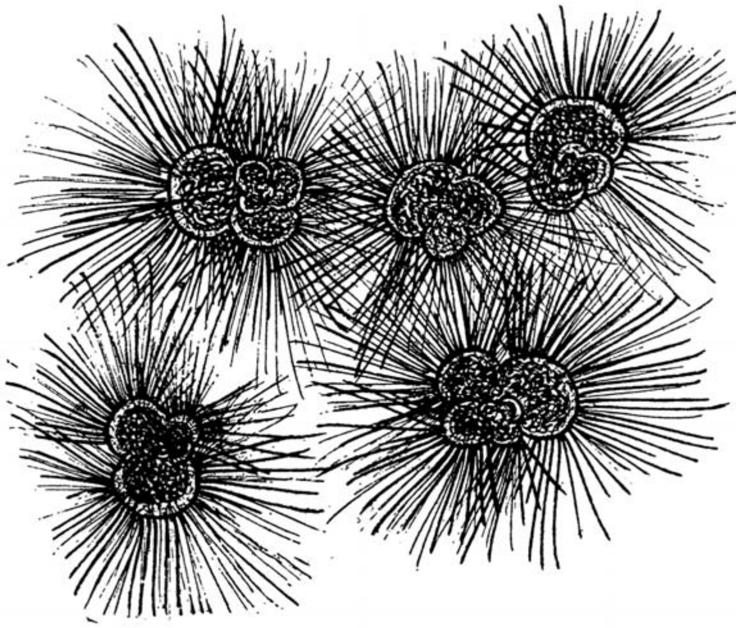


FIG. 10.—Sketch of living Globigerina from the surface of the Atlantic as seen under the microscope in plankton fresh from the tow-net. The opaque protoplasm inside the shell is of a brick-red colour. The wisps of spines are not seen on the shells in the ooze.

from his tow-net observations, that one square mile of tropical water 100 fathoms deep contained about 16 tons of carbonate of lime in the shells of Globigerina and allied organisms. These reach the bottom in a more or less perfect condition, according to the depth of water through which they have to fall. Once on the bottom and covered by others, they are safe from further solution, and typical Globigerina ooze is supposed (from the observations obtained by cable-laying ships in the North Atlantic) to accumulate at the rate of about one inch in ten years.

“3. *Red Clay.*—This deposit is characteristic of the abysses, the deeper parts of the floor of the ocean, and covers at least 50 millions of square miles at depths of 2,500 to over 5,000 fathoms. It forms the floor of more than half the Pacific.

It is a clayey deposit composed mainly of hydrated silicate of alumina and iron, derived from the decomposition of pumice and other volcanic particles and interstellar dust along with the residue of the dissolved Globigerina shells and other organisms. Quartz particles are rare or absent; but there are in places, especially in the Pacific, many manganese nodules of all sizes and layers of manganese on pumice, sharks ‘teeth, whales’ ear-bones, etc. The red colour of the clay is due to ferric oxide and peroxide of manganese, derived from the decomposition of volcanic rocks. Typical Red Clay is, then, a non-calcareous deposit, although it passes gradually into the calcareous Globigerina ooze of less deep water. It also passes insensibly into Radiolarian ooze in some localities where these siliceous organisms are present in quantity on the surface of the sea. It is the most widely distributed of all the pelagic deposits, and the floor in the deepest parts of every ocean, beyond the range of Globigerina ooze, is covered by this stiff reddish-brown clay. It is as characteristic of the deeper Pacific as Globigerina ooze is of the rather shallower Atlantic. The Red Clay of deep water in the South Pacific is probably accumulating at a very slow rate. According to Murray, at “possibly not more than a foot since Tertiary times.”

It is usually considered that there is no rock in the geological series which would correspond to consolidated Red Clay, and this is one of the arguments that has been used in support of the view that at least the deeper parts of the great ocean basins have been permanent for long periods of time.

“4. *Radiolarian Ooze.*—This deposit covers about two millions of square miles at the greatest depths in a few isolated areas in the tropical Pacific and Indian Ocean. It does not occur in the Atlantic, nor in the great Southern Ocean. Its range is from about 2,500 to 5,000 fathoms, but is determined apparently not so much by the depth as by the presence of enormous quantities of Radiolaria (with siliceous shells) in the surface waters of these localities.

The foundation of the deposit is Red Clay, of which it may be considered to be a variety in which the siliceous shells of Radiolaria are so abundant as to give a characteristic appearance under the microscope, and on analysis. The other mineral constituents, apart from the silica, which forms about 25 per cent. of the ooze, are those found in Red Clay. Radiolaria shells are found in smaller quantities in Globigerina ooze and in Red Clay and other deposits, in fact, wherever there are Radiolaria living in the surface waters above, but in these cases the minute and delicate siliceous shells are masked by the greater quantity and larger size and opacity of the Foraminifera and other organisms. It is only when, at depths over 2,500 fathoms, the calcareous shells have been dissolved away by the carbonic acid in the sea-water that the delicate Radiolaria shells, and some Diatom frustules, become conspicuous. Even siliceous shells, however, have been shown by Murray and Irvine to be dissolved to some extent in sea-water, and therefore it is only when the Radiolaria are present in great abundance on the surface, as in the tropical Pacific and Indian Oceans, that what is left of their remains are sufficient to form a Radiolarian ooze at the bottom.

“5. *Diatom Ooze.*—This is also, like Radiolarian ooze, a siliceous deposit, and is formed of the frustules or valves of Diatoms where these microscopic plants are present in enormous abundance in cold surface circumpolar waters. It occupies about 10 millions of square miles at depths of 600 to 2,000 fathoms, and is characteristic of the Antarctic seas and the great Southern Ocean, where it forms a belt round the globe extending, on the average, from about 50°to 65°S. latitude. There is also a broad belt extending across the North Pacific from the north of Japan to the terrigenous deposits of North America south of Alaska and the Aleutian Isles. At its edges in both north and south circumpolar areas it becomes mixed with and passes into terrigenous deposits, and is really present irrespective of depths being dependent more upon the absence of other deposits and the presence of enormous quantities of Diatoms in the water above, the frustules of which make up from 50 to 80 per cent. of the material. This is the only pelagic deposit which is formed of the remains of plants (with the exception of the minute Coccoliths in Globigerina ooze), and many of the animals in Antarctic seas are found to have their stomachs filled with it. But all submarine deposits contain organic matter, and many of the deep-sea animals graze upon the bottom and nourish themselves by passing the ooze through their alimentary canal.

Looking at the submarine deposits as a whole, the terrigenous form a broad belt along the shores of continental land and around islands, Red Clay occupies the greater part of the deep Pacific and lesser areas in the Atlantic and Indian Ocean, Globigerina ooze is characteristic of the Atlantic and parts of the Indian Ocean and South Pacific, the deep-water siliceous Radiolarian ooze and the shallow-water calcareous Pteropod ooze occupy restricted areas in tropical waters, and the siliceous Diatom ooze forms circumpolar belts in the cold waters of the Southern Ocean and the North Pacific.

I may conclude this subject with the following summary, adapted from the writings of Sir John Murray, on the distribution of carbonate of lime over the floor of the ocean:—

By far the larger part of the carbonate of lime which is found in the marine deposits now covering the floor of the ocean has been derived from sea-water by the action of living organisms. It is made up of fragments of fishbones, mollusc shells, corals, spicules of sponges, alcyonaria and tunicates, shells of foraminifera, remains of calcareous algæ, and indeed of all the calcareous structures secreted by marine organisms.

These calcareous remains may be divided into two classes, viz., (1) Those that have been secreted by organisms which live habitually in the surface waters of the ocean, such as Pteropods and Heteropods, pelagic Foraminifera, such as *Globigerina, Pulvinulina, Orbulina,* and other allied genera, and calcareous algæ, such as the Coccospheres and Rhabdospheres. The remains of all these pelagic (planktonic) organisms are especially abundant in the deposits far from land. Near the land their presence is masked by terrigenous detrital matters. In great depths they disappear, being dissolved by the action of sea-water either while falling through it or soon after they reach the bottom. In depths of 1,000 fathoms, far from land, they may make up fully 95 per cent. of the deposit. (2) Those organisms (the Benthos) that live on the bottom of the ocean, viz., corals, molluscs, Foraminifera (very different species from those of pelagic habit) and calcareous algæ, are poorly represented in the great depths, but in shallow water their remains may make up nearly the whole of the deposits (Neritic) now in process of formation. This is especially the case around coral islands.

It is well known that carbonate of lime is very sparingly secreted in the cold water either of the polar regions or of the deep sea, while it is very abundantly secreted in warm seas where there is a nearly uniform temperature throughout the year. In warmer water the lime is, in some cases, secreted in the form of aragonite (though calcite is also present), while in the colder water it appears more frequently in the form of calcite. In this connection it may be pointed out that in the deposits now forming on the floor of the ocean, the remains of organisms may be found which during their lives were always in a temperature of 35° F., mixed up with the remains of organisms which always lived in a temperature of about 80° F. This shows how difficult it may be to unravel the geological records of the past, for the remains of organisms which lived under wholly different conditions may be mixed together as fossils in the same geological stratum.

If we attempt to compare the submarine deposits forming at the present time with those of past ages, now represented by the sedimentary rocks of the geological series, it will be found that while some show a close correspondence, others—the deep-sea oozes—are not so obviously related to any known rocks of the visible crust of the earth.

The terrigenous deposits formed in shallow water round continents and containing mineral particles such as quartz grains derived from the adjacent land correspond with familiar sedimentary rocks of various geological horizons. Sandstone is consolidated sand; gravel of various kinds may be cemented together to form conglomerates and pebble-beds; deposits of mud may be compressed into shales and impure limestones.

Similarly, the neritic deposits can be correlated with various highly fossiliferous limestones, chalks and related rocks in many parts of the geological series.

The question then naturally arises—do the deep-sea deposits, formed from the remains of pelagic organisms, likewise become converted into any known rocks ? There is no doubt that they might do so. The "Challenger" dredged fragments of rock from the deep sea which were found, on examination with the microscope, to be composed of hardened and consolidated pelagic deposits; and it is possible to convert Globigerina ooze, or any other pelagic deposit, in the laboratory into a lump of stone which can be sliced like any other rock and examined in thin sections under the microscope (see Plate XII, Fig. 2). But there is no reason to believe that any rocks formed by the consolidation of deep-sea deposits are present in that part of the crust of the earth which we can examine—with the possible exception of the Polycystina earth of Miocene age at Barbados, which may be a fossil Radiolarian ooze.

Analogues of terrigenous deposits are to be found in all geological ages, and many calcareous rocks are formed of neritic shallow-water deposits, but we know of no undoubted analogue of the true deep-water pelagic deposits. Various rocks have from time to time been supposed to correspond to the oozes of the deep sea, since Huxley, in 1858, claimed Globigerina ooze as a modern chalk, but further investigation and consideration of the case has always led to the conclusion that such claims must be rejected as very doubtful. It must not be supposed, because Radiolarian ooze is an abyssal deposit, that ancient highly siliceous sandstones and cherts or shales containing fossil Radiolaria were necessarily formed as deep-sea deposits. Radiolaria can live in comparatively shallow water, or their dead shells may be carried by currents into shallower water, and some of the sandstones and shales in question show evidence (such as contained plant remains) of having been formed as shallow-water deposits near land.

It was generally held at the time of the "Challenger" expedition, and even by some geologists since, that the Cretaceous formation, or at any rate the Upper Chalk, was formed as a deep-sea deposit, and that, to put it another way, the chalk formation is still being deposited at the bottom of the Atlantic. Hence arose the doctrine of what was called "the continuity of the chalk." But the view is now generally held that in upper Cretaceous times the chalk of England was deposited in warm shallow water containing very little terrigenous material; and that therefore the Globigerina ooze of the abyssal Atlantic cannot be regarded as its lineal descendant. It may be regarded as established that at any rate the great mass of the stratified rocks which compose the continents as we see them must have been formed of such terrigenous and neritic deposits as are now being laid down within 200 or 300 miles of land, on the continental shelf and the upper part of the continental slope, and do not include to any marked extent deposits which closely resemble those now accumulating in the abysses of the Atlantic and the Pacific oceans.

This conclusion has an important bearing on the controversial subject known as the permanence of the continental ridges and the ocean basins. As most of the sedimentary rocks of past geological times were of marine origin, there is no doubt that the greater part of the continental land of the globe has been at one time or other, or even at various times, at the bottom of the sea, and no doubt considerable areas that were once land are now submerged. Land and sea have been occasionally changing places throughout the ages. But that fact does not necessarily imply that continental land ever occupied the great ocean basins, or that deep-seas once rolled over what are now continents. The study of the ocean depths and of the deposits from abyssal regions does not (in Sir John Murray's opinion, with which most oceanographers would agree) give any support to the view that vast continents have disappeared in what are now oceanic areas.

The contrary view—that continents and ocean basins have changed places in the past, and have even followed one another like successive waves round the globe—has been held from time to time. The myth of a "lost Atlantis" dates back at least to the time of Plato, and has been revived many times since; while a sunken continent, "Gondwanaland," has been supposed to occupy the Indian and Southern oceans in order to account for the distribution of geological formations and living organisms.

The stories of sunken lands and the legends of spectral or floating islands in the west are probably based partly on the evidence of submergence seen on the western coasts of Europe. The old river-beds of the Shannon and other streams can be traced far out to sea; the Porcupine Bank and the Rockall Bank are parts of the continent of Europe which have sunk, there are submerged forests with peat and tree trunks and remains of land animals in many places, and on the west coast of Africa the bed of the Congo has been traced as a submarine canon as far out to sea as the 1,000-fathom line. But these are only local oscillations of the continental margins. In addition, lost continents have been supposed to exist in mid-Atlantic and the Indian Ocean, and if every atoll indicates the position of a sunken peak, a vast area of the Pacific must, according to some views, have been occupied by mountain ranges.

It is not only geologists and oceanographers who have imagined the existence of former continents where we now have deep sea, but zoologists and botanists also have postulated extensive former land connections in order to account for the present distribution of land animals and plants—and some of these connections did undoubtedly exist, while others are still matters of controversy. Britain was certainly connected with the continent of Europe both to the south and the north in Tertiary times, and Europe was once connected with North America by way of Iceland and Greenland. The Antarctic continent was probably much larger in former times, and may possibly have joined New Zealand and Australia and connected the southern extremities of America and even Africa. The ancient granitoid rocks of the Seychelles probably indicate a former land connection (part of "Gondwanaland") from South Africa through Madagascar to Ceylon and India, dividing the Indian Ocean into two seas; and the present floor of the Indian Ocean is supposed to have been formed by sinking in upper Cretaceous times. There may also have been a land extension in Cretaceous times between Brazil and the west coast of Africa. But there was probably always an open Pacific Ocean and some kind of a North Atlantic, although the eminent Austrian geologist Suess supposed that the North Atlantic

Ocean was formed during Tertiary times by successive sinkings of large areas of a pre-existing land surface. The present isthmus of Panama was formerly a waterway between the Atlantic and the Pacific, and a great sea once extended through an enlarged Mediterranean across what is now the south of Asia and northwards along the line of the Caspian Sea through Russia to join the Arctic Ocean. The mountains of Tyrol, now 10,000 feet above the sea, once lay submerged beneath it bearing coral reefs and shallow lagoons; and many other extensions of the sea into what are now continental areas have come and gone.

Restorations of the distribution of land and sea, more or less well established, have been made by geologists for each great geological period, and they show that portions of the continents have one after another sunk beneath the waves and then reappeared as dry land. This has happened time after time, and so although sizes and shapes and land connections have varied through the ages, the main continental masses have persisted in parts and in some form. Similarly, notwithstanding repeated oscillations, extensions and restrictions, some parts of the great ocean basins have probably remained as permanent depressions on the earth's surface since very early times, and may possibly be relics of the original wrinkles on the cooling and contracting skin of the molten globe.

The most recent speculation bearing on the possible past history of the oceans is Wegener's hypothesis of the wandering or drifting apart of the present continents from an original continuous land mass which covered about half the globe in Carboniferous times. Suess had previously shown that there was reason to believe that the crust of the earth may be divided into a more superficial and lighter but more rigid layer (the "Sal"), which forms the continental areas, and a deeper and denser but more plastic mass (the "Sima ") which underlies the continents and comes close to the surface on the floors of the oceans. Wegener supposes the present continents, after separation from one another, to be floating as lighter but more rigid bodies on the surface of the plastic but heavier material which forms the bed of the oceans, and to have slowly drifted apart into their present positions. He points out the similarity in shape between the east coast of North and South America and the western coasts of Europe and Africa; and, in short, appeals to many similarities in shape, geological structure and other particulars which enable him to fit the various land masses of the globe together like the pieces of a dissected map or a puzzle picture so as to make a coherent whole with geological features, glaciation and distribution of organisms seen as a continuous pattern, whereas they are now widely separated on different continents.

According to this view the Atlantic Ocean has been formed gradually by America becoming detached from the common land mass and drifting slowly to the west, leaving Europe and Africa behind. There are many objections and difficulties in detail which have been urged against this most revolutionary theory, and the whole matter is at present a subject of acute controversy.

CHAPTER XI
CORAL REEFS AND ISLANDS

Islands may be divided into continental and oceanic, and oceanic into volcanic and coral islands. When we think of the innumerable coral islands and reefs of tropical seas, and especially of the Pacific, and when we remember that the Great Barrier Reef runs along the north-east coast of Australia for over a thousand miles, we must realize that these coral formations are amongst the greatest of oceanographical phenomena. It is not surprising that such extensive coral structures have excited the wonder and curiosity of voyagers, naturalists and poets, and that many fanciful speculations and scientific theories have been evolved to account for the observed facts of distribution and structure.

From the earliest times navigators have noticed and named three types of coral reefs:— “

The Fringing Reef, which grows along the coasts of continents or islands, keeping close to the shore and leaving no wide or open lagoon between the reef and the land.

The Barrier Reef, also related to the land but at a greater distance, so as to leave an open navigable channel.

The Atoll, a more or less circular ring of coral, having no visible relation to any land and enclosing more or less completely a lagoon, which may be of large extent and of any depth up to about 50 fathoms, usually much shallower.

Islands are merely the more elevated parts of reefs which form dry land and may be habitable. The majority of coral islands are on atolls.

Before passing to the theories which have been put forward to account for these forms of coral structures, let us consider what the reefs are made of. They are wholly produced by living organisms, animals and plants, and especially by the coral animals or polypes.

Huge coral structures of carbonate of lime are built up by innumerable minute polypes, each of which is like a small sea-anemone, and has a mouth surrounded by tentacles. There are some solitary corals, formed of single polypes, comparable with sea-anemones which have deposited lime skeletons in and around their bodies; but the majority of corals are colonies formed of an immense number of polypes produced by continuous budding.

There are certain deep-sea corals which do not form reefs, but may be of importance in helping to build up platforms upon which reefs can grow.

The true reef-forming corals live only in shallow water, as a rule not deeper than 30 fathoms, and in water which is never colder than about 68°F. They are, therefore, tropical animals, limited by the isotherms of 68° North and South of the Equator, a zone lying for the most part between 30°N. latitude and 30°S. latitude.

It must not be supposed, however, that coral reefs are wholly, or even chiefly, formed of coral skeletons produced by coral polypes. There are in addition many other calcareous organisms present, including Foraminifera, Molluscs, Polyzoa, and even Nullipores and other calcareous sea-weeds (such as *Halimeda),* and in some cases these form the greater part of the reef.

Once the facts of distribution are ascertained, there is no mystery in regard to the formation of the fringing reef. It merely grows and spreads under suitable conditions wherever it can in shallow water. It hugs the coast-line because the living organisms which are forming it cannot extend either upwards on to the shore or downwards into deeper and colder water, and so it ends by encircling the land.

The theories we have to consider, then, are to account for the formation of barrier reefs and atolls, and, omitting purely fanciful speculations, the first and most celebrated is that of Charles Darwin (1842), who based his view of the matter upon two facts, one physical and the other physiological. The physical fact is that many parts of the land are not stationary, but are undergoing slow movements of elevation or subsidence; and the physiological is that the coral polypes can only live in shallow water of a certain temperature. Darwin's theory is, in effect, that if a fringing reef (Fig. 11, F.) has become established round the shore of an island that is slowly subsiding, then as the land sinks the coral animals will build the reef upwards, so as to keep near the surface within the zone of shallow warm water, and so in course of time, because of the natural slope of the land and the more or less vertical upgrowth of the coral, the reef will become separated from the shore by a wide and moderately deep lagoon, and the fringing reef will have become converted into a barrier reef (B). Let these processes continue and eventually the original island will be completely submerged, and an atoll or ring of coral (A) will surround the lagoon which now occupies the position of the sunken land. According to this view, the three forms of reef are merely stages in one process of growth, which begins as a fringing reef and ends as an atoll (Fig. 11, Darwin).

The simplicity and the comprehensive nature of this theory proved very fascinating, and led to its wide acceptance by biologists and geologists alike. It was adopted in every textbook of physical geography, and the existence of an atoll came to be usually stated as one of the proofs of subsidence. The American geologist, J. D. Dana, from independent observations made during Wilkes's expedition, corroborated Darwin's views—which are now frequently referred to as the Darwin-Dana theory.

In course of time, however, other observers pointed out that atolls were sometimes found on areas that had obviously undergone elevation, and that old-established fringing reefs, indicating stationary conditions, might be found along with barrier reefs or atolls, which were supposed to indicate subsidence. Thus Semper's observations in the Pelew Islands showed the co-existence of atolls and other types of reef in the same archipelago, and Agassiz and several other more recent investigators threw grave doubt upon the validity of Darwin's theory to explain the structure and distribution of the reefs they had observed. Thus the matter became

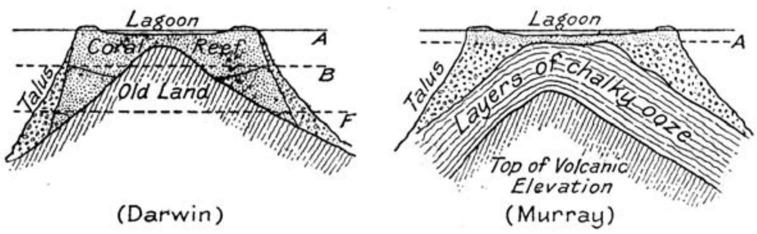


FIG. 11.—THEORIES OF THE FORMATION OF CORAL ATOLLS.

controversial—but no adequate rival theory was put forward until Murray's views, based on the "Challenger" observations, appeared in 1880.

A strong point in favour of Darwin's theory was that it had got over the difficulty of supplying an enormous number of suitable platforms in shallow water scattered over vast areas of the deep sea. By slow subsidence of a tropical continent or archipelago every peak and every island in succession would naturally come within the range of reef-building corals, and so form a suitable platform for what would eventually become an atoll. Granted the assumption of innumerable peaks and islands sinking slowly in an oceanic area suited to the life of the coral polypes, then the result will follow in accordance with Darwin's theory;

but it is a very large assumption, for which there is little or no justification.

The Darwin-Dana hypothesis implies that a vast belt of land in equatorial regions has been sinking down to the extent of thousands of feet during more than a million of years. If this has really taken place, it is one of the greatest phenomena in the earth's history.

Such was the position of affairs when the "Challenger" sailed on memorable exploring expedition, during which the investigation of depths and bottom deposits over the floor of the ocean enabled John Murray to construct his theory of coral growth and atoll formation, which is perhaps the best known after that of Darwin. Murray showed that abundant platforms could be provided by the building up of submarine volcanic elevations and banks by means of calcareous deposits formed from the shells and other hard parts of animals living on the bottom, and also of pelagic organisms in the water above, such as form Globigerina ooze and Pteropod ooze. He showed how the various agencies at work all tend to wear down or to level up all elevations rising from the floor of the ocean to about the lower limit of wave-action, which is the correct depth at which to form a suitable platform for reef-building corals to grow upon. The coral colonies established on such a platform will then naturally grow towards the surface and from the surface outwards in all directions to form a small tableland or plantation of coral. In such a plantation the conditions of life will be more favourable round the edges, where the breaking water brings abundant microscopic food and oxygen, than in the centre where the water is more or less stagnant and used-up. This leads to more active growth on the periphery, and to starvation, death, and decay in the centre, and thus a cup-shaped hollow is formed—a small atoll (Fig. 11, Murray).

This structure, once attained, remains and increases. The outer rim of a coral reef is always the most actively growing part; the lagoon, according to Murray, is being worn away or dissolved, and so the small atoll increases in size, growing outwards like a "fairy ring" on grass, and supported upon a growing "talus" of its own broken fragments (Fig. 11). On the same principle a fringing reef might grow outwards to form in time a barrier reef on a stationary or even a slowly rising area.

The strong points of Murray's theory are (1) that it does not require any great assumption, such as the subsidence of a vast area of land in tropical seas; and (2) that it depends upon observed facts and known processes in the life and growth of the coral animals.

This theory was favourably received by many biologists, especially by those who had themselves explored coral reefs. Several more recent investigators, however, differ from Murray's view that a lagoon may be formed or deepened by solution of the dead coral, and regard the lagoon as an area of deposition or sedimentation rather than of solution.

An interesting corroboration of Murray's views was furnished a few years later by Dr. H. B. Guppy, who found in the Solomon Islands upraised coral reefs formed of a relatively thin layer of coral upon limestones which were evidently consolidated Pteropod and Globigerina ooze, and the consolidated ooze was deposited upon a core of volcanic rock, the whole structure being a remarkable verification of what Murray had supposed would be the case.

These two theories, Darwin's and Murray's, with various modifications introduced by other investigators, such as Wharton, A. Agassiz, Stanley Gardiner, Davis, and others, now held the field, and opinion was very equally divided as to which was the more correct interpretation. Darwin himself had long ago expressed the hope that someone would some day make a boring through a Pacific atoll in order to determine what its base was formed of, and whether, as he supposed, coral which was living *in situ* went continuously down to depths where no reef-building coral could live.

When we want a thing of that kind done for the benefit of science in this country, we generally go to the British Association and ask that a research committee be appointed for the purpose, and that was done over thirty years ago, at the meeting of the British Association at Cardiff in 1891.

A typical atoll, thought to be of irreproachable character, called Funafuti, in the Ellice group, near the centre of the Pacific, was chosen for the purpose; and several successive expeditions, under the leadership first of Professor Sollas, of Oxford, and afterwards of Professor Edgeworth David, of Sydney, eventually, after many difficulties, succeeded in boring through the reef to a depth of 1,114 feet, and in bringing home a core formed of various layers of coral and other calcareous structures, which was most carefully examined from end to end, microscopically and chemically, and has been exhaustively discussed in a valuable report published by the Royal Society. Extraordinary to relate, this boring of Funafuti has not settled the matter. The upholders of the two rival theories each find in the Funafuti core support for their own views. Professor Sollas and other supporters of Darwin maintain that the corals found in the core at depths of over 1,000 feet prove that the reef is based upon what was once living coral *in situ,* which has been carried bodily down by subsidence from the shallow water in which it lived to that depth at which it was found; while Murray and his adherents answered: "Not at all. The present reef of Funafuti has grown out upon a talus of broken fragments, the boring has gone down through that talus, and the corals in the core are not *in situ,* but are pieces which have broken off from the edge of the reef and rolled down into deeper water."

There seems no way at present of settling the matter further; but it is very possible that both theories are partly right and partly wrong, and that different atolls have been formed in different ways. In a slowly sinking area no doubt Darwin's theory would apply, and a fringing reef would become first a barrier reef and then an atoll. But in other areas which are stationary, or slowly rising, platforms for coral reefs might be provided, as Murray supposed; and the coral growth, once formed, would no doubt become converted into the ring-like atoll-shape by natural processes, in accordance with Murray's views. It is probable, however, that Murray attached too much importance to solution, and that the lagoon is formed more by mechanical erosion than by chemical processes. Great destruction of the dead coral in the lagoon is now known to be effected by the scouring action of tidal currents and by boring algæ, mollusca, and worms, and by the ravages of fishes and Holothurians, which feed to a great extent upon the broken-up coral on the floor of the lagoon.

The late Dr. A. G. Mayer, of the Carnegie Institution of Washington, for several years recently made important investigations on the coral reefs both of Florida and Tortugas in the Atlantic, and of Samoa in the Pacific, and found that the rate of growth of reef-building corals in the Pacific was about twice as rapid as that of corresponding genera in the Atlantic, where there is much more precipitated coral mud and the food conditions are less favourable. He estimated that the existing reefs in the Pacific might easily have grown to their present dimensions in 30,000 years—since the last glacial epoch. He found at Samoa that the corals, at their present rate of growth, add annually about 840,000 lb. of limestone to the reef; but that, on the other hand, about four times that quantity (3,000,000 lb.) is being removed annually by the coral-eating Holothurians, aided by currents. Dr. Mayer made a boring through the fringing reef at Pago-Pago, Samoa, in 1918, at 575 feet from the shore, and came upon volcanic rock underlying the coral at a depth of 121 feet (20 fathoms), just the right depth for a platform suitable for reef-building corals.

W. M. Davis, of Harvard, from a critical examination of the physical features of islands and their coral reefs, comes to conclusions (1919) favourable to Darwin's theory. He lays stress upon embayments of the coast-lines due to erosion and the half-drowned valleys as proof of submergence, and he points to the unconformity between the coral reef and the underlying rock which is eroded, and therefore was once exposed to the air, which again is evidence of submergence. But these characters only prove that subsidence took place *before* the coral reef was formed upon the underlying rock, and do not show that the land was still sinking while the fringing reef was growing up to become a barrier reef or an atoll—which is the theory put forward by Darwin.

It is unnecessary to discuss every view that has been put forward by investigators of the coral-reef problem, but one other of outstanding importance must be mentioned. R. A. Daly, of Harvard, in a series of papers since 1915, has advocated what is known as the "glacial-control" theory, which is, that existing coral reefs are very recent, and have been formed only during late glacial and post-glacial times; that the pre-existing tropical reefs had been exterminated in glacial times, when, he estimates, the water withdrawn from circulation and locked up in the form of ice may have lowered the level of the ocean in tropical regions by as much as 50 to 70 metres; that the melting of the glaciers set free a great volume of water,[1] becoming rapidly warmer, which caused the tropical oceans to deepen gradually and permit the newly established coral reefs to form as thin veneers upon the numerous shallow platforms which had been produced by erosion or wave-action during the previous pre-glacial and glacial periods. As the water became warmer, reefs would be formed round the edges of these platforms as a consequence of the newly established coral colonies growing upwards to keep pace with the gradual deepening caused by the water set free from the ice slowly raising the level of the ocean.

[1] But the question arises whether this water may not have been locked up again by increasing glaciation in the Antarctic.

It seems that A. Tylor, T. Belt; and others, had to some extent anticipated Daly in attributing the origin of existing coral reefs to a change in the ocean level consequent on deglaciation; but Daly has discussed the matter much more fully than his predecessors in all its bearings, and has brought forward many new facts in support of his views.

The glacial-control theory is fundamentally opposed to the Darwin-Dana theory, but is not inconsistent with Murray's theory, from which it differs in details, such as the method of formation of the platforms, but not in general principle. Daly doubts whether archipelagos of atolls and barrier reefs ever existed before the glacial period, though possibly rare atolls may have been developed locally where a limited subsidence affected the floor of the Tertiary ocean.

In conclusion, it may be remarked that every serious investigator of coral reefs seems to have added something of importance, and that each of them, according to our present views, seems to be right on some points and wrong on others. It must be remembered that it is unlikely that one theory will explain all the details of all reefs, which may lie thousands of miles apart, and may have been formed under very different conditions.

Darwin and Dana showed how an atoll might be formed on an area of subsidence, but their theory does not apply to most atolls and barrier reefs that have been carefully examined.

Semper and A. Agassiz were correct in their criticisms of Darwin's theory in the case of the reefs they had investigated, and showed that atolls might be present where there was no subsidence.

Murray was right in his views as to the formation of submarine platforms, and the possibility of these being built up to the required level, and also as to the process by which a coral patch would naturally assume the atoll form, but he was probably wrong as to the formation of lagoons by solution.

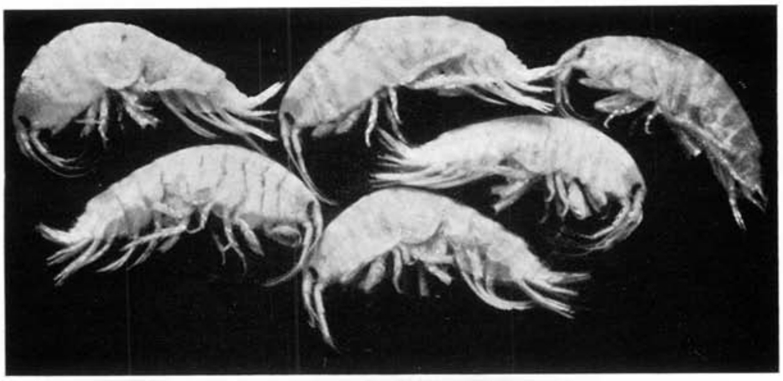


FIG. 1.—Common Shore Amphipoda; slightly enlarged.

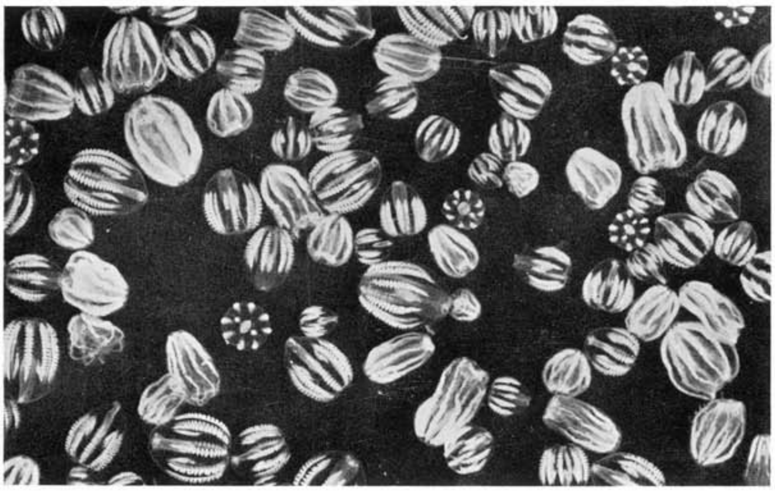


FIG. 2.—Luminescent Ctenophora (*Pleurobrachia pileus*, etc.); natural size.

[*Photos by* A. SCOTT.

Wharton and others have emphasized the importance of the levelling action of the sea on submarine peaks in order to provide flat areas on which coral patches and atolls might form.

As an important supplementary theory, Daly has advocated "glacial-control," i.e., that the melting of glaciers and snow at the end of the great Ice Age set free so much water as to raise gradually the level of the ocean about 30 fathoms, and so submerge the bases of the newly established reefs to that extent, which would have the same effect upon their growth as a sinking of the land to that amount; but this would be only a temporary and strictly limited raising of the sea upon the land, not comparable with the continuous subsidence postulated by Darwin.

I would remark, finally, that even if his theory has to be rejected, as not applicable to the majority of coral reefs and islands, Darwin did notable service to science in stating the coral-reef problem and attempting its solution.

CHAPTER XII

“PHOSPHORESCENCE,” OR LUMINESCENCE, IN THE SEA

One of the most widespread and most commonly observed, and at the same time most remarkable and mysterious, of the phenomena of the ocean is the so-called “phosphorescence.” Most summer visitors to the seaside and voyagers in ocean liners are familiar with the diffused glow of light in the water on a dark night, or the innumerable brilliant sparkles seen where a wave breaks on the shore, or an oar or a rope ruffles the surface, or when a coin or small stone is dropped over the side of a boat and leaves the track of its passage through the water illumined by points of light. All this has been known from the earliest times, and there are many records from observers of the phosphorescence of the sea in all parts of the world, tropics and polar alike, and almost as many speculations as to the cause and essential nature of the phenomena observed.

The term “phosphorescence” is unfortunate, as it is apt to lead to confusion with mineral phosphorescence, while the light in the sea is now known to be due solely to the luminosity of certain living organisms under certain conditions, and has no connection with the chemical element phosphorus. The more correct term, made use of by the most recent investigators, is “bio-luminescence,” or briefly the noncommittal word “luminescence” to which I shall adhere in this discussion of the subject.

The organisms producing this light in the sea are of many kinds—both animals and plants, large and small, highly and lowly organized. Luminescence is produced also in the case of a few land animals and plants, such as some earth-worms, millipedes, and various insects (beetles), the best known of which are glow-worms and fire-flies; but is not known to occur in any fresh-water organism. It is therefore a widespread, but by no means universal, accompaniment of life—a vital phenomenon, only manifested by certain living things, and by these only under certain conditions.

In the sea the organisms that give rise to luminescence range from the simplest minute unicellular forms (Protozoa, Protophyta, and Bacteria) up to Fishes, and the modes of emitting the light and the appearances thus produced are most varied. The following list is not intended to be exhaustive, but merely to give a few examples of each of the chief kinds of organisms that contribute most notably to the different appearances of luminescence:—

BACTERIA.—Many of these micro-organisms (e.g., the various forms of *Photobacterium* and *Microspira)* cause a flickering glow in the water, on wet sand, and on the bodies of fishes and other larger organisms. Fishermen and naturalists since the days of Aristotle have noticed that dead fish may glow in the dark, and this is not due to the bacteria of putrefaction, but to the photobacteria of the living fish, as when putrefaction sets in the luminescence ceases.

In other cases the photobacteria may invade the body of a larger organism, give rise to a disease, and cause it to glow in the dark. The late Professor Giard, while walking (in 1889) on the sands of Wimereux at night, noticed spots of light at his feet which moved from place to place, and, on catching some of these, found them to be living, but enfeebled, "sand-hoppers" (the Amphipods *Talitrus* and *Orchestia).* Investigation in the laboratory showed that the body was infested with photobacteria, that these caused progressive enfeeblement of the muscular system, and finally death, and that the infection could be transmitted from one sand-hopper to another. (Plate XIII, Fig. 1.)

It is evident, then, that the luminescence of a larger marine animal is not necessarily due to the production of light from its own body, but may be caused by an invasion of photobacteria.

PROTOPHYTA.—Minute unicellular plants in the surface layers of the sea are probably the cause of a good deal of the dull, generally diffused glow, which has been called "milky sea" in the Far East, "white water" in the Gulf of Aden and elsewhere. Sir John Murray considered that the unicellular plant *Pyrocystis* (possibly a Dinoflagellate allied to *Noctiluca)* is the chief cause of the diffused light often seen in tropical seas in calm weather.

PROTOZOA.—Many of the Flagellata exhibit luminescence, especially those belonging to the group Dinoflagellata (such as *Ceratium* and *Peridinium),* which have been known to be luminous since the time of Ehrenberg (1831), and possibly earlier. I have proved to my own satisfaction, through the microscope, that the bright sparkles in a sample taken from a luminescent sea on the west coast of Scotland were caused by the abundant Dinoflagellate *Ceratium tripos* (Plate XIV, Fig. 2); and similarly in the Southern Ocean, off the Cape of Good Hope, I once found that the organism lighting up the sea by night and colouring it almost blood-red by day was a small red *Peridinium* present in extraordinary abundance.

The aberrant Dinoflagellate *Noctiluca scintillans* (Plate XIV, Fig. 1) is the generally recognized cause of a great deal of the silvery luminescence of our home seas round the coasts of North-west Europe in summer and autumn, when this little organism is sometimes so abundant that every dip of a cup in the sea will contain hundreds, and every tide leaves pink-coloured masses of their bodies piled up on the sands. In the Irish Sea, for example, *Noctiluca* is very generally present in the plankton, and enormous swarms appear from

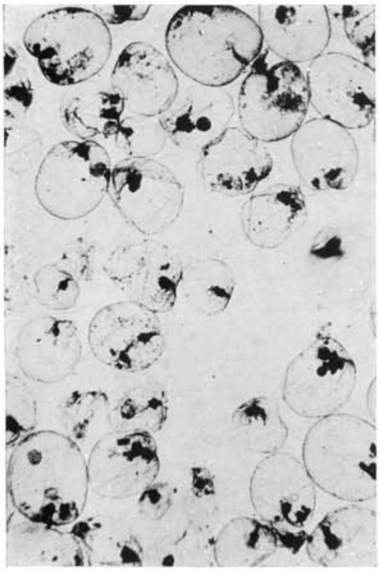


FIG. 1.—Plankton, consisting almost wholly of *Noctiluca scintillans.*

FIG. 2.—The Luminescent Dinoflagellate *Ceratium tripos.*

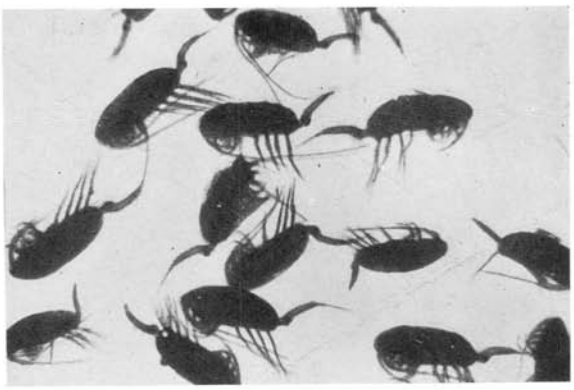


FIG. 3.—Copepoda (*Pseudocalanus elongatus*) from the surface-net.

All magnified.

[*Photo-micrographs by* A. SCOTT.

time to time, for the most part in late summer, August and September. An unusually late and very extensive visitation occurred in December, 1919, when in some parts of the Barrow Channel there was a well-marked brick-red oily zone on the beach caused by the stranded *Noctiluca,* and a bucket of the shore-water was compared by observers to "thick tomato soup," and after the sea-water was drained off it was found to contain fully 2,000 cubic centimetres of *Noctiluca.* Some of these placed in a small aquarium retained their power of luminescence for three weeks.

Noctiluca has been known as a common cause of luminescence in coastal waters for at least two centuries. In the middle of last century, A. de Quatrefages made notable observations on *Noctiluca,* in which he showed that the light was emitted from well-defined patches or slowly moving areas of the surface, each composed of a large number of scintillating points.

Many of the Radiolaria, both simple and compound, also show bright luminescence.

CŒLENTERATA.—Many of the Hydroid Zoophytes, the Medusæ, and the Alcyonarian Corals show brilliant luminescence. There is no need to mention all recorded cases, or even groups: a few examples will suffice. Some of the Medusæ are responsible for the large spots of light, as large as a coco-nut or a tea-tray, sometimes seen by voyagers, especially in warmer seas. Once when at anchor, in a native boat, on the pearl banks of the Gulf of Manaar, in an intensely dark night, I saw the black sea around us in all directions lit up by an innumerable assemblage of what looked like globes of fire, waxing and waning in brightness, all simultaneously glowing and then fading away into darkness, and after a few seconds lighting up once more. This periodic display continued for about an hour and then disappeared. Unfortunately, we were fixed to the spot and had no small boat, so it was impossible to capture a sample, but the impression produced was that the phenomenon was probably caused by a vast swarm of Medusæ excited to luminescence by either an internal periodic or an external accidental stimulation, such as a passing fish or a collision of two or more of the Medusæ. The stimulation of one of the crowd might be sufficient to start them all. The appearance from the deck of our ship was as if first one of the globes lit up and then another and another in rapid succession, suggesting that the luminescence of the one was stimulating the others to similar action.

The most brilliant light-producing Medusa in our own seas is *Pelagia noctiluca.* A small tankful of them once gave us a magnificent display in the dark at the Port Erin Biological Station, and when taken out in a bucket they looked like balls of fire, or rather incandescent metal, as the light is white and very intense. It was difficult to believe it would not burn one's fingers when touched.

Alexander Agassiz has recorded that in the luminous Ctenophora (such as Pleurobrachia, Plate XIII, Fig. 2), not only the adults but even young embryos are luminous, which shows that the light-producing material is not necessarily the secretion of a special gland, but may be formed in the protoplasm of the early cells.

The colonial Cœlenterates, when luminescent, remind one of fireworks or electric-light displays, as all the polypes, or groups of polypes, glow out one after another till the whole series of branches are ablaze. It is impossible to resist the conclusion that the stimulus spreads from one member of the colony to another. This is typically the case in the well-known sea-pen *Pennatula phosphorea,* so named by Linnæus in the eighteenth century, but known as a luminous animal by Gesner a couple of centuries before, and probably by others still earlier. (See Plate XVI, Fig. 1.)

This, like *Noctiluca,* is a classical example of luminescence amongst British animals; and when taken into a dark cabin immediately on being brought up in the dredge, *Pennatula phosphorea* is a wonderfully beautiful sight. The slightest mechanical stimulation is sufficient to start some of the polypes, and the impulse is then communicated to others until every branch and polype is outlined with light like a series of fairy-lamps. Panceri, who studied the luminosity of many marine animals in the Mediterranean, showed that the luminous matter in *Pennatula* is produced by eight bands of tissue in the interior of each polype, extending up to papillæ surrounding the mouth, so that the secretion was poured out on the surface when luminescence took place. The display is, however, in the main, clearly an illumination of the polypes. That is not the case in the closely allied giant sea-pen *Funiculina quadrangularis* (Plate XV, Fig. 1, a dozen specimens about 1/12 nat. size), where the colony may attain a length of 5 to 6 feet, and the light is emitted from the mucus on the surface, especially of the axis or stem. I have had both these kinds of sea-pen, freshly dredged in the Hebridean seas, glowing side by side in a tub in the dark on my yacht "Runa," and in the case of *Funiculina,* the light, which was of a lilac colour, compared by Wyville Thomson *(Depths of the Sea,* p. 149) to the flame of cyanogen gas, came mainly from the surface of the fleshy stem or axis of the colony. The slightest stimulation, such as gentle stroking with the finger, caused great outbursts of light to travel like lambent flames up and down the stem, while the polypes remained comparatively, if not wholly, in the dark (Plate XV, Fig. 2).

G. H. Parker has shown lately that the Alcyonarian colony *Renilla,* which glows with a beautiful golden green light, spreading over the surface in wave-like ripples from the spot stimulated, can only be excited to luminescence in the night. He was unable to cause any light-production during the day, which suggests that it cannot be wholly a physico-chemical process, but must be in part under nerve-control. In *Pennatula* and *Funiculina,* on the other hand, in my experiments on the yacht, I found no difficulty in exciting brilliant luminescence at any hour of the day.

ECHINODERMATA.—Comparatively few of these are known to produce light. Some Ophiuroids ("Brittle-stars"), however, show a brilliant luminescence, which in the case of *Ophiacantha spinulosa* is said to be of a uranium green colour. Wyville Thomson, describing some specimens dredged from deep water south-west of Ireland, writes: "The light from *Ophiacantha spinulosa* was of a brilliant green, corruscating from the centre of the disc, now along one arm, now along another, and sometimes vividly illuminating the whole outline of the starfish." In this and a few other Ophiuroids the light has been shown by recent investigations to come from internal cells in the tissues of the ventral and lateral plates and spines of the arms.

VERMES.—Many of the higher worms; or Annelids, are luminescent. In the Polynoids the light is emitted from definite light-organs arranged round the posterior edge of the elytra or scales which cover the dorsal surface of the worm, and as the elytra continue to glow with a bright light for some time after being detached from the body, this seems to be a case where the use to the animal of its luminescence is to distract the attention of the fish, crab, or other enemy.

In some of the Syllid worms the light-production is definitely related to reproduction, and is apparently of use in enabling the male to find the female on the surface of the sea during the periodic swarming for the purpose of mating. The light is produced from very definite light-glands placed in lateral series at the bases of the parapodia.

The light from some of these Annelids is described as violet blue, and in other cases as greenish blue. I have frequently seen a most vivid green light produced by a small polychaet worm which we dig up from the sand or from the debris round the roots of Laminaria at Port Erin. The light is even visible for a few seconds in the sunlight.

But the most brilliantly luminescent of all marine worms is certainly the tube-building *Chćtopterus,* which was studied

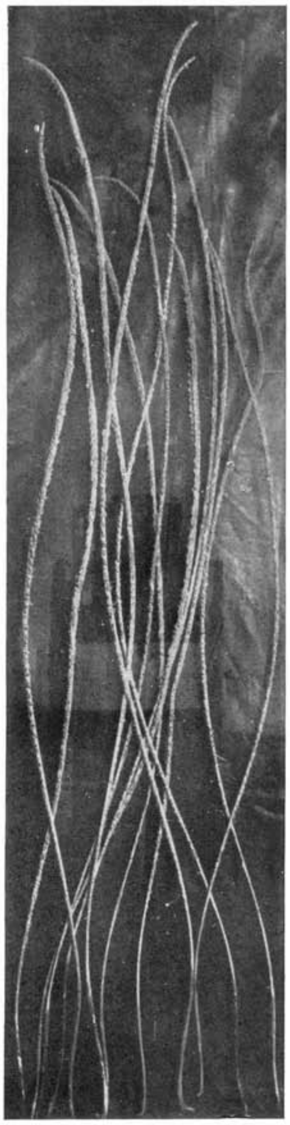


FIG. 1.—*Funiculina quadrangularis.* Group of dozen colonies about $\frac{1}{12}$ natural size.

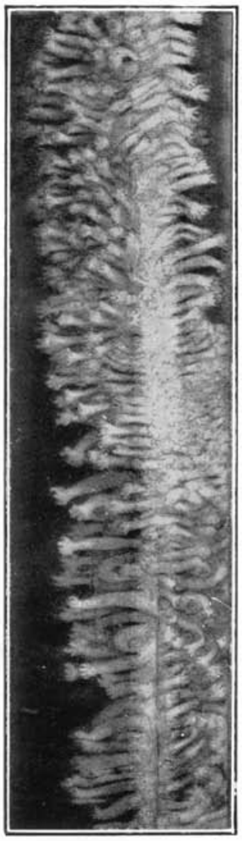


FIG. 2.—*Funiculina quadrangularis.* Small part of a colony, alive in sea-water, with polypes expanded; about natural size.
Dredged in Firth of Lorn, from S.Y. "Runa." in 1912.

[*Photos by* R. NEWSTEAD.

by Panceri (1873), Dubois (1887), and others since. The light, which varies from greenish blue to violet, is given off from most of the segments of the body, and is evidently an external secretion, as it can be rubbed off and spread through the surrounding water.

The use of the light in the case of *Chœtopterus* remains a mystery. It will probably illuminate the water around the mouth of the tube, and that may possibly attract minute organisms upon which the worm feeds. But, on the other hand, this illumination might well be a source of danger, as indicating to fish the presence of the hidden worm. Dahlgren has recorded that he has seen eels pulling the *Chœtopterus* out of its tube. This is evidently not a case where the enemy is warned off from its prey by the light.

CRUSTACEA.—Many of the Crustacea, both high and low, are light-producing, and the light-organs range in structure from simple groups of surface cells to the most complicated eye-like internal organs. For the purpose of this brief survey, it must suffice to select three examples—the Ostracoda, such as *Cypridina*; Copepoda, such as *Metridia*; and Schizopoda, such as *Meganyctiphanes.*

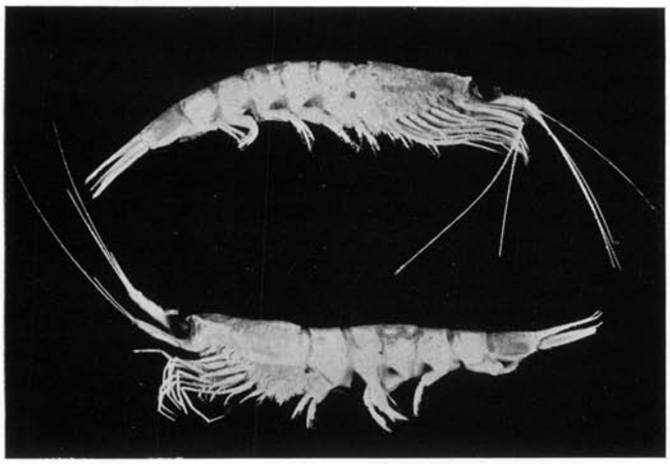
Cypridina and other luminous Ostracods have been observed by many naturalists, and the minute structure and the bio-chemical processes involved have been especially elucidated by Ulric Dahlgren and E. N. Harvey in America. The light-organs are unicellular glands opening above the mouth and discharging the light-producing, mucus-like, yellow secretion freely into the water. The light is blue in colour, and is only produced at night. Harvey has shown (as Dubois had previously done in the case of the mollusc *Pholas)* that the secretion contains two distinct substances, which must be brought together in the presence of oxygen and water in order to produce light. Dubois had named these "luciferine" and "luciferase" in *Pholas.* Harvey, finding that his two substances from *Cypridina* did not correspond wholly in their reactions, applied the new terms "photogen" and "photophelein"—which, we may hope, further research will show to be unnecessary. Harvey showed that these essential substances might be dried, extracted with ether, or treated in various other ways, without affecting their power of subsequently producing light. The process, then, is quite independent of the animal body in which the substances were produced, and so far is a physico-chemical phenomenon. Similarly, Giesbrecht found that he could thoroughly dry some of the luminous Copepoda at Naples, and months afterwards caused these dried bodies to produce light by adding a little sea-water.

The power of luminescence has only been definitely established in the case of about half a dozen kinds of Copepoda (Plate XIV, Fig 3), but some of these are widely distributed, and have been frequently observed. The light-glands are scattered over various parts of the body and pour their secretion out to the exterior. On a voyage to Australia by the South Atlantic, I observed on many occasions these luminescent Copepoda caught in fine nets on the sea-water bath taps; and, having isolated one of the sparkling specimens under the microscope in the dark, have watched how its luminous secretion was emitted on stimulation, and, spreading from the head along the dorsal surface, floated away from the body and hung in the water for some seconds as a luminous cloud. This has been interpreted as possibly of use as a "sacrifice-lure." The Copepod, when in danger, emits the glowing secretion and escapes, leaving the luminous cloud in the water to distract the attention of the enemy.

In the luminescent Schizopoda (such as *Euphausia* and *Meganyctiphanes)* the light-producing organs are conspicuous, highly organized structures, comparable in some respects with an eye or a bull's-eye lantern, and having a source of light with a reflector behind and a lens in front. They were, in fact, supposed to be eyes at first, and are described in the older books under the term "accessory eyes." It

[Photo by R. NEWSTEAD.

FIG. 1.—*Pennatula phosphorea*, half a dozen colonies alive in a jar of sea-water; natural size.



[Photo by A. FLEMING.

FIG. 2.—*Meganyctiphanes norvegica*, from deep water, Loch Fyne; natural size.

was the naturalists of the "Challenger" expedition who demonstrated that these were organs for the production, not the reception, of light.

The usual arrangement of these photospheres, as they have been called, is—a pair on the head behind the true eyes, two pairs on the sides of the thorax, and four median ventral on the first four segments of the abdomen.

In British seas, *Meganyctiphanes norvegica* (Plate XVI, Fig. 2), is abundant in deep water off the western coasts, and frequently comes to the surface in swarms at night. On several occasions in the Hebrides, when we brought some up in the deep tow-net, I have taken a few in a large jar of sea-water into a darkened cabin and watched how, on stimulation, they have lit up their little lamps and sailed round and round the jar—a beautiful sight. Two or three such, freshly caught, gave sufficient light to enable one to read for a few seconds the newspaper on which the jar was placed. In the case of all these photospheres of *Meganyctiphanes* and some allied Crustacea, the light is internal, and is produced in a closed organ in which the oxygen necessary for the luminescence must be obtained from the blood. The photosphere is always well supplied with blood sinuses and with nerves. It has been suggested that the light may be of use to these animals in enabling them to see their prey, or whatever lies in front or below the head.

MOLLUSCA.—I select two examples of luminescence from this group of animals—first, the classic case of *Pholas,* the bivalve that bores deep holes in stiff clay or in soft rocks on the seashore, and in which Dubois first demonstrated the presence of luciferine and luciferase as the essential substances concerned in the production of light; and secondly, the Cephalopoda, or cuttle-fishes, in some of which complicated closed light-organs are present on various parts of the body.

In the case of *Pholas,* the light-producing power has been known since classical times, but Panceri (1873) first determined that the light-giving mucus was produced, not from the whole surface that it usually covers, but from five definite patches of the integument. These are, then, external organs formed of simple cellular glands in the deeper layer of the skin, and pouring out the luminous secretion on the surface. Dubois later (1887) showed that this secretion contained the two essential substances luciferine and luciferase, which require to be brought into contact in the presence of water in order to produce light, and that this action was independent of the life of the *Pholas,* and could still take place after the substances had been dried or treated with various reagents. The light-production was, in fact, shown to be a chemical phenomenon which could be produced in the laboratory by substances which were no longer alive, although originally formed by a living animal.

The colour of the light in *Pholas* is greenish blue, and very brilliant and persistent even after separation from the body; but it is difficult to say what the use can be to an animal deeply buried at the bottom of a hole in the rock —unless it be that the luminous secretion spreads from the body up to and around the mouth of the burrow and acts as an attraction to minute swimming organisms, which are then sucked in and used as food. (See Fig. 12.)

In the highest group of molluscs, the cuttle-fishes, we find both primitive light-producing glands, which eject their secretion into the surrounding water, where the luciferine and luciferase in contact with oxygen generate light (external combustion), and also most elaborate and more deeply placed organs, under nerve-control, with internal combustion, the photogenous secretion never leaving the cells in which it is formed.

The most highly differentiated of these closed photogenous organs show cornea, lens, and reflectors arranged around the central light-producing cells, the whole being surrounded by a protecting coat or capsule, and presenting, as in the case of the higher crustacea, a singular resemblance to the structure of an eye.

The cuttle-fish lights have generally been described as blue, but in the case of the deep-sea *Thaumatolampas diadema* most of the twenty-two organs scattered over the body show a white light, the two anal lights are

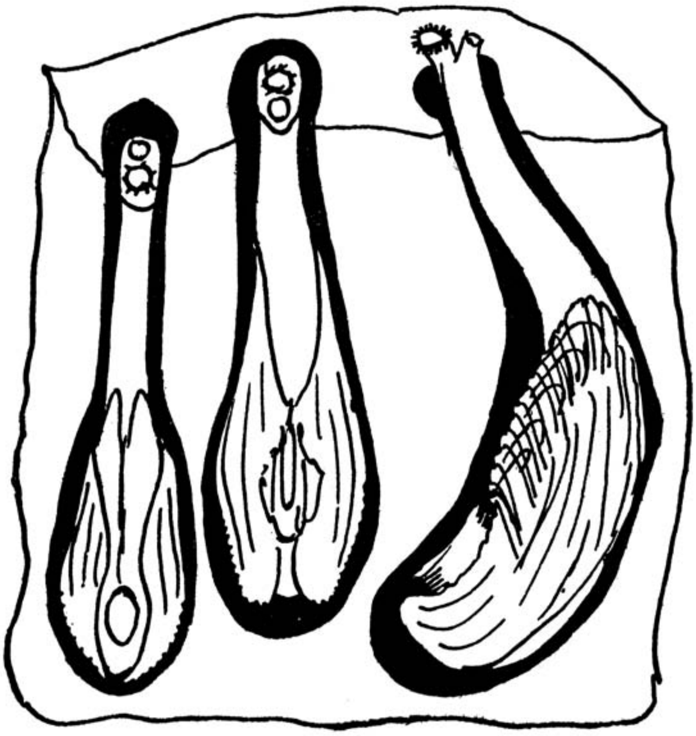


FIG. 12.—Three specimens of *Pholas dactylus* in their burrows, nat. size.

ruby-red, a median visceral light is ultramarine, and two ocular lights are sky-blue. Whether all these different colours are produced in the cells from which the light emanates, or, as seems more probable, are caused by some of the layers of tissue through which the light passes to the exterior, is not yet fully known, but the two ruby lights owe their colour to a screen of red chromatophores in the skin (Fig. 13).

TUNICATA (Ascidians).—Only one, very remarkable, case need be discussed in this group—that of *Pyrosoma.* This is a large, free-swimming colony in the form of a hollow cylinder with one end closed

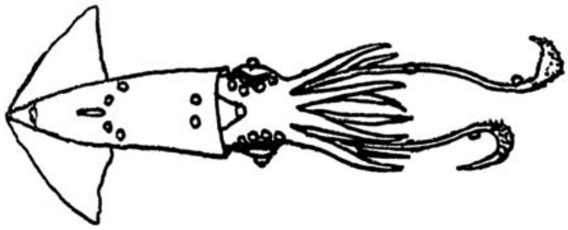


FIG. 13.—SKETCH OF DEEP-SEA LUMINOUS CUTTLE-FISH with numerous light-organs.

(Fig 14). The walls of the cylinder are formed of the ascidiozooids, or members of the colony, placed closely side by side, with their mouths on the outer surface. Each ascidiozooid has two photogenous glands placed one on each side of the anterior end of the body a little behind the mouth, and therefore close to the outer surface of the colony. Each gland consists of a mass of granular cells surrounded by a blood sinus. The light is described

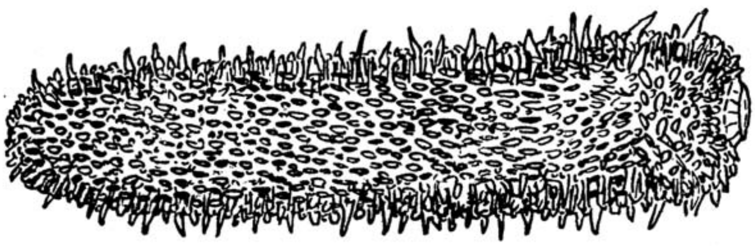


FIG. 14.—Small Colony of *Pyrosoma,* natural size.

as red in some cases and blue in others, and as a colony only a few inches in length may have several thousands of these sparkling points, the volume of light emitted makes *Pyrosoma* one of the most brilliantly luminescent animals of tropical seas.

As in *Pennatula* and many other cases, any stimulation serves to excite luminescence in *Pyrosoma,* and Moseley, in his *Notes of a Naturalist,* states that, when the "Challenger" expedition captured a specimen over 4 feet in length, "I wrote my name with my finger on the surface of the giant *Pyrosoma* as it lay on deck in a tub at night, and my name came out in a few seconds in letters of fire."

FISHES.—Deep-sea luminous fishes have been well known since the time of the "Challenger" expedition. A few of the more notable forms belong to the genera *Scopelus, Chauliodus, Astronesthes,* and *Photostomias.* The light-organs may be in various positions on the head, on the gill-covers, along the sides of the body, or on the ventral surface. *Ipnops murrayi* has two very large photogenous organs occupying most of the flattened upper surface of the head. *Melanocetus johnsoni* has the light on the extremity of a long flexible process from the top of the head, so as to form a lure which may attract prey to the wide-open, formidable mouth below. There is also much variety in the structures. The essential glandular parts of the organs are probably in all cases enlargements and differentiations of the mucous glands of the skin, and the reflectors and other accessory layers are developed from the surrounding integumentary tissues. All these light-producing organs of fishes are well supplied with nerves.

It is possible that luminescence in deep-sea fishes may serve a number of useful purposes, such as general illumination of the surrounding water, the attraction of prey, protection and warning, and it has even been suggested that the specific arrangement of the lights facilitates recognition by other members of the same species, like colour-schemes in terrestrial animals. Murray and Hjort have shown that many of the tropical luminous fishes do not come from the greatest depths, but inhabit intermediate waters, and may even appear at the surface of the sea at night.

Here, then, we have a great phenomenon of the ocean —of all oceans—and at all depths, appearing sometimes in one form and sometimes in another: it may be as a dull continuous glow, or it may be seen as myriads of brilliant sparks, like a pyrotechnic display, and in all cases caused by the presence in the water of living creatures. These luminescent organisms are of the most varied kinds, from the lowest and simplest up to fishes, from particles of microscopic size up to the gigantic *Pyrosoma,* and the light may be produced within a simple protoplasmic cell, or it may be emitted from a complicated organ composed of many layers of cells. It may be a constant, steady light apparently independent of surrounding conditions, or an instantaneous flash produced as the result of direct stimulation, and evidently under nerve-control. And yet the actual method of production of the light is probably in all cases the same, and is essentially a physico-chemical process, consisting of the slow oxidation of one or more protein substances secreted by the living protoplasm. Moreover, in many cases, it may be so in all, it has been shown that two substances must be produced—the protein, called luciferine, and an enzyme, luciferase—which must be brought into contact in the presence of oxygen in order to produce the characteristic apparently cold light. Bio-luminescence differs from all artificial illuminants in being an emission of light without any sensible heat. It is a conversion of chemical energy into radiant energy. The light is a physical accompaniment of the chemical metabolism of the organism, part of the energy set free taking this form in place of the more usual one of heat. It is a highly efficient method of light production; and it has been stated that the best artificial illuminant has only about four per cent. of the luminous efficiency of the fire-fly.

As we have seen, it was the French physiologist Raphael Dubois who first determined the presence of luciferine and luciferase in the case of the marine boring bivalve mollusc *Pholas dactylus,* and also in the case of a terrestrial insect, the luminous beetle *Pyrophorus noctilucus,* and showed the part these proteins played in the production of light; but the discovery has since been extended to the luminous organs and secretions of various other animals, especially by the recent work of the American investigators, Ulric Dahlgren and E. Newton Harvey. The latter finds that although the luciferines and luciferases of different luminous animals are similar substances, they are not identical, but are absolutely specific; for the luciferine, for example, of animal A (say a Mollusc) will not give light with the luciferase of animal B (a Crustacean), and the luciferine of B gives no light with the luciferase of A.

Another point, requiring further investigation into the chemistry of these substances, is the relation between their composition and the various very distinct colours of the light produced. Observers speak of the silvery light of *Noctiluca,* the green glow of Ctenophores, the brilliant blue of the little Crustacean *Cypridina,* the lilac flashes of some sea-pens, the ruby-red of a cuttle-fish, and the dim white light produced over large areas of the ocean by minute luminous Protozoa in the case of the so-called “milky sea” or “white water” in the Gulf of Aden, the China Sea, the Indian Ocean, and elsewhere in the tropics.

Newton Harvey, in his most recent work (January, 1923), has shown that the luminescent reaction in such a case as *Cypridina* is probably represented by the equation— Luciferine + oxygen = oxy-luciferine + water.

But the presence of luciferase, acting as a catalyst, is also necessary for the production of light. Moreover, the action is reversible, and the oxy-luciferine formed can be reduced back to luciferine, which will again oxidize under the appropriate conditions. Harvey suggests that the steady luminescence of organisms such as Bacteria, which go on glowing day and night, may be due to continuous oxidation of luciferine to oxy-luciferine and reduction of oxy-luciferine to luciferine again in different parts of the protoplasm of the same cell. This is a highly economical process of light-production, as no sensible heat is emitted —the radiation is apparently all cold light.

The two essential substances can be isolated, and when the reaction is performed in a test-tube the light is only produced on the surface of the fluid where the luciferine can obtain oxygen from the air. Any shake or other stimulation of the tube which enables the fluid to dissolve more oxygen is enough to cause an increased glow or a flash of light like that produced by many luminous animals on stimulation. This observation suggests that, in some cases at least, the light produced in the living animal, either by external or internal stimulus, is a consequence of more oxygen reaching the photogenous cells as the result of some increase of permeability of the surface layer. This, however, will apparently not explain all cases of light-production on stimulation, and Newton Harvey thinks it doubtful whether stimulation can cause any sudden increase in the permeability of the luminescent cells to oxygen.

Finally, it may be asked—What is the use to the organism concerned of this remarkable production of cold light by means of the oxidation of one or more protein substances secreted by the living protoplasm but retaining the power of light-production, in some cases, at least, long after separation from the body? It is not necessary to suppose direct utility in all cases. In the lowest organisms where there is a steady glow not depending upon any stimulation, it may be that the light is merely a by-product of metabolism, that is, of the chemical processes going on in the living protoplasm and resulting in the production of light just as of heat in other cases. But where the photogenous secretion is the product of a special gland or of definite organs which may have a complicated structure comparable mechanically to an eye or a bull's-eye lantern, and where the emission of light is a direct response to special stimulation (as in higher Crustacea and fishes) utility must be assumed; and the different colours and intensities of the light produced the different forms and situations of the glands or photospheres and the different light schemes or patterns all suggest that the use is not one and the same in all cases, but may differ widely in the different luminous organisms.

In stating these uses we are on somewhat uncertain ground. Much experimental evidence is necessary, such as can only be obtained on oceanographic expeditions and by observations on the living organisms at biological stations. But it seems probable (1) that luminous lures such as are seen on some fishes may serve as an attraction or bait for prey; (2) that some photospheres may be recognition marks for the attraction of other individuals of the same species for mating or other purposes; (3) that the sudden flashing of light may be a protection of an alarming or warning nature to enemies, like the brilliant colours and threatening attitudes of some land animals (possibly the warning may be an indication of a distasteful animal to be avoided as food); (4) that the luminous clouds of secretion sometimes emitted may distract an enemy and allow an active Copepod to escape; (5) that a detached luminous fragment cast off from the body may be a "sacrifice lure" to deceive the enemy; (6) that in the case of some stationary animals where the nutrition depends upon ciliary currents or upon waving tentacles, the light may attract swarms of minute organisms which can then be captured as food; and (7) that in the case of predaceous animals prowling about the dark sea-bottom, lights on the head, near the eyes or on the lower surface of the body may be of use for general illumination of the abysses in the constant search for food.

The various cells, tissues and organs that give rise to luminescence in marine organisms may be regarded as an evolutionary series. Starting with the emission of light from a single cell as a non-utilitarian incident of the metabolism of the living protoplasm, we may imagine this vital characteristic becoming of survival value in some sets of organisms and not in others, according to the difference of environment and habits. Furthermore, the value of one type of light-production might be greater in one set of animals than that of another type in a different set. Thus superficial photogenous tissue, or more deeply seated glands, a more general diffusion, or a concentration in special photospheres, might each be of more use in one case than in another under different environmental conditions. Thus we can imagine the gradual evolution through the ages, under the action of variation and natural selection or elimination, of the different kinds of luminescent organs in accordance with their survival value in one kind of animal or another—and thus the diversity of the light-producing organs and their sporadic distribution in the animal kingdom does not seem unnatural. We can, at any rate, imagine a possible explanation of the mystery, and hope that further experimental work will throw much needed light upon the real utility of the various types of luminescence.

CHAPTER XIII

PLANKTON: ITS NATURE AND INVESTIGATION

The animals and plants that live in the sea have been divided, according to their habits and the regions they inhabit, into the following three sets:—

1. *Benthos*—those that live attached to or crawling over the sea-bottom.
2. *Nekton*—Those that swim freely in the water.
3. *Plankton*—those that float or drift in the water with little or no powers of independent locomotion.

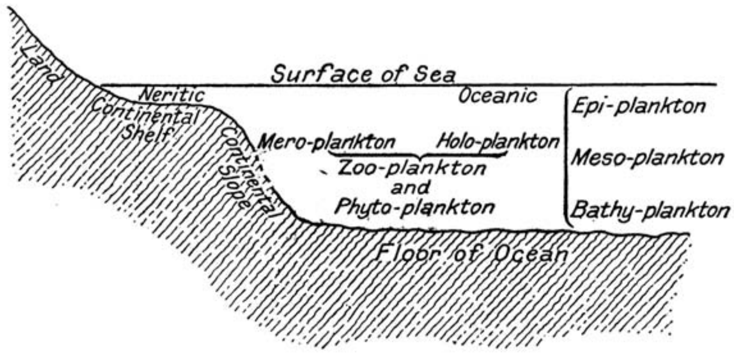
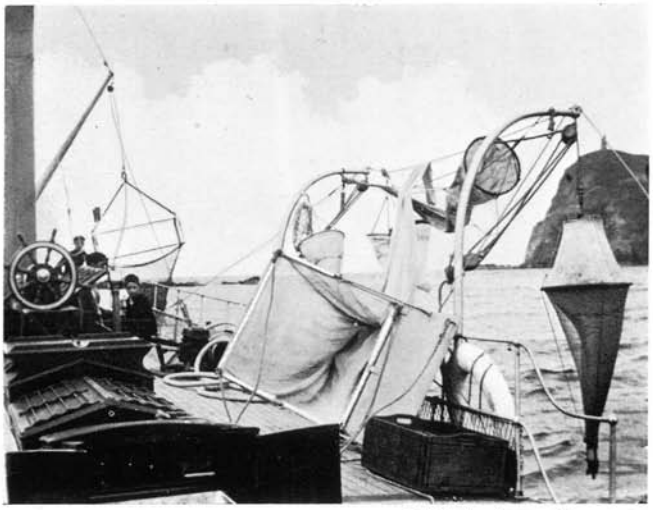


FIG. 15.—DIAGRAM TO SHOW DISTRIBUTION AND TYPES OF PLANKTON.

The term "Plankton" was introduced by Victor Hensen in 1887, and was popularized by Ernst Haeckel a few years later *(Plankton-Studien,* 1890), and classified under various subdivisions such as Phyto- and Zoo-plankton, Neritic and Oceanic, Macro- and Micro-plankton, Epi-, Meso- and Bathy-plankton, and other convenient groups according to the nature and habitat of the organisms (see Fig. 15). Holoplanktonic forms are such as remain free and pelagic during the whole of their life (Diatoms, Copepoda, etc.), and Meroplanktonic those that are transitory only, such as the embryonic, larval and other free stages of benthonic animals (Cœlenterates, Echinoderms, Molluscs and many others). Fig. 2, on Plate XVII, shows the appearance under the microscope of a sample of mixed plankton containing both plants and animals, both holo- and mero-planktonic.

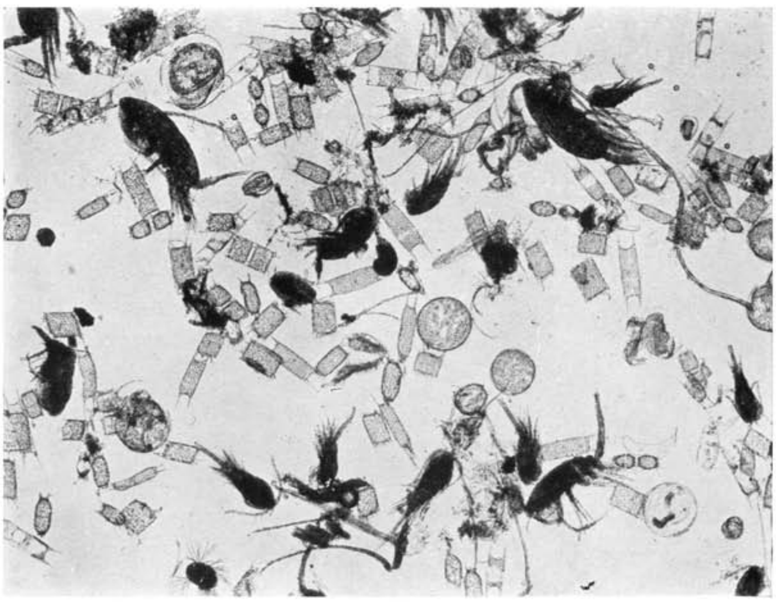
The importance of the plankton in the scheme of nature and in relation to the nutrition of the larger animals of the benthos and the nektonic fishes can scarcely be overstated, and many investigators all over the world—on special expeditions and at biological stations—during the last half-century, have made contributions to knowledge of the nature of the plankton and its detailed distribution both in space and time and the many other problems of its occurrence. Fig. 1, on Plate XVII, shows the plankton net outfit on a Yacht engaged in scientific work.

The earlier investigations of the plankton were almost entirely qualitative, that is, they consisted in identifying the organisms caught, working out their minute structure and tracing their life-history; but more recently much attention has been directed to the quantitative distribution of organisms in the sea mainly as the result of the elaborate investigations of the Kiel school of Planktologists and the German Plankton Expedition of the "National," through the Atlantic, in 1889. Previously, the plankton had been caught by various forms of tow-nets, from the simple open cheese-cloth or silk tapering bag, as used by the "Challenger" and many other expeditions, to the more complicated "closing" nets of Agassiz, Nansen and other Scandinavian investigators, which were designed to sample special zones of water below the surface (Fig. 16). But the Kiel school consisting of Hensen, Brandt, Apstein, Lohmann, and their disciples, introduced more precise methods, and designed nets of definite shape and dimensions which were calculated to strain a known



[*Photo by* EDWIN THOMPSON.

FIG. 1.—Set of Plankton Nets, drying after use on the yacht. Agassiz trawl hanging from the derrick forward.



[*Photo-micrograph by* A. SCOTT.

FIG. 2.—Mixed Plankton, containing Diatoms, Copepoda and Polychaet

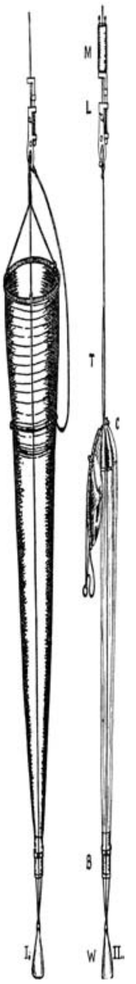


FIG. 16.—“NANSEN” CLOSING TOW-NET IN ACTION.
I. Open, as it descends and as it fishes coming up.
II. Closed, as it is when hauled in after fishing. B, brass bucket containing the catch. C, canvas front to net. L, releasing apparatus. M, brass messenger sent down line to effect closing. T, the throttling noose. W, weight.

column of water and give a catch which, when multiplied by a coefficient, would be the exact contents of so many fathoms of, say, a square metre in section—a most desirable result, if possible of attainment. Moreover, the Kiel planktologists assumed a uniform distribution of the organisms in sea areas under constant conditions; and by these methods arrived at far-reaching conclusions in regard to the amount of food matters in the sea, such as the numbers of floating fish-eggs and of the fish-populations—all based upon (1) the supposed uniform distribution over wide areas and (2) the validity of a comparatively small number of samples taken at considerable distances apart. Fig. 3, on Plate XVIII, shows one form of the Hensen quantitative net.

Before considering these and other quantitative methods more in detail, it may be convenient to name and characterize briefly a few of the leading groups of the plankton and some representative genera which may require to be mentioned further on in the discussion. Amongst the microscopic plants of the plankton there are a few Algæ and an immense number of Diatoms.

Trichodesmium erythrœum is one of the "blue-green" algæ, which, however, is of a yellowish-brown colour and occurs as bundles or clusters of short hair-like filaments in enormous abundance on the surface of some of the warmer seas, especially in the Indian Ocean and the Red Sea (hence so named). It is most irregularly distributed, and may occupy narrow tracts miles in length, or patches of large area, and then be totally absent in equally large adjoining spaces. Our knowledge of this phenomenon dates back to the times of Cook's voyages in southern seas when the tracts of yellowish discoloured water were referred to (in the journal of Sir Joseph Banks) by the sailors' name of "sea-sawdust." This and other swarms were also noticed by Charles Darwin in the South Atlantic during the voyage of the "Beagle" in 1835.

Coccospheres and *Rhabdospheres* are minute unicellular algæ having calcareous plates and spines, found in very great abundance throughout the open oceans, and especially abundant, according to Sir John Murray, in the tropics—though often overlooked on account of their minute size.

Diatoms are found most abundantly near the coasts and in colder waters such as the Southern Ocean and the North Pacific. They vary greatly in size and shape (globes, drums; spindles, ribbons, hairs, etc.), but are usually of a yellowish-brown colour and are enclosed in siliceous shells (the frustules) which may be elaborately and delicately carved and prolonged into spines and other projections. A few of the more notable forms are:—

Chœtoceras—a genus containing many species, some of which are amongst the most abundant Diatoms in the Irish Sea in late spring and early summer, and sometimes again in late autumn. As many as 150 millions have sometimes

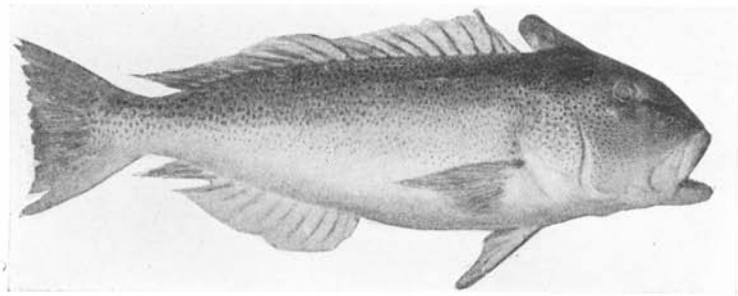


FIG. 1.—The Tile Fish.

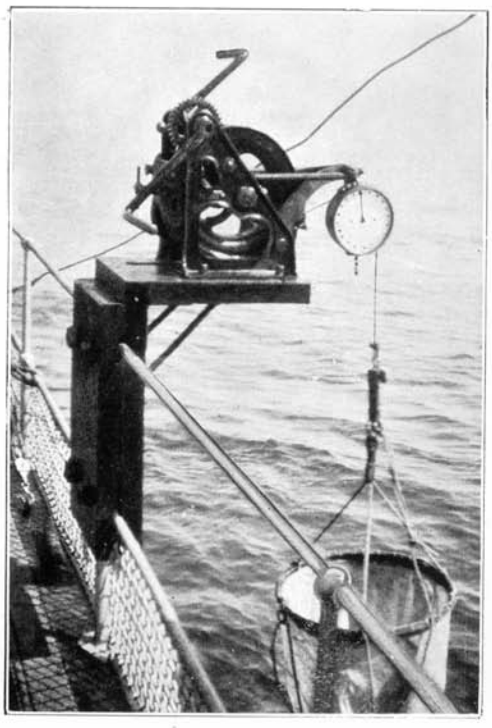


FIG. 2.—Lucas Sounding Machine as used with "Nansen" vertical closing net on rail of the yacht.

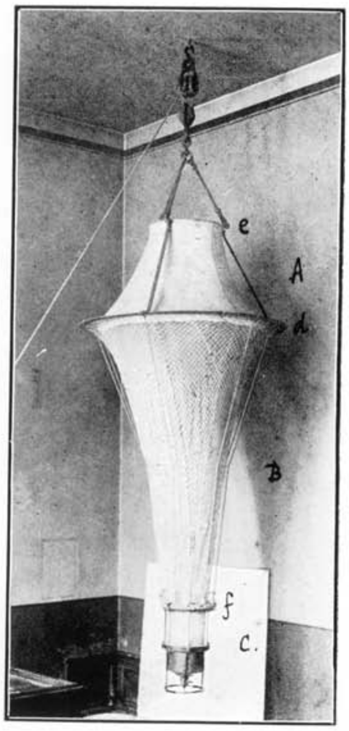


FIG. 3.—A "Hensen" Quantitative Net.

been obtained in one haul of a small tow-net in May. *Chœtoceras* (Plate XIX, Fig. 2) is characterized by the long slender curved spines which project in groups from the ends of the cells.

Rhizosolenia—another large genus, some of the species (Plate XIX, Fig. 1) of which are very abundant in our seas in early summer and late autumn, reaching the maximum usually in June, when up to 180 millions have been taken in one haul of the tow-net.

Coscinodiscus appears as discoid and drum-shaped forms in which the siliceous frustrules are marked with concentric and other geometric curves so as to form elaborate patterns. It is a winter and early spring form. (Seen as discs on Plate XVII, Fig. 2.)

Biddulphia is also a common winter and spring form and has square or oblong cells with spines at the corners and bright yellow contents. In addition to the common European species, *B. mobilienis (? B. regia),* a more elongated form, *B. sinensis* (Plate XVII, Fig. 2), has appeared of late years and is now abundant. It is supposed to have come from far eastern seas, and, according to Ostenfeld, to have been found first in the North Sea near the Elbe in 1903, and to have spread from there to the Irish Sea, the English Channel and up the coasts of Denmark to Norway.

Dinoflagellata or Peridiniales are minute unicellular organisms which are usually regarded as Protozoa, but have been claimed by some as plants. They may be very abundant on occasions and are of great importance as the food of some of the larger organisms of the plankton and even of small fishes. Two genera are very abundant in our seas: *Ceratium* (Plate XIV, Fig. 2), which is said to be the chief food of the sardine at times on the coasts of France and Portugal, and *Reridinium,* which is sometimes so abundant as to discolour the sea.

Noctiluca scintillans (Plate XIV, Fig. 1), a globular gelatinous Protozoon, related to the Dinoflagellates, which gives rise to a good deal of the phosphorescence of the sea. It may occur in dense swarms, especially in inshore waters, and may be abundant in one place and totally absent in other localities not far distant. It has been found swarming in the sea round Anglesey in August, while none were found round the Isle of Man. A few years ago it occurred in enormous abundance in the Barrow Channel in December, which is unusually late for these coasts; but in the Baltic it usually appears in great swarms late in the year. Its home, where it is commonly present throughout the year, is said to be the English Channel and the southern part of the North Sea (see also p. 214).

The Diatoms and the Dinoflagellata and their allies are frequently grouped together as "Phytoplankton" in opposition to the animals (Zooplankton) which follow:—

The Copepoda, small shrimp-like Crustacea averaging about an eighth of an inch in length, are the most important group of the zoo-plankton and are found in all seas at various depths and at almost all times of year. Some, such as the genera *Parapontella* and *Temora* (Plate XXIII), are characteristic of coastal waters ("neritic"), while others, such as *Acartia* (Plate XIX, Fig. 4) and *Anomalocera,* are "oceanic" in origin. *Calanus finmarchicus* (Plate XIX, Fig. 3) is one of the largest of Copepoda found in the British seas, and probably the most important from a practical fisheries' point of view, as it is an element in the food of various migratory fishes such as the mackerel and the herring. Its home appears to be in the North Atlantic to the south of Iceland, but it occurs on occasions in large swarms in various other parts of the European seas, and appears to be a constant inhabitant of deep water near the bottom of some of the Scottish sea-lochs.

Sagitta (Plate XX, Fig. 2), the "arrow-worm," and *Tomopteris* are both transparent, pelagic worms frequently met with in the plankton and usually more abundant in deeper zones of water than at the surface.

FIG. 1.—Phyto-plankton, consisting of the Diatom *Rhizosolenia semispina.*

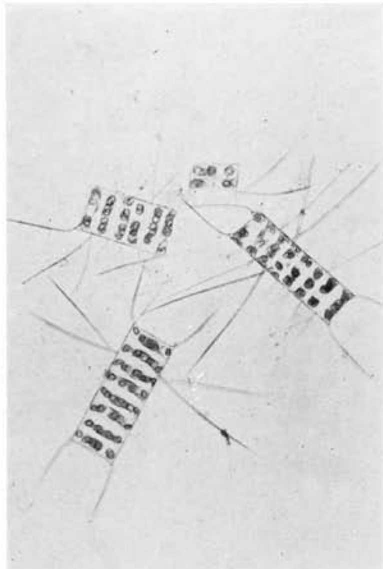


FIG. 2.—The Diatom *Chætoceras decipiens.*

FIG. 3.—Zoo-plankton, consisting of the Copepod *Calanus finmarchicus.*

FIG. 4.—The Copepod *Acartia clausi.*

All magnified.

[*Photo-micrographs by* A. SCOTT.

Podon and *Evadne* are small Crustacea allied to Copepoda, which may occur as dense local swarms in summer, and are an important element of the food of young fishes.

Oikopleura is a minute, pelagic, highly-organized animal, related to the sedentary Ascidians of the benthos, but having a locomotory tail provided with a rudimentary backbone (notochord) and remaining free-swimming throughout life. It is abundant in our seas at all times of year, and is commonly known as Appendicularia.

In addition to these and many other adult organisms, there are in the plankton immense numbers of the eggs, embryos, larvæ and free-swimming stages of most of the fixed and crawling animals, such as zoophytes, starfishes, worms, crabs and molluscs, on the bottom. It is evident then, even from this brief survey, that the plankton may contain representatives of almost all kinds of marine organisms and may be immensely varied both in amount and nature at different localities and times of year.

We now return to the methods of capture, and the investigation of the problems plankton presents to the oceanographer, in its distribution both horizontally and vertically and in its seasonal and other variations.

Let us consider one or two published examples of the problems in the economics of the sea which Hensen and his fellow-workers undertake to solve by their quantitative methods:—

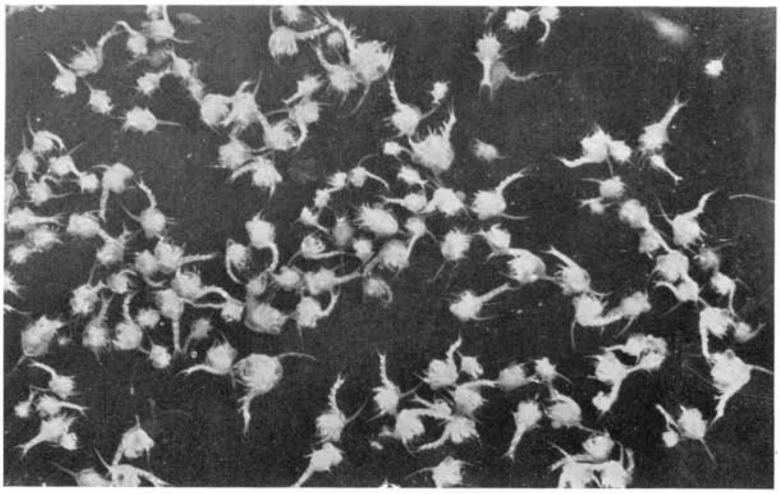
From certain samples obtained in the west Baltic it was calculated that every square mile contained 80 to 100 billion Copepoda, and from the relative proportions of eggs, larvæ and adults it was deduced that for the sixteen square miles of a certain fishery district the annual consumption of Copepoda must be 15,600 billions, and that consequently that locality supports Copepod-food sufficient for 534 million herrings of an average weight of 60 grammes.

Then, again, we are told that Brandt found about 200

Diatoms per drop of water in Kiel Bay, and that Hensen estimated that there are several hundred millions of Diatoms under each square metre of the North Sea or the Baltic; and it has been calculated that there is approximately one Copepod in each cubic inch of Baltic water.

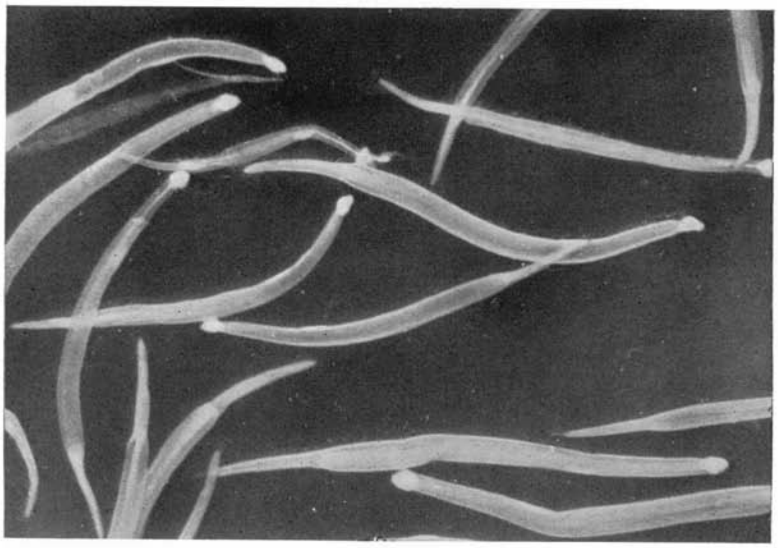
The floating eggs and embryos of the more important food-fishes occur in quantities in the plankton during certain months in spring, and Hensen and Apstein have made some notable calculations based on the occurrence of these in a series of 158 samples which led them to the conclusion that, taking six of our most abundant fish, such as the cod and some of the flat fish, the eggs present were probably produced by about 1,200 million spawners, leading them to the conclusion that the total fish population of the North Sea (of these six species), at that time (spring of 1895) amounted to about 10,000 millions. Further calculations led them to the result that the fishermen's catch of these fishes amounted to about one-quarter of the total population.

Now all this is not only of scientific interest, but also of great practical importance if we could be sure that the small series of samples upon which these colossal calculations are based were adequate and representative, but it will be noted that these samples represent only one square metre in 3,465,968,354. Hensen's statement, repeated in various works in slightly differing words, is to the effect that using a net of which the constants are known, hauled vertically through a column of water from a certain depth to the surface, he can calculate the volume of water filtered by the net and so estimate the quantity of plankton under each square metre of the surface; and his whole results depend upon the assumption, which he considers justified, that the plankton is evenly distributed over large areas of water which are under similar conditions. In these calculations in regard to the fish eggs he takes the whole of the North Sea as being an area under similar conditions, but we have known



[*Photo-micrograph by* A. SCOTT.

FIG. 1.—Zoëa stage of the Crab, magnified.



[*Photo by* A. SCOTT.

FIG. 2.—*Sagitta bipunctata*, the Arrow-worm; about twice natural size.

since the days of P. T. Cleve and from the observations of Hensen's own colleagues that this is not the case, and they have published chart-diagrams showing that at least three different kinds of water under different conditions are found in the North Sea and that at least five different planktonic areas may be encountered in making a traverse from Germany to the British Isles.

There is also direct evidence of irregularity in the distribution of such fish eggs. Hjort and Petersen, in 1905, showed that cod eggs are found in great quantities over the isolated banks of the coast of Norway, while none or very few are found over the channels between the banks. Schmidt also found eggs and fry of cod on the Rockall Bank, but not outside it. If the argument be used that wherever the plankton is found to vary, there the conditions cannot be uniform, then few areas of the ocean of any considerable size remain as cases suitable for population-computation from random samples.

The Kiel School of Planktologists cannot have it both ways. They claim that the adequacy of their samples holds good for an area of sea all of which is under similar conditions. They tell us at one time that the North Sea contains water of different kinds from different sources and with several types of plankton. If, then, it is not homogeneous—as of course, from all the evidence, it is *not*—then they cannot average the samples and multiply up for the whole area as Hensen and Apstein have done.

We have published many examples from the Irish Sea of marked irregularity in the plankton. If the plankton were uniformly distributed, then two ordinary open horizontal nets towed together at the same time ought to show similar catches, and they sometimes do; but very often they do not. Even when the volume of the catch is much the same in a pair of nets, the totals may be made up very differently, as in the case of nets A and B shown in the table on next page.

April 13, 1907—Surface.	Net A = 16 c.c.	Net B = 15·5 c.c.
Balanus nauplii	3,000	None
Copepoda nauplii	7,000	2,000
Copepoda	13,000	None
Coscinodiscus	8,000	14,000
Biddulphia	40,000	70,000
Rhizosolenia	1,000	3,000
Thalassiosira	2,000	7,000
Chætoceras	None	1,000
Oikopleura	2,000	150

The following, showing a sudden change in the nature of the plankton, is quoted from one of the Port Erin Plankton Reports:—

"We were fortunate enough on one occasion to obtain incontrovertible evidence of the sharply defined nature of a shoal of organisms, forming an instructive example of how nets hauled under similar circumstances a short distance apart, may give very different results. On the evening of April 1 (1907), at the 'alongshore' Station III, north of Port Erin, one mile out, I took six simultaneous gatherings in both surface and deeper waters. Two of the nets were the exactly similar surface tow-nets called A and B. At half-time I hauled in A, emptied the contents into a jar, and promptly put the net out again. This half-gathering was of very ordinary character, containing a few Copepoda, some Diatoms and some larvæ, but *no Crab Zoëas.* At the end of the fifteen minutes, when all the nets were hauled on board, all the gatherings, including A, showed an extraordinary number of Crab Zoëas (Plate XX, Fig. 1), rendering the ends of the nets quite dark in colour. A was practically the same as B, although A had only been fishing for seven minutes. It was evident that at about half-time the nets had encountered a remarkable swarm of organisms which had multiplied several times the bulk of the catch and had introduced a new animal in enormous numbers. Had it not been for the chance observation of the contents of A at half-time, it would naturally have been supposed that, as all the nets agreed in their evidence, the catches were fair samples of what the water contained over at least the area traversed—whereas we now know that the Zoëas were confined to at most the latter half of the traverse and may have been even more restricted. Under these circumstances, an observation made solely in the water traversed during the first seven minutes would have given a very different result from that actually obtained; or, to put it another way, had two expeditions taken samples that evening at what might well be considered as the same station, but a few hundred yards apart, they might have arrived at very different conclusions as to the constitution of the plankton in that part of the ocean."

As an example of marked differences in the micro-plankton in small areas, the Norwegian Professor H. H. Gran *(Pub. de Circon.,* No. 62, 1912), finds at two neighbouring stations in the Skagerak two distinctly separated layers of water each with its own characteristic flora. One layer is from the surface to about 20 metres, and the second from about 40 metres to 100. There is a boundary layer between the two at about 30 metres. He points out, moreover, that the plankton has a very different character at these two adjacent stations—the Diatoms at the one being what we should expect to find in the southern part of the North Sea, while at the other the Diatom plankton may have come from the north part of the North Sea between Scotland and Norway. His conclusions are:

"It will be apparent already from the few investigations, which have been mentioned here as examples, that an exact quantitative investigation of the plankton at different depths will be able to give interesting information, not only regarding the biological conditions of the species, but also regarding their dependence on the currents. Such an investigation, where the quantity of plankton at certain depths with certain biological conditions is determined, is in any case of much more value for many questions than vertical hauls or investigation of water-samples, which are taken to be representative of a whole column of water from the surface to a definite depth. The result of these latter methods, which have been used especially by the Kiel naturalists, is, that the interesting details found on comparing the plankton flora at different depths disappear in an average, which often has a very doubtful value. In any case, it is better, as Lohmann has done, to calculate the average for the plankton of the whole column of water, *after* reliable and exact observations have been made at definite depths." So far Gran, who may be regarded as a very reliable authority.

Now these are cases of catches taken in shallow water or in coastal areas, and it may be said—it has been said—that results may be very different out on the high seas far from land where the conditions are more constant and the plankton ought to be more regularly distributed; but when we look at the evidence that is available we find that there is much that tells the other way. Many naturalists on long voyages have told of the swarms of some planktonic organism met with in quite limited areas—organisms such as *Trichodesmium, Medusæ, Salpa, Physalia* and *Clione.* Most of these are members of the macro-plankton, it is true, but macro-plankton is of the greatest importance as the food of fishes and whales. Then, to record a personal experience, I have examined the plankton daily on twelve ocean traverses, through the North and South Atlantic, the Indian Ocean, and the great expanse of the Southern Ocean (going to North America, to South Africa, to Ceylon, and to Australia), caught by means of fine silk nets on taps with sea-water running day and night, and the variations from day to day have usually been very marked, and not in the macro-plankton only, but also in the case of the Diatoms and Peridinians belonging to the micro- or nannoplankton.

On one occasion in mid-ocean I encountered a good example of a swarm of a very minute organism so abundant as to colour the water. In the Southern Ocean, between the Cape of Good Hope and Australia, the sea was noticed one afternoon to be blood-red in the curl of the waves where the sunlight shone through. I pointed it out to several members of the British Association party on board, and all agreed that it was most striking. My tap-net a little later showed that the colour was due to a minute red Peridinian, which must have been present in enormous profusion over a limited area in the open sea where there was no recognized current carrying special conditions—and cases are on record of swarms of this or an allied form not only colouring the sea locally, but also causing such a pollution of the water as to result in widespread death of larger marine animals so as to cause a nuisance when cast up on the Australian coasts. In the recent literature of the subject there are many other similar cases of marked irregularity of even the more minute plankton in the open ocean, such as Ove Paulsen's observation that the sea to the east of Iceland in July was blood-red for days from the presence of *Mesodinium pulex,* and also his record of very unequal distribution in the open Atlantic Ocean near the Faroe Bank—the quantity of plankton being very much greater in one haul than in the previous one. But to my mind the chart-diagrams of the quantitative planktologists themselves tell in the same direction; for example, the one giving the results of the Plankton Expedition in the Atlantic shows a very marked irregularity, not only as between arctic, temperate, and tropical waters, but also almost day by day in most parts of the ocean traversed.

In all these cases, no doubt it may be said the plankton results were different because the conditions were not similar; but it is surely not justifiable to say that in the open sea the plankton must be evenly distributed because the conditions are constant over large areas, and then, whenever a case of irregularity in distribution is observed, to say that only proves that the conditions cannot have been constant at that locality. If all these areas are ruled out, then it becomes a question whether what remains of the ocean is of any use to us as a basis for calculations as to the planktonic contents of the sea either for practical fishery purposes or for purely theoretical speculations. Moreover, it must be remembered that the coastal waters, which it is agreed are not homogeneous in character, and where the plankton is very irregularly distributed, are just the areas of most practical importance in connection with the fishing industries. All the great fisheries of the world are carried on in coastal waters, so far as is known to us of mixed character and containing a very irregularly distributed plankton.

P. T. Cleve has shown that in January, 1897, the North Sea, our most celebrated North European fishery area, contained at least five different types of plankton (named from their characteristic organisms)—"Tripos" plankton, in the centre; "Halosphæra" plankton forming a belt around that and stretching from Denmark to Scotland; "Concinnus" plankton, nearer each shore and extending down the coasts of Holland and Belgium towards the English Channel; while "Tricho" plankton and "Sira" plankton border the south of Norway and fill up the Skagerak. And a similar mixture of different types and quantities of plankton will probably be found to obtain in other large fishery areas—not to say oceans—when they come to be adequately investigated.

As another example of evidence of irregularity in distribution of the plankton, take the results obtained by Dr. Herbert Fowler in his expedition in the North Atlantic in the summer of 1900—a cruise which has thrown much light upon the relations of oceanic plankton. Dr. Fowler's results are valuable in demonstrating the varied composition of the plankton from day to day in the open sea. His sixteen stations were so close together that the whole area investigated measured only sixty-six miles by twenty-two, and his results for the Chætognatha *(Sagitta,* Plate XX, Fig. 2) show that even at adjacent stations on successive days the numbers obtained were very different, one catch being many times another, and the greatest about thirty times as much as the least. Now, if a vessel taking observations, say, twenty miles apart, were to have traversed this area and obtained only one of these gatherings, she might have gone off with a so-called sample which was ten or twenty times too great or too small to represent fairly the average, in either case giving an indication that was false and might lead to entirely erroneous conclusions. Similarly in the case of *Doliolum,* Dr. Fowler found an enormous disproportion between the amounts of the catch on the different days, even at closely adjacent localities. It is obvious that if the number of *Doliolum* present in the area were calculated from one of his samples, the result would be entirely different from that based upon other samples. Cases of this kind could be multiplied, and have no doubt occurred in the experience of most naturalists who have done much work at sea.

The stock area of the open ocean, often quoted as being under constant conditions, is the Sargasso Sea, far from the disturbing influence of the coasts and isolated by a vast surrounding current. There the conditions must be as uniform as in any large oceanic area, and we would certainly expect that there, if anywhere, the plankton would be uniform. But in the twenty-four hauls made in the Sargasso Sea during the Plankton Expedition the catches varied in volume from 1.5 to 6.5 cubic centimetres. Where the difference in range is so great as this, is one justified in taking an average and using it to multiply up for the purpose of estimating the population of the vast area?

Moreover, it is not justifiable to add together the estimated amounts of the various possible sources of error and deduct these from the apparent irregularity, as some of these sources of error, such as the movements of the ship, may, for all we know, have added to the bulk of the smallest catch or have diminished that of the largest, and so may have actually lessened the evidence in regard to the natural irregularity of the plankton, and the same is true of any possible error there may be in the reading of the catch. The total mean divergence of the average catch has been estimated at 32 per cent., and Schütt attributes 20 per cent. of this to the possible errors of the experiment all combined, and he then deducts this from the 32 per cent. so as to reduce the amount of divergence; but some of the errors may have to be added, not deducted, or they may neutralize one another. They are quite unknown and it must not be assumed that they tell in all cases, or at all times, in favour of uniformity.

The Sargasso Sea, and no doubt some other oceanic areas of limited extent, are probably more constant in their physical conditions and more uniform in plankton contents than inshore seas and than many other parts of the ocean; but it may be doubted whether they are sufficiently uniform to yield results by Hensen-net methods that would enable us to make a census or a quantitative estimate of the whole area.

Great stress has been laid by some writers upon the efficacy of vertical hauls as giving reliable and therefore comparable samples of the contents of a column of water of known dimensions. I shall therefore discuss in some detail the results obtained from a recent series of such hauls taken in the Irish Sea.

A few experiments have been made in the past, by Hensen and others, in hauling comparable nets simultaneously or the same net several times in rapid succession in order to estimate the amount of variation in the results or the divergence of each sample from an average. With the view of getting further evidence from a new series of data, taken with all possible care under favourable conditions, I carried out a number of similar experiments at Port Erin during several months in the spring, summer and autumn of 1920. They consisted of seven series of four to six successive (that is, as nearly as possible simultaneous) vertical hauls taken with the "Nansen" net of No. 20 silk.[1] The "Nansen" net is shown in Fig. 16, on p. 233, and, attached to the Lucas sounding machine, at Plate XVIII, Fig. 2.

An apparent uniformity in the successive catches of each series was obvious at the time of collecting. It seemed to the eye to be the same catch that was emptied from the Nansen-bucket into the bottle of formaline time after time throughout a series. And this apparent uniformity of volume was in most cases confirmed by the subsequent measurements in the laboratory—for example, the six successive hauls from 8 fathoms on April 3 all measure 0.2 c.c., four out of five of those from 20 fathoms on April 6 are 0.6 c.c., and all four on August 7 from 20 fathoms measure 0.5 c.c. The remaining four series show some variation, but the percentage deviation from the average of each series is in no case great (see table, p. 248).

If, however, we make a microscopic investigation of the catches, we find that even in the same series, similar volumes of the plankton may be made up rather differently, and may in some cases show surprising differences in the numbers of a species in successive hauls, such as 10 and 100, 40 and 800, 4,000 and 18,000. Notwithstanding, then, some appearance of similarity between the hauls of a series, there is a considerable percentage deviation in the case of some hauls from the average of their series—not infrequently about plus or minus 50 per cent., and in several cases about 70, and in one case plus 129. The following table gives the percentage deviations in the case of the volumes of the catches, and also of the counted or estimated numbers of

[1] For full details as to the conditions of the experiment, and the methods of obtaining the results here given, see "Variation in Successive Vertical Plankton Hauls at Port Erin," *Trans. Biol. Soc. L'pool,* vol. xxxv, p. 161, 1921.

the four chief groups of organisms present, viz. Diatoms, Dinoflagellates, Copepoda and the Nauplii of Copepoda.

Date and. Depth.	No. of hauls.	Vol. in c.c. aver- age.	Greatest per cent. devia- tion from average.	Dia- toms ditto.	Dino- flagel- lates ditto.	Cope- poda ditto.	Cope- pod Nau- plii ditto.
April 3— 8 fathoms	6	0·2	0	− 52	− 42	− 14	− 19
				+ 24	+ 24	+ 21	+ 39
April 6— 20 fathoms	5	0·58	− 14	− 51	− 53	− 50	− 44
			+ 3	+ 41	+ 56	+ 42	+ 41
April 8— 20 fathoms	6	0·52	− 23	− 24	− 20	− 40	− 39
			+ 15	+ 17	+ 15	+ 22	+ 22
April 13— 8 fathoms	5	0·48	− 17	− 41	− 65	− 22	− 57
			+ 25	+ 73	+ 44	+ 33	+129
May 25— 20 fathoms	4	16·125	10	− 21	− 22	− 72	− 33
			+ 21	+ 15	+ 23	+ 60	+ 56
August 7— 20 fathoms	4	0·5	0	− 70	− 27	− 13	− 21
				+ 59	+ 17	+ 32	+ 10
September 16– 20 fathoms	4	6·1	− 26	− 36	− 22	− 36	− 31
			+ 23	+ 30	+ 36	+ 53	+ 37

In all there are about fifty species of organisms that occur with fair regularity throughout the series: twenty-four species of Diatoms, four of Dinoflagellates, eight of Copepoda and about fourteen other organisms or groups of organisms which are not of so much importance and may be omitted. Of the twenty-four species of Diatoms, as a general rule, if a species occurs in one of the hauls of a series it occurs in all, and in many cases in much the same proportions in all; that is, there may be two or three or even more times as many individual cells in one haul as in another, but all will be in the tens, or in the hundreds, or the thousands, or millions. For example, on April 3 we have:—

Coscinodiscus radiatus, 1,600, 2,600, 2,600, 2,800, 2,800, 2,200.

Streptotheca thamensis, 40, 30, 30, 40, 40, 60.

Many other similar examples might be given from the detailed records, but on the other hand other occasions show more variation.

It is much the same with the four common species of Dinoflagellates recorded. There again we find cases of considerable constancy in the hauls of a series, such as:—

May 25. *Peridinium divergens,* 46,000, 62,000, 50,000, 44,000;

and other cases of more variation, even in that same series, such as:—

May 25. *Ceratium furca,* 6,000, 2,000, 8,000, 1,000.

Are we entitled from this to conclude that the Peridinium is evenly distributed through the zone of water sampled and the Ceratium much less so? I doubt it.

The Copepoda seem also to indicate in many cases a fairly even distribution. Sometimes they occur only in units, and yet each haul of the series shows a few:— "

April 3. *Oithona similis,* 8, 4, 3, 3, 5, 11.

April 13. *Temora longicornis,* 10, 5, 10, 10, 10.

April 13. *Oithona similis,* 20, 20, 20, 20, 20.

Other cases, again, seem to indicate considerable variation in adjacent hauls. Which of these contradictory impressions received from an inspection of the results of the hauls is true to nature? If the Oithonas on April 13 had been very irregularly scattered through the water, is it likely that we could catch exactly 20 in each of five successive hauls? On the other hand, if they are evenly distributed, how can we account for one haul (April 6) catching 40 and the next 140, or for the series on May 25:—20, 80, 460, 290, in the four successive hauls?

Some of the other common organisms of the plankton outside the above main groups also give conflicting evidence. The pelagic arrow-worm, *Sagitta bipunctata,* is present in nearly every haul in numbers varying from one to twenty-seven, but in some series one or two individuals are present in every haul, while in another series the successive hauls varied from one to eleven. The impression one receives from an inspection of the lists and numbers as they stand is that if on each occasion one haul only in place of four or six had been taken, and one had used the results of that haul to estimate the abundance of any one organism or group of organisms in that sea-area, one might have arrived at conclusions about 50 per cent. wrong in either direction.

Is such a result of any real value as a basis for calculations as to the population of the sea? And is it possible that such numerical variations are compatible with the hypothesis of an even distribution of the plankton throughout a sea-area of constant character? The answer to such questions depends to some extent upon the possible range of error under the conditions of the experiment, and upon the possibility of allowing for that experimental error, and of reducing it by more refined methods of collecting and estimating. I feel confident that the possibility of error in the collecting was reduced to a minimum. There is also the possibility of error in the microscopic examination and estimation of the contents of the catch. This can only apply in the case of the more minute organisms, present in great abundance, such as the Diatoms which have to be estimated from counted samples. In the case of Copepoda and Sagitta and other larger organisms, this source of possible error is excluded, as these are picked out from the entire preserved catch with the eye or a hand lens, and counted directly. Sampling and estimation are not applied to the macro-plankton, and yet the variation is as great there as in the case of the estimated micro-plankton.

The experimental error to be expected in the case of the three chief groups of organisms, and also in the case of a typical species of each, has been calculated, by means of a formula for obtaining the probable error, with the following results.

The total number of Diatoms on April 3 varied in the six hauls from 3,880 to 10,020, the mean being 8,055. Two of the hauls are below the mean and four above. The smallest haul is 52 per cent. below the mean, and the largest haul is 24 per cent. above. The question is: Do these variations in the catch come within the limits of the probable error of the experiment? If we assume that the estimation of the number of Diatoms in each haul is correct, then the possible errors are those inseparable from all such collecting at sea—slight movements of the boat, unknown currents in the water, irregularities in the verticality of the line, etc. In this case of the Diatoms on April 3, the "probable error" is found to be = 1,458, and the "range" is the mean $\pm$ the probable error, that is from 6,600 to 9,500. Comparing this range with the estimated results of the hauls, we find that three of the series are within the range and three are outside it, and two of the latter (3,880 and 10,020) are very considerably beyond the limits of the probable error of the experiment.

The Diatoms of the other hauls give much the same result when treated in the same manner—that is, roughly 50 per cent. or rather more of the observed variation in the catches is not covered by the calculated range of error of the experiment.

A series of detailed tables are given in the full report from which the above is summarized, in which each of the principal groups of the plankton, and also three prominent organisms, the Diatom *Coscinodiscus radiatus,* the Dinoflagellate *Ceratium tripos* and the Copepod *Pseudocalanus elongatus,* are shown for all seven series of hauls treated as in the case of the Diatoms of April 3 discussed above, and giving in each case the figures necessary to make a comparison between the range of variation in the catches and the calculated range of error. These tables show that in each case a large proportion—from 50 per cent. to 22 out of 34—of the observed variations are outside the range of error of the experiment.

To the question, What light does a series of, say, six successive hauls throw upon the validity of a single haul, say, the first of the series? the answer seems to be that as regards mere size (volume) and general nature (such as phyto-plankton, zoo-plankton, or mixed) of the catch the series confirms the representative character of the single haul in a general way and within limits.

But if one next proceeds to deal quantitatively with the groups and the individual species, it is found that the hauls in a series may differ widely: up to fully 50 per cent. of the variations from the mean of the series extend beyond the range of error and are therefore not due to possible imperfections in the experiment. Thus more than half the differences between the hauls of a series remains unaccounted for, and may naturally be interpreted as evidence of an unequal distribution of the plankton in closely adjacent areas of water or in the same area in successive periods of time.

Whether the present methods of collecting and of estimating are sufficiently accurate to enable us to determine the amount of this inequality in the distribution, so as to be able to assign probable upper and lower limits to the number of each organism per unit volume of water, may be doubtful, but we may hope that improvements in method and accumulation of evidence may in time enable us to make some approximation to an estimate of the population of various sea-areas. Other more refined methods of collecting samples of the micro-plankton have been recently devised such as the filtering and centrifuging (or other exhaustive examination) of small measured quantities of water, or the cultivation of every organism in a very small volume of water. These methods have added much to our knowledge of the minuter and more elusive forms—the "nanno-plankton," but the drawback to all of them is that they deal with relatively small volumes (one, three or five litres) of the water, and it must remain doubtful whether the same organisms in the same quantity would have been present in the next bucketful of water that might have been taken from the sea.

Even if we had no hope of attaining to greater accuracy our present planktonic results are of some value. Although estimates which may be 50 per cent. wrong in either direction do not justify us in calculating exactly the number of organisms or of potential food present per area of sea or volume of water, they do give us a useful approximation. Even if 100 per cent. out, doubling or halving the estimated number is a relatively small variation compared with the much larger increases and reductions, amounting to, it may be, ten thousand times in the case of Diatoms, ten to fifty times in the Dinoflagellates and five to twenty times in Copepoda, which we find between adjacent months—and even greater differences if we take groups of months—in a survey of the seasonal variations of the plankton.

Successive improvements and additions to Hensen's methods in collecting plankton have been made by Lohmann, Apstein, Gran, and others, such as pumping up water of different layers through a hose-pipe and filtering it through felt, filter-paper, and other materials which retain much of the micro-plankton that escapes through the meshes of the finest silk. Use has even been made of the extraordinarily minute and beautifully regular natural filter spun by the pelagic animal *Appendicularia* for the capture of its own food. This grid-like trap, when dissected out and examined under the microscope, reveals a surprising assemblage of the smallest Protozoa and Protophyta, less than thirty micro-millimetres in diameter, which would all pass easily through the meshes of our finest silk nets. That the regularity of the meshes in the silk rapidly deteriorates with use is seen from a comparison of Plate XXI, Figs. 1 and 2.

The latest refinement in capturing the minutest-known organisms of the plankton (excepting the Bacteria) is a culture method devised by Dr. E. J. Allen of Plymouth. By diluting half a cubic centimetre of the sea-water with a considerable amount (1,500 c.c.) of sterilized water treated with a nutrient solution, and distributing that over a large number (70) of small flasks in which after an interval of some days the developed organisms can be counted, he calculates that the sea contains 464,000 of such organisms per litre, whereas the centrifuge showed only 14,450 per litre; and he gives reasons why his cultivations must be regarded as minimum results, and states that the total per litre may well be something like a million. Thus every new method devised seems to multiply many times the probable total population of the sea and reminds one of the poet Spenser's lament in "The Faerie Queen":— "

"O what an endlesse worke have I in hand,
To count the sea's abundant progeny,
Whose fruitful seede farre passeth those in land,
* * * * *
Then to recount the sea's posterity
So fertile be the flouds in generation,
So huge their numbers and so numberlesse their nation."

The conclusion in regard to this branch of plankton investigation must be that there is probably no one method which can give us a complete quantitative estimate of the total number of organisms in a sample of sea-water; but by the combination of a number of methods—coarse and fine nets for the larger organisms, centrifuging and cultivation flasks for smaller—we may hope in time to approximate to a solution of the problem, how to obtain a planktonic census of the sea. And even then it will only be the sea at that time and place.

Therefore, in my judgment, the validity of the conclusions arrived at by the quantitative methods depend too much upon exactly where and when the samples are taken. At another neighbouring locality, or at a different time, the results might be very different. There are, obviously,

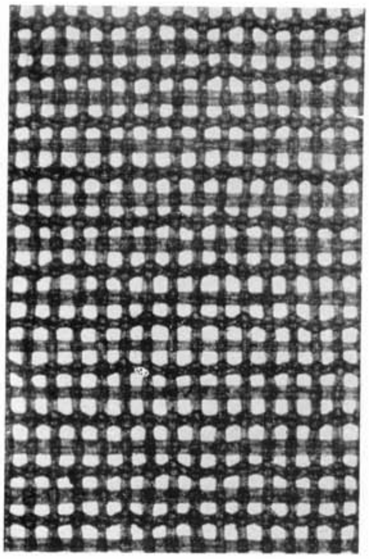


FIG. 1.—Plankton-net Silk, Mesh of No. 20, when new. × 23.

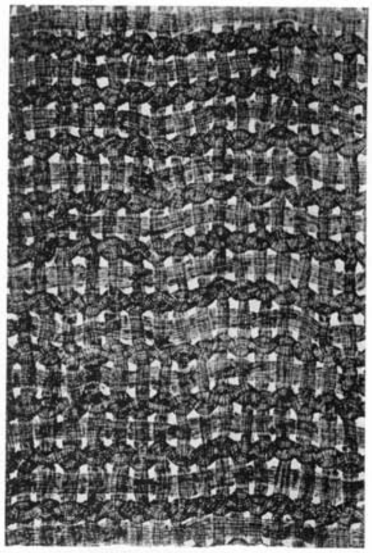


FIG. 2.—The same silk after use in the "Nansen" net, for a few weeks. × 23.

FIG. 3.—Zoo-plankton, consisting of *Oithona Helgolandica*; magnified.

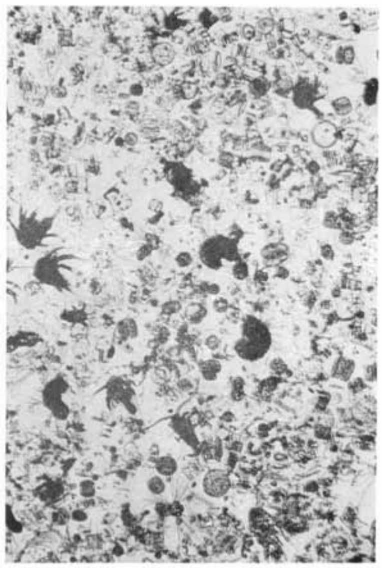


FIG. 4.—Mixed Plankton, consisting of Diatoms, Nauplii, Polychaet larvae, etc.; magnified.

three possible sources of error in the quantitative methods:—

1. The imperfections of the net as a filtering apparatus. These of course apply to all nets and are generally admitted, and improvements and substitutes, such as pump and filter and centrifuge, have been proposed and used. Kofoid finds that the coefficient of the net may vary from 1.5 to 5.7, according to its condition, and that it may retain anything from 1/2 to 1/45th of the solid contents of the water filtered.
2. The vertical haul may defeat its object by mixing zones of plankton which ought to be sampled separately. Closing quantitative nets have been devised to meet this difficulty, but Paulsen has shown recently that these vertical nets may fish while being lowered down, as well as when coming up, and therefore are not reliable.
3. The irregularity in distribution of the plankton. No device can get over this difficulty. The only remedy is more frequent sampling and more accurate and detailed determination of the characters, both physical and biological, of the various areas, currents and zones of water making up our seas—and all that is being done, and must be done in still greater detail, by oceanographers all over the world.

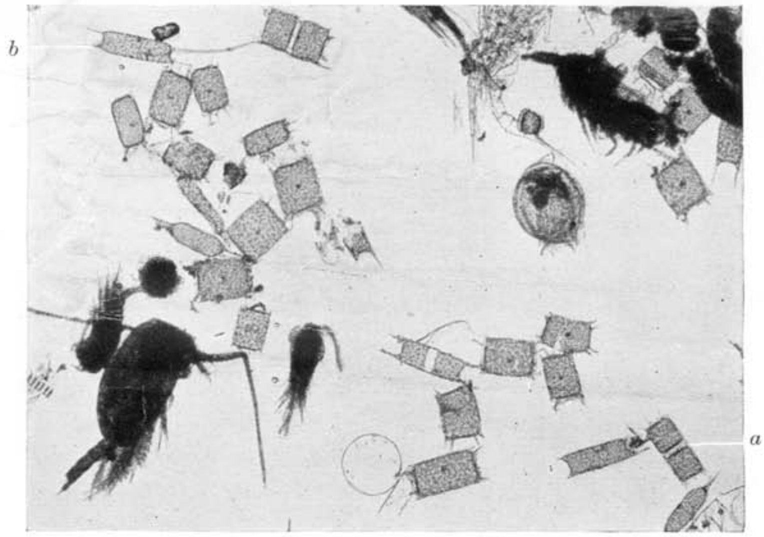
We need not, however, fail to appreciate the labours of the plankton school at Kiel, or be at all hopeless as to science attaining to a more exact knowledge of the populations of the oceans. The leading idea of quantitative estimation is a good one, the implements devised are very ingenious, and the long-continued laborious computations of some of the German professors have been most praiseworthy. But the method is still open to serious objections, the most fundamental of which is the obvious irregularity in the distribution of the plankton—horizontally, vertically and chronologically—an irregularity which must vitiate any calculations based upon comparatively few and distant samples. Marine biologists will probably do better to concentrate their efforts upon the intensive study of small areas before trying to estimate the contents of an ocean.

CHAPTER XIV

PLANKTON *(continued)*: ITS VARIATIONS AND ITS PROBLEMS

There are many other problems of the plankton in addition to those of the quantitative estimates—possibly even some that we have not yet recognized—and various interesting conclusions may be drawn from some recent planktonic observations. Here is a case of the introduction and rapid spread of a form new to British seas.

Biddulphia sinensis (see Fig. 1 on Plate XXII) is an exotic Diatom which, according to Ostenfeld, made its appearance at the mouth of the Elbe in 1903, and spread during successive years in several directions. It appeared suddenly in our plankton gatherings at Port Erin in November, 1909, and has been present in abundance each year since. Ostenfeld, in 1908, when tracing its spread in the North Sea, found that the migration to the north along the coast of Denmark to Norway corresponded with the rate of flow of the Jutland current to the Skagerak—viz. about 17 cm. per second—a case of plankton distribution throwing light on hydrography—and he predicted that it would soon be found in the English Channel. Dr. Marie Lebour, who recently examined the store of plankton gatherings at the Plymouth Laboratory, finds that as a matter of fact this form did appear in abundance in the collections of October, 1909, within a month of the time when according to our records it reached Port Erin. Whether or not this is an Indo-Pacific species brought accidentally by a ship from the Far East, or whether it is possibly a new mutation which



[*Photo-micrographs by* A. SCOTT.

FIG. 1.—Plankton showing (*a*) *Biddulphia mobiliensis* and (*b*) *B. sinensis.* × 25.

FIG. 2.—Nauplius stage of *Balanus.* × 30.

FIG. 3.—Cypris stage of *Balanus.* × 30.

appeared suddenly in our seas, there is no doubt that it was not present in the Irish Sea plankton gatherings previous to 1909, but has been abundant since that year, and has completely adopted the habits of its English relations—appearing with *B. mobiliensis* in late autumn, persisting during the winter, reaching a maximum in spring, and dying out before summer.

The Nauplius and Cypris stages of *Balanus* in the plankton form an interesting study. The adult barnacles are present in enormous abundance on the rocks round the coast, and they reproduce in winter, at the beginning of the year. The newly emitted young (Nauplii) are sometimes so abundant as to make the water in the shore pools and in the sea close to shore appear muddy. The Nauplii (Fig. 2 on Plate XXII) first appeared at Port Erin, in 1907, in the bay gatherings on February 22 (in 1908 on February 13), and increased with ups and downs to their maximum on April 15, and then decreased until their disappearance on April 26. None were taken at any other time of the year. The Cypris stage (Fig. 3 on Plate XXII) follows on after the Nauplius. It was first taken in the bay on April 6, rose to its maximum on the same day with the Nauplii, and was last caught on May 24. Throughout, the Cypris curve keeps below that of the Nauplius, the maxima being 1,740 and 10,500 respectively. Probably the difference between the two curves represents roughly the death-rate of *Balanus* during the Nauplius stage. That conclusion I think we are justified in drawing, but I would not venture to use the result of any haul, or the average of a number of hauls, to multiply by the number of square yards in a zone round the coast in order to obtain an estimate of the number of young barnacles, or, after a further calculation, of the old barnacles that produced them—the irregularities are too great.

To my mind it seems clear that there must be three factors making for irregularity in the distribution in space and time of a plankton organism:—

1. The sequence of stages in its life-history—such as the Nauplius and Cypris stages of *Balanus.*
2. The results of interaction with other organisms—as when a swarm of *Calanus* is pursued and devoured by a shoal of herring.
3. Abnormalities in time or abundance due to the physical environment—as in favourable or unfavourable seasons. And these factors must be at work in the open ocean as well as in coastal waters.

Then, turning to other problems, let us take next the fact—if it be a fact—that the genial warm waters of the tropics support a less abundant plankton than the cold polar seas. The statement has been made and supported by some investigators and disputed by others, both on a certain amount of evidence. This is possibly a case like some other scientific controversies where both sides are partly in the right, or right under certain conditions. At any rate there are marked exceptions to the generalization. The German Plankton Expedition in 1889 showed in its results that much larger hauls of plankton per unit volume of water were obtained in the temperate North and South Atlantic than in the tropics between, and that the warm Sargasso Sea had a remarkably scanty microflora. Other investigators have since reported more or less similar results. Lohmann found the Mediterranean plankton to be less abundant than that of the Baltic, gatherings brought back from tropical seas are frequently very scanty, and enormous hauls on the other hand have been recorded from Arctic and Antarctic seas. There is no doubt about the large gatherings obtained in northern waters. I have myself in a few minutes' haul of a small horizontal net in the north of Norway collected a mass of the large Copepod *Calanus finmarchicus* sufficient to be cooked and eaten like potted shrimps by half a dozen of the yacht's company, and I have obtained similar large hauls in the cold Labrador current near Newfoundland.

On the other hand, Kofoid and Alexander Agassiz have recorded large hauls of plankton in the Humboldt current off the west coast of America, and during the "Challenger" expedition some of the largest quantities of plankton were found in the equatorial Pacific, and Diatoms were found to be as abundant in the Arafura Sea (lat. 10°S.) as in the Antarctic. Murray and Hjort found in their Atlantic expedition that Coccolithophoridæ, separated from the sea-water by the centrifuge, were very abundant in tropical seas, and they found large quantities of Crustacea at deeper zones in the tropics. Moreover, it is common knowledge that on occasions vast swarms of some planktonic organism may be seen in tropical waters. The yellow alga Trichodesmium may cover the surface over considerable areas of the Indian and South Atlantic oceans; and some pelagic animals such as Salpæ, Medusæ and Ctenophores are also commonly present in abundance in the tropics. Then, again, American biologists have pointed out that the warm waters of the West Indies and Florida may be noted for the richness of their floating life for periods of years, while at other times the pelagic organisms become rare and the region is almost a desert sea.

It is probable, on the whole, that the distribution and variations of oceanic currents have more than latitude or temperature alone to do with any observed scantiness of tropical plankton. These mighty rivers of the ocean in places teem with animal and plant life, and may sweep abundance of food from one region to another in the open sea.

But even if it be a fact that there is this alleged deficiency in tropical plankton, there is by no means agreement as to the cause thereof. Brandt first attributed the poverty of the plankton in the tropics to the destruction of nitrates in the sea as a result of the greater intensity of the metabolism of denitrifying bacteria in the warmer water; and various other writers since then have more or less agreed that the presence of these denitrifying bacteria, by keeping down to a minimum the nitrogen concentration in tropical waters, may account for the relative scarcity of the phyto-plankton, and consequently of the zoo-plankton, that has been observed. It has been said that the colder seas, with more plankton, contain more nitrogen (three parts in a million parts of water) than the warmer waters, with less plankton, which have only one part per million. But Gran, Nathansohn, Murray, Hjort and others have shown that such denitrifying bacteria are rare or absent in the open sea, that their action must be negligible, and that Brandt's hypothesis is untenable. It seems clear, moreover, that the plankton does not vary directly with the temperature of the water. Furthermore, Nathansohn has shown the influence of the vertical circulation in the water upon the nourishment of the phyto-plankton—by rising currents bringing up necessary nutrient materials, and especially carbon dioxide from the bottom layers; and also possibly by conveying the products of the drainage of tropical lands to more polar seas so as to maintain the more abundant life in the colder water. Pütter's view is that the increased metabolism in the warmer water causes all the available food materials to be rapidly used up, and so puts a check to the reproduction of the plankton.

According to van t'Hoff's law in Chemistry, the rate at which a reaction takes place is increased by raising the temperature, and this probably holds good for all biochemical phenomena, and therefore for the metabolism of animals and plants in the sea. This has been verified experimentally in some cases by Jacques Loeb. The contrast between the zoo-plankton of Arctic and Antarctic zones, consisting mainly of large numbers of small Crustaceans belonging to comparatively few species, and that of tropical waters, containing a great many more species, generally of smaller size and fewer in number of individuals, is to be accounted for, according to Sir John Murray and others, by the rate of metabolism in the organisms. The assemblages captured in cold polar waters are of different ages and stages, young and adults of several generations occurring together in profusion,[1] and it is supposed that the adults "may be ten, twenty or more years of age." At the low temperature the action of putrefactive bacteria and of enzymes is very slow or in abeyance, and the vital actions of the Crustacea take place more slowly and the individual lives are longer. On the other hand, in the warmer waters of the tropics the action of the bacteria is more rapid, metabolism in general is more active, and the various stages in the life-history are passed through more rapidly, so that the smaller organisms of equatorial seas probably only live for days or weeks in place of years.

This explanation, if confirmed, may account also for the much greater quantity of benthonic organisms which has been found so often on the sea-floor in polar waters. It is a curious fact that the development of the polar marine animals is in general 'direct' without larval pelagic stages, the result being that the young settle down on the floor of the ocean in the neighbourhood of the parent forms, so that there come to be enormous congregations of the same kind of animal within a limited area, and the dredge will in a particular haul come up filled with hundreds, it may be, of an Echinoderm, a Sponge, a Crustacean, a Brachiopod, or an Ascidian; whereas in warmer seas the young pass through a pelagic stage and so become more widely distributed over the floor of the ocean. The "Challenger" expedition found in the Antarctic certain Echinoderms, for example, which had young in various stages of development attached to some part of the body of the parents, whereas in temperate or tropical regions the same class of animals set free their eggs and the development proceeds in the open water quite independently of, and it may be far distant from, the parent animal.

[1] Whether, however, the low temperature may not also retard reproduction is worthy of consideration.

Another characteristic result of the difference in temperature is that the secretion of carbonate of lime in the form of shells and skeletons proceeds more rapidly in warm than in cold water. The massive shells of molluscs, the vast deposits of carbonate of lime formed by corals and by calcareous seaweeds, are characteristic of the tropics; whereas in polar seas, while the animals may be large, they are for the most part soft-bodied and destitute of calcareous secretions. The calcareous pelagic Foraminifera are characteristic of tropical and sub-tropical plankton, and few, if any, are found in polar waters. Globigerina ooze, a calcareous deposit, is abundant in warmer seas, while in the colder Antarctic the characteristic deposit is siliceous Diatom ooze.

It has been recorded that tropical plankton is especially scanty around coral reefs, and the explanation has been given that the abundant animal life of the reef feeding on the microscopic plants of the plankton keeps the amount visible at any one time very low. It may be a case of rapid production and rapid consumption compared with the slower rates of living and of reproducing in colder seas. And in all plankton investigation and estimation it must be borne in mind that the rate of production of successive generations, of which we know very little, is probably quite as important as the quantity of developed organisms present at a given moment. This is a matter I shall have to return to in a later chapter in connection with the fundamental food supply of the ocean as the basis of man's harvest from the sea.

The adaptation of many planktonic organisms to the special conditions of their life in the surface waters is interesting, and shows two main tendencies—to render them inconspicuous, and to ensure buoyancy. Many, such as Medusæ, are gelatinous and transparent, or, if coloured, are of a bluish tint, so as to tone in with their surroundings. In order to maintain their position at any required level, or alter it without too much expenditure of muscular effort, many free-swimming or floating animals, from Fishes down to Protozoa, have some form of hydrostatic apparatus, such as the swim-bladders of Fishes, the gas-containing floats or pneumatophores of Siphonophora, the oil-globules of Radiolaria and of some fish-eggs, or have the tissues so reduced in bulk and so permeated with water, as in Medusæ, Salpæ, etc., that the specific gravity of the body becomes much the same as that of the surrounding sea. In some cases the gas in the float can be secreted or absorbed as required, so as to compensate for increased or diminished pressure when changing to a different level.

Another device has been adopted in many cases in order to take advantage of the varying viscosity of the water in accordance with depth and temperature, viz., an increase of the surface of the body in relation to its bulk by means of changes of shape and formation of outgrowths, such as flat expansions, long spines, and branched or plume-like setæ. Many examples of such remarkable devices, leading to extraordinary and very ornamental appearances, are seen in Copepoda, Foraminifera, Radiolaria, etc., especially in warmer seas, where the viscosity is low.

One of the most striking phenomena of the plankton, in temperate seas at least, is the way in which it differs both in quantity and quality, in the same locality, at different times of year. In British seas, for example, a typical haul of the plankton-net in spring (say March or April) will consist almost wholly of Diatoms and allied organisms (Plate XIX, Fig. 1, and Plate XXII, Fig. 1); it is a phyto-plankton; while a corresponding haul in summer (say July or August) will have few Diatoms, if any, but will show a large number of Copepoda (Plate XIX, Figs. 3 and 4), and many other kinds of minute animals, making up a typical zoo-plankton. At the time of the spring Diatom maximum a small silk tow-net hauled for about fifteen minutes through about half a mile of the surface water of the Irish Sea will usually catch some millions of individual Diatoms, constituting on the average some 999,999 out of each million of organisms in the gathering. Similarly, when the zoo-plankton is at its height in summer, the same net may contain a gathering of Copepoda numbering hundreds of thousands of individuals, making up about 999 out of every thousand organisms present. At other intermediate times of year the plankton is smaller in amount, and of a mixed nature (Pl. XVII, Fig. 2; Pl. XXI, Fig. 4).

It is evident that there is an annual planktonic cycle (text-fig. 17) as follows:—After a winter minimum, the spring maximum of phyto-plankton starts about March (when the sea has still a low temperature), and increases to a climax in April, May, or June, after which the Diatoms rapidly diminish in number to their minimum in the height of summer, when their place is taken by the Copepoda and other animals of the zoo-plankton, to be followed by a secondary lesser Diatom maximum in late autumn (September or October), after which the whole plankton diminishes to the winter minimum. This cycle has been followed year after year at several localities in North-West Europe; but further observations throughout the year are still required in regard to tropical seas and the open oceans.

In a series of observations carried on at the Port Erin Biological Station during fifteen years, 1907–21 (when on the average six plankton hauls were taken and examined[1] every week, amounting to over 7,500 samples in all), it is found that the spring maximum for the total plankton varies from April to June, and is in most years in May; and if the total plankton be analysed into its three chief constituents (Fig. 17), Diatoms, Dinoflagellates, and Copepoda, they are found to succeed one another in that order. For example, the Diatom maximum was in March in 1907, in April in 1909, and in May in 1908; the Dinoflagellate maximum was about a month later in each

[1] For a summary of the results, see "Spolia Runiana V," *Journ. Linnean Soc., Botany,* July, 1922.

case, and the Copepod maximum usually about a month after that of the Dinoflagellates.

The cause of all these seasonal changes is still very obscure, and they may be due to the interaction of several factors. In addition to the normal succession of stages in the life-histories of the organisms throughout the year, and the diminution or extermination of those (such as Diatoms) which form the food of others (such

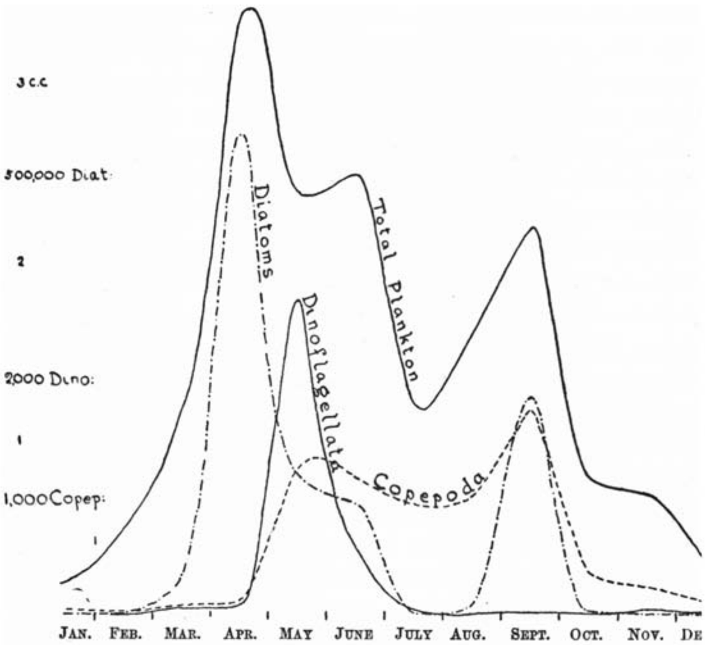


FIG. 17—CURVES FOR TOTAL PLANKTON AND FOR CHIEF CONSTITUENT GROUPS IN PORT ERIN BAY IN 1912.

as Copepoda and young fishes), we naturally turn to the meteorological conditions prevailing at the various seasons as being a possible cause of the increase or the diminution in numbers. Although one may arrive at the general conclusion that variations in the amount of the plankton from year to year must be due ultimately to meteorological conditions, it is not easy to demonstrate the connection between cause and effect in detail. The plankton increase in spring cannot be due to temperature, as the records of sea temperatures at Port Erin show that they are as low, if not lower, in March, at the time when the phyto-plankton is waking up to activity, as at any time during the winter. But although the sea has not yet commenced to warm up, the days are much longer and there are more hours of sunlight, and it seems probable that this great increase in phyto-plankton, one of the most important phenomena of the ocean, depends primarily upon the rapid increase in the amount of solar energy which accompanies the lengthening days of early spring about the time of the vernal equinox. But this rapid increase in Diatoms is no doubt also aided by the relatively large amount of carbon dioxide and other necessary food matters, including silica for their shells, accumulated in the sea during the winter. Gran and Gaarder's investigations in the Christiania Fjord show a connection between the plankton in spring and the amount of oxygen in the water, and also indicate some relation between the increase of plankton and the presence of nutrient matters in the water. The rapid disappearance of the Diatoms after their maximum may be due to a combination of causes—the exhaustion of the carbon dioxide and the silica in the water, the depredations of the increasing numbers of Copepoda, young fishes, and other diatom-eating animals, or even to the toxic effect upon the water of their own metabolism in dense crowds.

Moreover, the conditions that suit one Diatom apparently do not suit another, and so we have a regular succession of different generic forms appearing at different times, and therefore under different conditions. The first to become abundant are the winter and early spring forms—the circular discs or drum-shaped species of *Coscinodiscus* and the almost square or oblong bright yellow species of *Biddulphia* (Plate XXII, Fig. 1). These two genera are at their maximum in March and early April in an average year. Then follow the abundant species of *Chætoceras* (Plate XIX, Fig. 2), jointed filaments with groups of delicate curved hairs and spines projecting at their sides, and although species differ somewhat in their times of appearance, the genus as a whole is characteristic of late April and early May. After *Chætoceras* comes the equally large and important genus *Rhizosolenia* (Plate XIX, Fig. 1), long, slender, needle-like forms of a dark brown colour when present in mass. In the Irish Sea we have three most abundant species which follow in this order—*Rhizosolenia semispina* in late May, *R. shrubsolii* in June, and *R. stolterfothi* in late June and early July. When any one of these kinds of Diatoms is present in abundance, it may discolour the sea, and give a characteristic appearance to a plankton gathering in a glass vessel. *Coscinodiscus* and *Biddulphia* give a yellowish brown tint and a granular appearance. *Chætoceras* colours the water pale green, and when the numerous filaments sink to the bottom they adhere together in fluffy masses like cotton-wool. *Rhizosolenia* in mass has a dark greenish brown colour and a very characteristic silky appearance.

Then, again, some species of *Chætoceras* and *Rhizosolenia* help to constitute the second (autumnal) maximum in September and October, and *Biddulphia sinensis* makes its appearance in quantity in November.

There are many other genera and species of Diatoms which appear in the plankton during the year, all, no doubt, with their special characters and requirements. I have only taken, as examples, the few that are most abundant in the Irish Sea, and are probably the most important as food for animals in the plankton.

There are thus many problems of the plankton connected with the determination of the causes of all these seasonal variations I have referred to—first the sudden awakening of microscopic plant-life in early spring, when the water is still at its coldest, and when in the course of a few days the upper layers of the sea may become so filled with Diatoms that a small tow-net will capture hundreds of millions of individuals in a few minutes. And these myriads of microscopic organisms, so abundant as to colour the water, after persisting for a few weeks, may disappear as suddenly as they came—which is another problem for the oceanographer. Then later in the summer follow the swarms of Copepoda and many other kinds of minute animals, and these again may give place in the autumn to the second maximum of Diatoms, or in some years of the Dinoflagellates, such as *Ceratium* and *Peridinium*—all of which requires explanation.

I have already referred to some of the theories which have been advanced to account for these more or less periodic changes in the plankton, such as Liebig's "law of the minimum," which limits the reproduction of an organism by the amount of that substance necessary for existence which is present in least quantity—it may be nitrogen, or silicon, or phosphorus. According to Raben, for example, it is the accumulation of silicic acid in the sea-water during winter that determines the great increase of Diatoms in spring, and again in autumn, after a further accumulation. Some writers have considered these variations in the plankton to be caused largely by changes in temperature, supplemented, according to Ostwald, by the resulting changes in the viscosity of the water; but, as I have indicated above, my opinion is that those investigators are more probably correct who attribute the spring development of phyto-plankton to the increasing power of the sunlight and its value in photosynthesis, the process by which green plants (including Diatoms) obtain the necessary supply of carbon from the carbon dioxide in the sea-water.

As was pointed out by Edward Forbes just seventy years ago, the seas around the British Islands (his "Celtic Province") are the meeting-ground of northern ("Boreal") and southern ("Lusitanian") faunas—"The Celtic Province is the neutral ground of the European seas; it is the field upon which the creatures of the north and those of the south meet and intermingle."[1] We can now give an oceanographic explanation of the facts by showing that no less than three masses of sea-water of different origin and character may enter and affect the British seas in varying quantity, viz. (1) Arctic water, such as normally surrounds Iceland and the east of Greenland, and may extend farther south and eastwards towards Norway, the Faroes, and Shetland; (2) Atlantic water (Gulf Stream drift), which impinges on the western shores of Ireland and may flood the English Channel, and even extend round the Shetlands and down into the North Sea; and (3) "Coastal" water, such as flows out of the Baltic and, mixed with the other waters, bathes the coasts of N.W. Europe generally, and to a large extent surrounds the British Islands. Each of these bodies of water contains characteristic plankton organisms, and this accounts for much of the variation in our fauna from year to year.

The Irish Sea, for example, may be regarded as primarily an area of coastal water, which is liable to be periodically invaded to a greater or less extent by bodies of warmer and salter Atlantic water, carrying in oceanic plankton, and more rarely by Norwegian or Arctic water, causing an invasion of northern organisms. The variations in the nature and amount of the plankton at the same locality in different years depend partly upon the volume and period of such southern and northern invasions, but also upon other factors, such as temperature, sunshine, rainfall, wind, etc., at the time and previously. Of the half-dozen most abundant Copepoda of the Irish Sea, only one, *Temora longicornis* (Plate XXIII), is a "Neritic" form, native to the locality. The others are all usually regarded as "Oceanic," that is, as having their true home and centre of distribution somewhere to the north, west, or south in the open Atlantic.

In many oceanographical inquiries there is a double object.

[1] *Natural History of the European Seas,* p. 80, Van Voorst, 1859. But this portion was written by Forbes about 1853.

There is the scientific interest and there is the practical utility—the interest, for example, of tracing a particular swarm of a Copepod like *Calanus,* and of making out why it is where it is at a particular time, tracing it back to its place of origin, finding that it has come with a particular body of water, and perhaps that it is feeding upon a particular assemblage of Diatoms; endeavouring to give a scientific explanation of every stage in its progress. Then there is the utility—the demonstration that the migration of the *Calanus* has determined the presence of a shoal of herrings or mackerel that are feeding upon it, and so have been brought within the range of the fisherman and have constituted a commercial fishery.

We have evidence that pelagic fish which congregate in shoals, such as herring and mackerel, feed upon the Crustacea of the plankton, and especially upon Copepoda. A few years ago, when the summer herring fishery off the south end of the Isle of Man was unusually near the land, the fishermen found large red patches in the sea where the fish were specially abundant. Some of the red stuff, brought ashore by the men, was examined at the Port Erin Laboratory and found to be swarms of the Copepod *Temora longicornis* (Plate XXIII); and the stomachs of the herring caught at the same time were engorged with the same organism. It is not possible to doubt that during these weeks of the herring fishery in the Irish Sea the fish were feeding mainly upon this species of Copepod. Some years ago, Dr. E. J. Allen and Mr. G. E. Bullen published some interesting observations, from the Plymouth Marine Laboratory, demonstrating the connection between mackerel and Copepoda and sunshine in the English Channel; and Farran states that in the spring fishery on the West of Ireland the food of the mackerel is mainly composed of *Calanus.*

Then, again, at the height of the summer mackerel fishery in the Hebrides, in 1913, we found the fish feeding upon the Copepod *Calanus finmarchicus* (Plate XXIV, Figs. 1 and 2),

FIG. 1.—*Temora longicornis*, from the "red patches" on the sea; magnified.

FIG. 2.—*Temora longicornis*, from the stomach of a mackerel; magnified.

[*Photo-micrographs by* A. SCOTT.

which was caught in the tow-net at the rate of about 6,000 in a five-minutes' haul, and 6,000 was also the average number found in the stomachs of the fish caught at the same time.

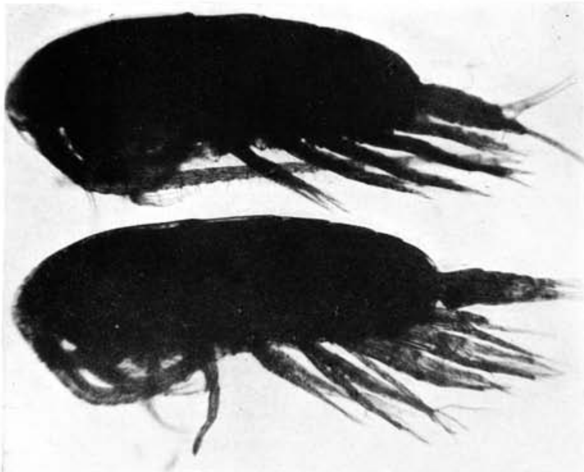
These were cases where the fish were feeding upon the organism that was present in swarms—a monotonic plankton—but in other cases the fish are clearly selective in their diet. If the sardine of the French coast can pick out from the micro-plankton the minute Peridiniales in preference to the equally minute Diatoms which are present in the sea at the same time, there seems no reason why the herring and the mackerel should not be able to select particular species of Copepoda or other large organisms from the macro-plankton, and we have evidence that they do. Thirty years ago (in 1893) the late Mr. Isaac Thompson showed me that young plaice at Port Erin were selecting one particular Copepod, a species of Jonesiella, out of many others caught in our tow-nets at the time. H. Blegvad in Denmark showed in 1916 that young food fishes, and also small shore fishes, pick out certain species of Copepoda (such as Harpacticoids) and catch them individually—either lying in wait or searching for them. A couple of years later Dr. Marie Lebour published a detailed account of her work at Plymouth on the food of young fishes, proving that certain fish undoubtedly do prefer certain planktonic food.

These Crustacea of the plankton feed upon smaller and simpler organisms—the Diatoms, the Peridinians, and the Flagellates—and the fish themselves in their youngest post-larval stages are nourished by the same minute forms of the plankton. Thus it appears that our sea-fisheries ultimately depend upon the living plankton, which no doubt in its turn is affected by hydrographic conditions. A correlation seems to be established between the Cornish pilchard fisheries and periodic variations in the physical characters (probably the salinity) of the water of the English Channel between Plymouth and Jersey. Apparently a diminished intensity in the Atlantic current corresponds with a diminished fishery in the following summer. Possibly the connection in these cases is through an organism of the plankton.

Nathansohn, Gran and others lay stress upon the importance of vertical currents in bringing nutriment to the plankton, and suggest that some of the irregularities may be due to such up-welling currents from deeper water. The enormous quantity of plankton over the Faroe Bank is probably due to vertical currents caused by the bank facing the Gulf Stream drift. It is a matter of common observation among fishermen that where there are strong tidal races and swirls sea-birds congregate, and are found to be feeding on small fishes, and these in their turn are eating the abundant plankton brought and nourished by the current.

It is only a comparatively small number of different kinds of organisms—both plants and animals—that make up the bulk of the plankton that is of real importance to fish. One can select about half a dozen species of Copepoda which constitute the greater part of the summer zoo-plankton suitable as food for larval or adult fishes, and about the same number of generic types of Diatoms which similarly make up the bulk of the available spring phyto-plankton year after year. This fact gives great economic importance to the attempt to determine with as much precision as possible the times and conditions of occurrence of these dominant factors of the plankton in an average year. An obvious further extension of this investigation is an inquiry into the degree of coincidence between the times of appearance in the sea of the plankton organisms and of the young fish, and the possible effect of any marked absence of correlation in time and quantity.

Just before the war the International Council for the Exploration of the Sea arrived at the conclusion that fishery investigations indicated the probability that the great periodic fluctuations in the fisheries are connected with the fish larvæ being developed in great quantities only in certain years. Consequently they advised that plankton work should be



[*Photo-micrograph by* A. SCOTT.

FIG. 1.—The Copepod *Calanus finmarchicus* from the West Coast of Scotland. × 20.

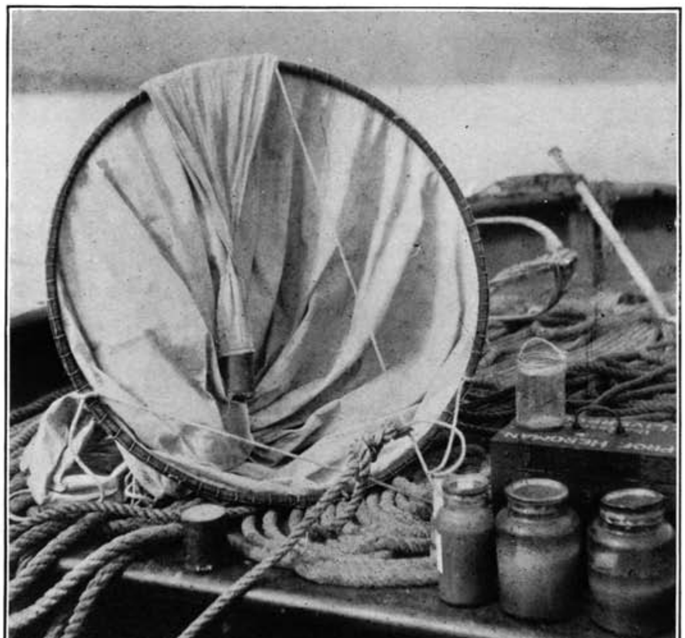


FIG. 2.—Photograph of large hauls (about 1,000 c.c. in a jar) of *Calanus*, taken from the yacht "Runa" in 1913 on the West Coast of Scotland, with the large "Nansen" net shown. The largest haul was estimated to contain at least half a million individuals.

directed primarily to the question whether these fluctuations depend upon differences in the plankton production in different years. It was then proposed to begin systematic investigation of the fish larvæ and the plankton in spring, and to determine more definitely the food of the larval fish at various stages—all of which was interrupted by the war.

About the same time Dr. Hjort made the interesting suggestion that possibly the great fluctuations in the number of young fish observed from year to year may not depend wholly upon the number of eggs produced, but also upon the relation in time between the hatching of these eggs and the appearance in the water of the enormous quantity of Diatoms and other plant plankton upon which the larval fish, after the absorption of their yolk, depend for food. He points out that, if even a brief interval occurs between the time when the larvæ first require extraneous nourishment and the period when such food is available, it is highly probable that an enormous mortality would result. In that case even a rich spawning season might yield but a poor result in fish in the commercial fisheries of successive years for some time to come. So that, in fact, the numbers of a "year-class" of fish may depend not so much upon a favourable spawning season as upon a coincidence between the hatching of the larvæ and the presence of abundance of phyto-plankton available as food.[1]

The curve for the spring maximum of Diatoms corresponds in a general way with the curve representing the occurrence of pelagic fish eggs in our seas. But is the correspondence sufficiently exact and constant to meet the needs of the case? The phyto-plankton may still be relatively small in amount during February and part of March in some years, and it is not easy to determine exactly when, in the open sea, the fish eggs have hatched out in quantity and the larvæ have

[1]For the purpose of this argument we include in "phyto-plankton" the various groups of Flagellata and other minute organisms which may be present with the Diatoms.

absorbed their food-yolk and started feeding on Diatoms.

If, however, we take the case of one important fish—the plaice—we can get some data from our hatching experiments at the Port Erin Biological Station, which have now been carried on for a period of nearly twenty years. An examination of the hatchery records for these years in comparison with the plankton records of the neighbouring sea, which have been kept systematically for the fifteen years from 1907 to 1921 inclusive, shows that in most of these years the Diatoms were present in abundance in the sea a few days at least before the fish larvæ from the hatchery were set free, and that it was only in four years (1908, '09, '13, and '14) that there

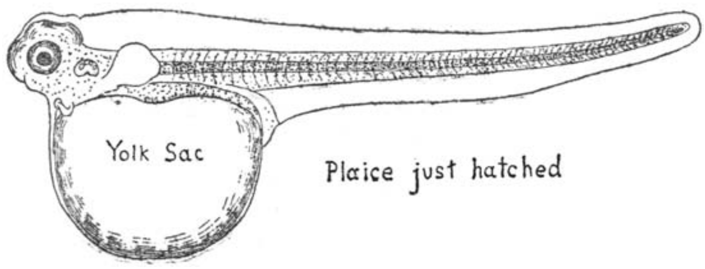


FIG. 18—YOUNG LARVAL PLAICE WITH SUPPLY OF FOOD-YOLK × 15.

was apparently some risk of the larvæ finding no phyto-plankton food, or very little. The evidence so far seems to show that if fish larvæ (Fig. 18) are set free in the sea as late as March 20, they are fairly sure of finding suitable food;[1] but if they are hatched as early as February, they run some chance of being starved.

But this does not exhaust the risks to the future fishery. C. G. Joh. Petersen and Boysen-Jensen, in their valuation of the Limfjord, in Denmark, have shown that in the case not only of some fish, but also of the larger invertebrates on

[1] All dates and statements as to occurrence refer to the Irish Sea round the south end of the Isle of Man. For further details see *Report Lancs. Sea-Fish. Lab.* for 1919.

which they feed, there are marked fluctuations in the number of young produced in different seasons, and that it is only at intervals of years that a really large stock of young is added to the population.

The prospects of a year's fishery may therefore depend, primarily, upon the rate of spawning of the fish, affected no doubt by hydrographic and other environmental conditions; secondarily, upon the presence of a sufficient supply of phyto-plankton in the surface layers of the sea at the time when the fish larvæ are hatched, and that in its turn depends upon photosynthesis and physico-chemical changes in the water; and, finally, upon the reproduction of the stock of molluscs or worms at the bottom, which were all transitory members of the plankton in their embryonic and larval stages, and which constitute the fish food at later stages of growth and development.

The question has been raised of recent years—Is there enough plankton in the sea to provide sufficient nourishment for the larger animals, and especially for those fixed forms, such as Sponges, that are supposed to feed by drawing currents of plankton-laden water through the body? In a series of papers from 1907 onwards Pütter and his followers put forward the views (1) that the carbon requirements of such animals could not be met by the amount of plankton in the volume of water that could be passed through the body in a given time, and (2) that sea-water contained a large amount of dissolved organic carbon compounds which constitute the chief, if not the only, food of a large number of marine animals. These views have given rise to much controversy, and have been useful in stimulating further research, but I believe it is now admitted that Pütter's samples of water from the Bay of Naples and at Kiel were probably polluted, that his figures were erroneous, and that his conclusions must be rejected, or at least greatly modified. His estimates of the plankton were minimum ones, while it seems probable that his figures for the organic carbon present represent a variable amount of organic matter arising from one of the reagents used in the analyses. The later experimental work of Henze, of Raben, and of Moore, shows that the organic carbon dissolved in sea-water is an exceedingly minute quantity, well within the limits of experimental error. Moore puts it, at the most, at one-millionth part, or one mgm. in a litre. At the Dundee meeting of the British Association in 1912 a discussion on this subject took place, at which Pütter still adhered to a modified form of his hypothesis of the inadequacy of the plankton and the nutrition of lower marine animals by the direct absorption of dissolved organic matter. Further work at Port Erin since has shown that, while the plankton supply as found generally distributed would prove sufficient for the nutrition of such sedentary animals as Sponges and Ascidians, which require to filter only about fifteen times their own volume of water per hour, it is quite inadequate for active animals, such as Crustaceans and Fishes. These latter are, however, able to seek out and capture their food, and are not dependent on what they may filter or absorb from the sea-water. This result accords well with recorded observations on the irregularity in the distribution of the plankton, and with the variations in the occurrence of the migratory fishes which may be regarded as following and feeding upon the swarms of planktonic organisms. I shall deal with this question of nutrition in marine animals in further detail in the final chapter.

Our knowledge of the relations between plankton productivity and variation and the physico-chemical environment is still in its infancy, but gives promise of great results in the hands of the bio-chemist and the physical chemist. Recent work by Sörensen, Palitzsch, Witting, Moore, and others have made clear that the hydrogen-ion concentration as indicated by the relative degree of alkalinity and acidity in the sea-water may undergo local and periodic variations, and that these have an effect upon the living organisms in the water and can be correlated with their presence and abundance.

To take an example from our own seas,[1] Professor Benjamin Moore and his assistants, in their work at the Port Erin Biological Station in successive years from 1912 onwards, have shown that the sea around the Isle of Man is a good deal more alkaline in spring (say April) than it is in summer (say July). The alkalinity, which gets low in summer, increases somewhat in autumn, and then decreases rapidly, to disappear during the winter; and then once more, after several months of a minimum, begins to come into evidence again in March, and rapidly rises to its maximum in April or May. This periodic change in alkalinity will be seen to correspond roughly with the changes in the living microscopic contents of the sea represented by the phyto-plankton annual curve, and the connection between the two will be seen when we realize that the alkalinity of the sea is due to the relative absence of carbon dioxide. In early spring, then, the developing myriads of Diatoms in their metabolic processes gradually use up the store of carbon dioxide accumulated during the winter, or derived from the bi-carbonates of calcium and magnesium, and so increase the alkalinity of the water, till the maximum of alkalinity, due to the fixation of the carbon and the reduction in amount of carbon dioxide, corresponds with the crest of the phyto-plankton curve in, say, April.

Prof. B. Moore has calculated that the annual turnover in the form of carbon which is used up or converted from the inorganic into an organic form probably amounts to something of the order of 20,000 or 30,000 tons of carbon per cubic mile of sea-water, or, say, over an area of the Irish Sea measuring 16 square miles and a depth of 50 fathoms; and this probably means a production each season of about two tons of dry organic matter, corresponding to at least ten tons of moist vegetation, per acre—which suggests at

[1] I have already referred to these variations in alkalinity in the chapter on Hydrography, but they require to be noticed here in their relation to plankton production.

least the possibility that there may be much more ultimate food matter in the sea than is at present made use of, and that a scientific aquiculture in the future may discover the means of converting more of the available carbon into fish food and then into fish, so as to increase our marine harvest.

Testing the alkalinity of the sea-water may therefore be said to be merely ascertaining and measuring the results of the photosynthetic activity of the great phyto-plankton rise in spring due to the daily increase of sunlight.

It must not be supposed that in these two chapters I have been able to give an exhaustive account of plankton occurrence, investigations, methods, difficulties, and results; but possibly enough has been said to give some idea of the nature of the matter and its importance both in scientific interest and in practical utility. I shall have to return to the subject of plankton in relation to the ultimate food of the sea in the final chapter.

CHAPTER XV

APPLIED OCEANOGRAPHY AQUICULTURE—OYSTER AND MUSSEL FISHERIES

Oceanography has many practical applications—chiefly, but by no means wholly, on the biological side. Even if attention be directed only to contents of the sea of direct value to man, as food, bait, adornment and other useful products, these range from whales and fur-seals downwards through many groups of lower marine animals, and even sea-weeds (kelp, etc.), to the inorganic salt which is obtained by evaporation in salt-pans and otherwise on many coasts. As examples, it is only necessary to mention the valuable pearl fisheries of Eastern seas and of many coral lagoons, the sponge fisheries of the Levant, the precious red-coral of the Mediterranean, the clam of America, the trepang of China, our own lobster, crab, shrimp, prawn, and many other minor coastal industries, before passing to two more important products—(1) shellfish, such as oysters, and (2) the true fishes, such as sole, cod, and herring—both of which will be treated more in detail as man's harvest from the sea.

These great fishing industries throughout the world deal with living organisms of which the vital activities and interrelations with the environment are matters of scientific investigation. Aquiculture is as susceptible of scientific treatment as agriculture can be; and the fisherman who has been in the past too much the nomad and the hunter, if not, indeed, the devastating raider, must become in the future the settled farmer of the sea if his harvest is to be less precarious. Perhaps the nearest approach to cultivation of a marine product, and of the fisherman reaping what he has sown, is seen in the case of the oyster and mussel industries on the west coast of France, and of these I shall now give a short account from notes made on a personal visit some thirty years ago.

Oyster-culture is spread over a number of centres from Arcachon in the south to Brittany and the Channel in the north, and may be conveniently divided into the capture and rearing of the very young oysters, or "spat," which takes place at Arcachon and elsewhere, and the fattening and preparing the full-grown shellfish for the market, which is seen at Marennes and other centres farther north.

Arcachon, on the west coast, a little south of Bordeaux, is notable for the large shallow bay, or inland sea, shut off from the ocean outside by a long bar of sand, in which is a single narrow opening through which the tide runs strongly. At low tide a large area of the bay is dry, and this is occupied by oyster-farms, the only evidence of which at high water is the rows of saplings marking the boundaries of submerged fields. As the tide falls, fields, banks, ditches, sluices, spat-collectors and young oyster-ambulances all make their appearance; and the oyster-culturists, men, women and children, troop out from the town and may be seen for the next few hours, some in boats proceeding along the water-ways, others wading in the fields inspecting their stock, collecting and shifting, removing enemies of the precious oyster, and performing other necessary operations. It reminds one of market-gardening and working on allotments, and it is a busy scene until the rising tide drives the workers from their farms back to the town. Plate XXV shows two views on different parts of an oyster parc at low tide.

The bay of Arcachon is, from its natural features, a splendid rearing-ground for immense quantities of young oysters. The old breeding oysters produce their free-swimming larvæ in summer (July), and these larvæ, during the days of their free existence, are carried in enormous numbers by the outgoing tide down the runnels and streams which converge towards the channel that opens to the Atlantic. The first object of the oyster-farmer is to place artificial "collectors" in the course of these streams, so as to intercept the microscopic young oysters in that earliest stage, and so save them from being carried out to sea and lost.

When the proper time comes, the oyster larva will settle down for life by attaching itself to any object which is firm and clean—not slimy, like some sea-weeds. They have been found elsewhere growing in numbers on the soles of old boots, on the stems and bowls of old tobacco-pipes, and on fragments of glass-ware and crockery. In natural oyster-beds on the sea-bottom the young become attached to the shells of the old oysters, to other dead shells, such as those of cockles, and to any stones there may be in the neighbourhood. On many oyster-beds, especially in Holland, great quantities of old shells of oysters and cockles are scattered over the ground as "cultch," for the young "spat" to settle upon. But at Arcachon, and elsewhere in France, special "collectors" are constructed and carefully placed in the best positions at the right time of year. The simplest are merely bundles of twigs, or "fascines," tied together and anchored with stones. The more usual collectors are earthenware tiles, coated with a preparation of lime and sand, so as to be clean and slightly rough, which facilitates the attachment of the larva. Moreover, this layer of whitewash forms a medium which can be cracked off later on, when the young oyster has grown sufficiently to be independent of support, and thus the tiles are left intact, need not be broken up to free the oysters, and so can be used as collectors year after year. The proportions of lime and sand in the whitewash differ on different farms, and so do the methods of arranging the tiles. They may be stacked on the ground in open piles, so that the ebbing tide will run through the openings, or they may be arranged in rough wooden crates, the successive layers of tiles being placed alternately longitudinally and transversely, in order to break up the currents of water, delay its passage, and cause eddies, so as to afford every opportunity for those larvæ that are ready to come in contact with the lime-coated surface and adhere to it. As many as a couple of hundred young oysters may sometimes be found attached to one tile. The success of a "spat-fall" depends largely upon the weather during the critical days, and upon the collecting tiles being placed in position just at the right time—not too early, as then they may become coated with diatoms and other minute organisms, which render the surface slimy, and so prevent the oyster larvæ from adhering.

At Arcachon the young oysters are allowed to remain on the tiles at least till October or early in winter, when they are about the size of the finger-nail, say 1/2 to 3/4 inch in diameter. Then the tiles are collected and taken ashore, and the process of "détroquage," or separating the oysters from the tiles, takes place. This is effected very rapidly by a skilled hand, the little oyster, with the film of lime to which it is attached, being flicked off the tile rapidly by a square-ended knife.

Many of the oysters are sold at this stage to the "éleveurs," who rear and fatten them elsewhere; but many, on the other hand, are kept for another year or two in the parcs at Arcachon. These latter, after removal from the tiles, are placed in flat trays having a floor and a lid of close galvanized wire netting of about 1/2-inch mesh, and these trays are fixed between short posts in the sea on the oyster-parc, so that the tide can run freely through them, supplying the oysters with food and oxygen. Such trays are called "ambulances," or "caisses ostreophiles," and measure about 6 feet by 4 feet, by 6 inches deep. They serve to keep the young oyster during the early period of its life out of the sediment, and they also protect it from

OYSTER-CULTURE AT ARCACHON: TWO VIEWS OF WORK IN AN OYSTER PARC AT LOW TIDE.

its numerous natural enemies, such as the boring sponge *(Cliona),* which ruins the shell; starfishes and crabs, which manage to suck or pick out the soft animal; and whelks *(Purpura* and *Nassa)* and other Gastropods, which can bore a hole through the shell and prey upon the oyster within.

The ambulances are constantly looked after by the oyster-men, and especially women, who come at low tide, when the "caisses" are exposed, open the lid, and pick over the contents, removing any enemies or impurities which may have got in, such as crabs, taking out any dead shells, and rearranging the oysters, if necessary, so that all may have a fair chance of obtaining food and growing normally. The young oysters grow rapidly in the ambulances, and have soon to be thinned out. The larger ones are removed to other "caisses"—or, if large enough, they are thrown into the open enclosures or little fields of the parc. Additional young ones may now be added, or all the space may be required for a time by those left. In this way, by thinning out, rearranging, and adding, relays of young oysters in their first year may occupy the ambulances for eight months, although an individual oyster may only be in for one month or so. Eventually all the oysters not sold to "éleveurs" or exported get transferred from the ambulances to the field-like enclosures of the parc (Pl. XXV).

During the last half-century the number of oyster-parcs at Arcachon has varied from about 3,000 to 6,000. The number of oysters exported in the year has generally varied from about 300 million to 500 million, and the value from about a million francs upwards, according to the current prices for oysters.

The whole of this prosperous industry, both at Arcachon and elsewhere on the coast of France, was started between 1859 and 1865, by a professor of biology, M. P. Coste, who, instigated by the Government, made investigations and experiments, and is said to have imported Scottish oysters from the then flourishing natural beds in the Firth of Forth; and now we buy back from the French ostreoculturists the descendants of our own oysters to replenish our neglected and depleted beds. It is an object-lesson in the value of aquiculture.

The further rearing and preparing for market of the oysters produced at Arcachon takes place farther north, on the west coast of France, in the neighbourhood of La Rochelle, Marennes, and Le Croisic. In these and many other places along that flat coast there are large, shallow ponds, or "claires," into which sea-water is brought by means of canals with sluices, so that the "claires," in some cases several miles inland, may be filled at high spring tides and remain as areas of stagnant sea-water, becoming warmer and denser, and more and more occupied with Diatoms and other vegetation, as the days go on, until the next high tide affords an opportunity of refreshing the water. In this somewhat artificial environment the half-grown oyster from Arcachon is highly nourished, rapidly increases in size, and becomes fat, soft, and luscious. Moreover, in certain "claires" the process known as "greening" takes place. The gills and certain other parts of the oyster acquire a bluish green colour, which is probably due to the pigment in the Diatom *Navicula fusiformis* variety *ostrearia,* which abounds in these "claires" and upon which the oysters feed. Such green oysters ("huîtres vertes de Marennes") are highly esteemed in the Parisian and some other markets.

The final stage in the preparation of the oyster is to cleanse it from impurities, decomposing organic matter, and possibly germs, by placing it for a few days in clean tiled tanks, known as "bassins de dégorgement," in which the pure sea-water is frequently renewed, so as to wash away all deleterious matter.

Oysters, mussels, and other shellfish are, of course, liable, from the nature of their food—microscopic particles carried in from the water or the mud close to land—to become infected with various bacteria, including, it may be, if there is sewage contamination in the neighbourhood, disease germs such as the bacillus of typhoid. Experiments have shown that the common intestinal colon bacillus is of frequent, if not constant, occurrence in the oyster and other shellfish, and that the typhoid bacillus may, though very rarely, be present, and can live for a short time in the mollusc's interior. These disease organisms can, however, be readily washed out by a stream of running water or by placing for some hours in water which is frequently changed. The living shellfish, in fact, tends by its vital processes to clear itself of such matters, and the typhoid bacillus is fortunately a comparatively delicate organism, and cannot live for long in pure sea-water.

Oyster-culture is pursued in Holland on much the same lines as in France, with somewhat less elaboration, and without the differentiation between the collecting and rearing and the later stages of cultivation seen at Arcachon and Marennes. In a Dutch oyster-farm, as at Ierseke or at Bergen-op-zoom, or elsewhere on the Scheldt, we may see spat collection by means of tiles, and also the distribution of cockle-shells to form a "cultch," the rearing of young oysters in ambulances, their further cultivation in the later years of their life in ponds, which can be filled and emptied from canals with sluices; and in some cases young oysters shipped from Arcachon are relaid and fattened in Holland, and even on some parts of the English coast, in place of going to the "claires" of Marennes and Brittany.

Oyster-culture in the Mediterranean, where there is little or no tide, is carried on in the Bay of Spezia and elsewhere by means of poles stuck in the sea-bottom in shallow water connected by a network of coarse twisted ropes, in the interstices of which the oysters are attached so that they hang in great vertical strings in the water. This is merely a device for accumulating as large a number of oysters as possible in a given area of water, and also to render them easily accessible, so that a man going round the poles in a boat can haul up rope after rope and pick off such oysters as he desires for the market. They are said to grow large with extreme rapidity, thus hanging freely in the water. The spat is collected on fascines sunk in deeper water at the mouth of the bay, and transferred, when of sufficient size, to the ropes inshore. There are other similar methods of cultivation at Taranto, Lake Fusaro, and elsewhere in the south of Italy, where this form of aquiculture has been practised continuously since the time of the Roman Empire, when it is said to have been started by Sergius Orata, called by Cicero "Luxuriorum Magister." The methods which Coste introduced to revive the depleted oyster-beds of France in the middle of last century were based upon what he had seen in the south of Italy. Plate XXVI, Fig. 2, illustrates the method of cultivation seen in the Bay of Spezia.

It is unnecessary to give further examples from the south of Europe, but the following shows a different form of aquiculture, in which oceanographic knowledge in regard to temperatures and salinities of the water plays a part.

There are some remarkable salt-water ponds on the west coast of Norway where oysters are grown with great success. Such a pond, for example, is found at Espevig, and the following particulars are taken from the account given by Herman Friele to the International Fishery Congress at Bergen in 1898. This pond is separated from the fjord outside by a low sandy barrier about 5 feet above high-water mark. It is only at a high spring tide or during an inshore gale that the waves pass over this barrier and renew the salt water in the pond. The pond is also supplied with fresh water from a small stream, and normally the surface layer of the water is completely fresh. At a depth of 3 to 5 feet, however, it is as salt as the fjord outside. The temperature of the deeper salter water is very high—about 28°C. (82°F.) —and abundance of organisms, both animals and plants, are found growing on the rocky sides, while the muddy bottom is covered with large clusters of oysters. Professor

[*Photo by* A. SCOTT.

FIG. 1.—Part of a Mussel Skear in Morecambe Bay.

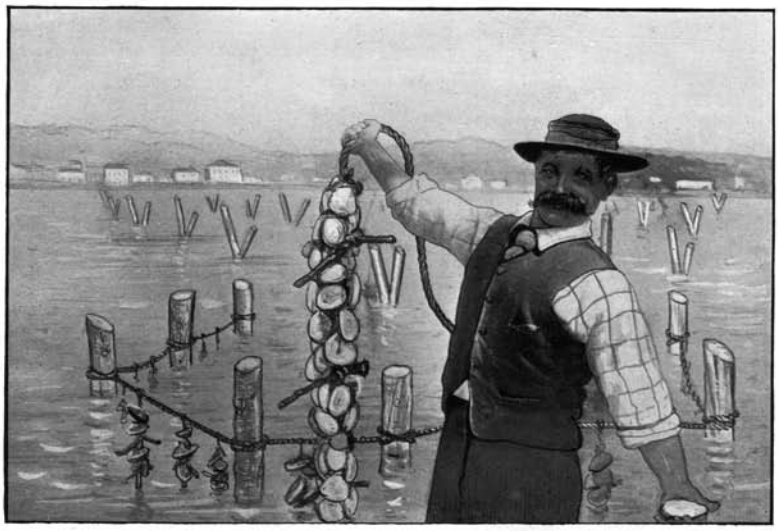


FIG. 2.—Oyster Culture in the Bay of Spezia.
(From sketch by the Author in 1894.)

Helland's explanation of the high temperature of the salter deeper water in the pond is that the layer of fresh water on the surface forms a cover, preventing the deeper water below from coming to the surface and losing its heat. So he considers that the heat of the lower water layers, derived from the sun, constantly accumulates throughout the summer. From his observations he shows that only a few days of sunshine are necessary to make a considerable difference in the temperature; he has observed a rise of two degrees in one day. The ponds may be regarded as hot beds for oyster-growth. The rocky sides are covered with masses of old oysters, which are left undisturbed as a breeding stock, while from wires stretched across the pond and supported at intervals by empty barrels are hung bundles of birch branches or fascines to serve as collectors of the spat. About 3,000 of these collectors are placed in the pond in early summer, and the spat settles upon them between June and September; but the collectors are left in position until the following April, when the young oysters are removed with shears and sent either to another pond, where they are laid out in galvanized wire ambulances, or to the oyster company's grounds on the shore near Stavanger.

An average harvest from the Espevig pond is about one million young oysters, and it is said that in some years the deposit of spat may be so large that one can hardly put a needle's point between the individual young oysters, and the whole of the collector looks as if it had been dipped in mortar. In such a case, however, only a comparatively small number of these young oysters has room to develop; the rest are sacrificed to overcrowding, but this loss might be reduced by some alteration in the collectors. The whole system is suggestive of possibilities in scientific aquiculture far beyond what is at present practised.

The American oyster, which is a separate species *(Ostrea virginiana),* is cultivated or fished at many places on the Atlantic coast from New England down to Carolina, and also on the Pacific at San Francisco and elsewhere. In some of these localities the beds are exposed at low water, and the oysters can be collected by hand. Elsewhere they are always submerged, and the oysters are dredged from the bottom or fished up by means of long double rakes known as tongs. But these methods, which can scarcely be called cultivation, do not differ materially from our own oyster-beds and layings at Whitstable, Colchester, and elsewhere on the English coasts, and do not show the differentiation in method and division of labour which have been successfully evolved by the French ostreoculturists.

Turning now to mussel-culture, this also is seen in its most elaborate form on the west coast of France, where in the great, shallow, muddy bay known as Anse del'Aiguillon, a remarkable system of cultivation on stakes connected by wattling, and known as "bouchots à moules," has been carried on for many centuries. It was established by an Irishman called Walton, who was wrecked there in 1235 from a small vessel containing sheep. He was the only survivor, but managed to save some of the sheep, which are said to be the origin of some highly prized flocks still found in that district. Reduced to great straits to make a living, this man is said to have woven rough nets of grass, which he spread on stakes on the wide expanse of mud exposed in the bay at low tide in order to capture sea-fowl. He noticed that his nets became covered with young mussels, which were thus protected from being buried in the mud, grew rapidly in size, and afforded food to himself and his neighbours. This suggested the planting of stakes interlaced with twigs to afford attachment to the mussels, and so the bouchot system, which now extends for miles, and affords a flourishing industry to various villages, such as Esnandes and Charron, became established. The boucholeurs of the present day still maintain the ancient method of planting their wattled stakes and collecting and transplanting their mussels from place to place at different seasons as seems best for the growth and protection of the shellfish, and of visiting their different kinds of bouchots at low tide in curious little flat-bottomed boats known as "acons," which can be propelled over the soft mud (in which a man would sink) by means of one foot encased in a large sea-boot projecting over the side of the boat. I have myself experienced this curious method of navigation on mud during a visit to the bouchots, and I give here a reproduction of a rough sketch made at the

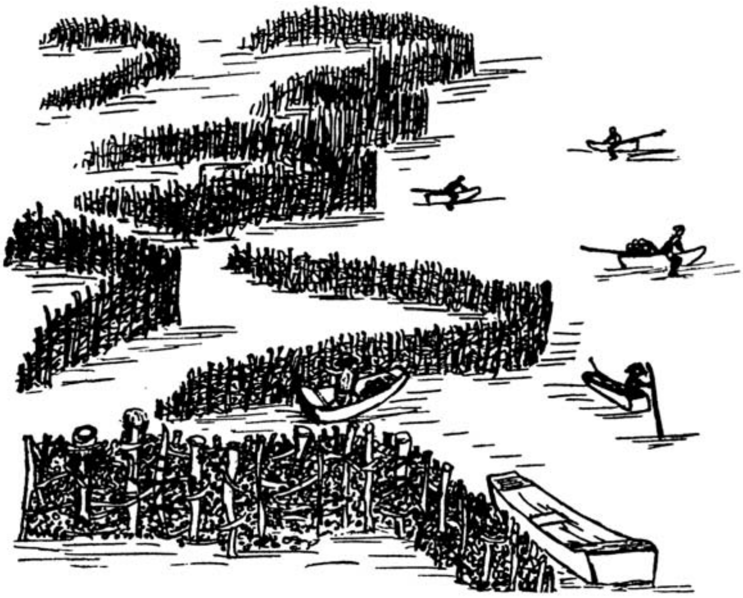


FIG. 19.—BOUCHOT MUSSEL CULTURE ON THE WEST COAST OF FRANCE.

time (Fig. 19).

In other countries where there are no localities suitable for this bouchot system mussels occur in beds, or "scars," which, like the oyster-beds, are in some cases exposed at low tide, while in others they are wholly submerged, and the mussels have to be obtained by dredges or other implements from a boat. Such beds, under some circumstances, are liable to become overcrowded to such an extent that the individual mussels have not room to grow to their full size, and so become stunted or misshapen. In these cases great benefit to the fishery results from thinning out and transplanting to other suitable but less densely populated localities. Plate XXVI, Fig. 1, shows an overcrowded mussel-bed.

The shellfish industries of the west coast of England are of considerable importance, both as food and bait. In recent years the returns in the Lancashire and Western Sea-Fisheries District alone amounted to about two-fifths of the total for England and Wales, and the value to the fishermen was about £40,000. There is probably no area of land or water in our country that gives such a high return in weight of food per acre as a mussel-bed, and the shellfish are eminently responsive to cultivation and susceptible of improvement. Here, at least, if not yet in the open sea, we may have an aquiculture comparable to agriculture on land.

In Morecambe Bay, some years ago, the local sea-fisheries committee made a notable experiment[1] in order to show the fishermen what could be done in this direction, by judicious transplanting, at small cost. The work was carried out on the mussel-beds at Heysham, in Morecambe Bay, probably the most extensive mussel-producing grounds on the west coast of England (see Plate XXVI, Fig. 1).

In 1903 the committee gave a grant of £50 to be expended on labour in transplanting overcrowded and stunted mussels, which had ceased to grow, to neighbouring areas not so thickly populated. The result was most striking. At the end of a few months the old starved, undersized mussels— "blue-nebs," as the fishermen called them—had grown 3/8 inch or more, and had reached the legal selling size. The animals inside the shell were in fine condition, and these

[1] For the full details, see the article by Scott and Baxter in the *Lancashire Sea-Fisheries Laboratory Report* for 1905.

[*Photo by* A. Scott.

Transplanted Mussels in Morecambe Bay,

showing the original size of the "blue neb" and the large expanse of smooth black new growth; natural size.

mussels found a ready market at a good price. Shellfish which in their original condition could never have been of any use as food, had been turned into a valuable commodity at comparatively little labour and expense. The money value to the fishermen of these mussels that had been transplanted for £50 was estimated to have been at least £500. In 1904, again, a grant of £50 resulted in the transplanting of some boat-loads of undersized mussels, which were sold later on at a profit of over £500.

In the following year (1905) a grant of £75 resulted in the sale of the transplanted mussels some months later for £579. On that occasion over 240 tons of the undersized mussels had been transplanted in six days' work. It was found that on the average the transplanting increased the bulk of the mussels about 2 1/2 times, and the increase in length to the original shell was in some cases well over an inch (see Plate XXVII).

These experiments, on the industrial scale, were not carried further. The Lancashire committee only desired to show what could be done and how to do it, and had no intention of running a commercial concern; but the results are very suggestive and encouraging as to what might be done in the further cultivation of our barren shores.

An interesting application of scientific methods to the improvement of a shellfish industry has been in practice for some years at Conway, in North Wales. The extensive mussel-beds in the estuary are badly polluted by sewage, and have been under investigation by the scientific staff of the Lancashire and Western Sea-Fisheries Committee since 1904. Dr. James Johnstone showed, as the result of many experiments, that the polluted mussels, when relaid in clean sea-water, were able to purify themselves by eliminating from 90 to 95 per cent. of the sewage bacteria in two to three days. He also found that the mussels can live in water containing up to five parts per million of chlorine, while the sewage bacteria are sterilized by one part of chlorine per million, and this obvious method of treating polluted shellfish was suggested to the authorities.

The regulation of the beds, however, eventually passed into the hands of the Conway Corporation, and they, under the supervision of the Board of Agriculture and Fisheries, erected special purification tanks and water-circulating apparatus, and introduced the method of treating the mussels by sea-water containing a trace of chlorine. Thus successive consignments of polluted mussels brought by the fishermen are passed through the chlorinated sea-water before being sent to market. In a country such as ours, where the estuaries and the more densely populated shores, where shellfish are grown and eaten, are liable to become increasingly infected with sewage organisms, it is obviously most important that scientific methods of both cultivation and purification of all kinds of edible shellfish should be adopted without delay.

CHAPTER XVI
THE SEA-FISHERIES

Our food from the sea is in the main obtained from the great commercial sea-fisheries, the discussion of which in their scientific aspects is a very large subject, obviously only to be outlined, with a few examples of different methods of investigation, within the limits of a single chapter. It is scarcely necessary to emphasize the vital importance of the sea-fisheries which supply our markets. The harvest from the sea was never of more importance to the nation than it is now, and it probably will become of still greater importance in future years. The sooner all classes of the population learn to appreciate the value of fish as a highly nutritious food, the better it will be for the welfare of the community, and the greater will be the encouragement to those concerned in the industry to use their best endeavours both to increase the supply and to make the best possible use of it by preserving the produce, so that nothing caught be allowed to go to waste. There is still much to be done in the two directions (1) of exploiting local and periodic coastal fisheries and discovering the best methods of making available for future use what cannot be consumed at the moment; and (2) of educating the public to overcome prejudice and make a fuller and more systematic use of unaccustomed but excellent fish food—such as, for example, the summer-caught rich-in-fat herring cured in brine as a winter food.

Most people have very little idea of the magnitude of our British fisheries, now the greatest in the world, of the rate at which they were increasing of recent years—before the war—or of the predominating position to which our fishing-fleets had attained. In 1914, our fisheries made up nearly one-half of the total for all countries of North-West Europe, and nearly 70 per cent. of the North Sea fisheries alone. The total produce of our sea-fisheries had more than doubled in the previous quarter of a century, and the average of the last few years before the war amounted to over a million tons (about 23,500,000 cwts.), bringing in about £15,000,000 when landed, and to be valued at probably three times as much, say nearly fifty millions sterling, by the time it reached the consumers. In 1922, the value of the total fish as landed was about £18,000,000.

This great increase, previous to 1914, in the amount of fish brought to the markets, had been due to improvements in the boats and in the methods of fishing, and to an enormous extension of the fishing-grounds. The picturesque old sailing trawler of Brixham, working in local waters with a small beam-trawl, had developed into the large but ugly and highly efficient modern steam-trawlers equipped with huge otter-trawls, and making lengthy voyages to Iceland and the White Sea in the North, or the Canaries and the coast of Morocco to the south—conducting their operations, in fact, over an area of the continental shelf occupying more than a million square miles and down to depths of over 200 fathoms.

All this applies to the time before the war. As a natural result of war conditions, and the economic disturbances that followed, the produce of the sea-fisheries dropped to less than a third of what it had been—the total catch during war-time averaged about 7,000,000 cwts. per annum. Very many millions of fish were therefore left uncaught in the sea to grow and propagate, and it has been an interesting speculation and investigation ever since whether or not this unforeseen and undesired experiment in restriction of fishing, on an enormous scale, has resulted in the restocking of depopulated grounds, such as parts of the North Sea. That has probably happened to some extent. Some post-war statistics show an increased stock on the ground; but there is also some evidence of natural fluctuations in the fish population which may give rise to conflicting evidence, and so obscure the results of protection. The matter cannot yet be regarded as settled.

The true fishes (Pisces) that are caught by the fishermen and sold for food in our markets belong to two main divisions—(1) the Elasmobranchs, such as skates, rays, and dogfish, with a cartilaginous skeleton; and (2) the Teleosts, including all the ordinary bony fishes. For practical purposes, the bony fishes may be divided into the "round" and the "flat" fish. Round fish are those—such as cod, herring, and salmon—where the body is more or less circular in cross-section, while flat fish include the equally familiar soles and plaice, with flattened upper and lower surfaces. Amongst round fishes there are two groups of primary importance, those related to the cod (Gadidæ) and those of the herring tribe (Clupeidæ). The former include:—

Hake—a southern fish, forming the greater part of the catch off the south of Ireland, in the Bay of Biscay, and southwards to Morocco.

Haddock—a northern fish, forming nearly half the total catch from the North Sea.

Cod—a northern fish, very abundant north of the British area, around the Faroes, Iceland, Norway, etc.

Whiting—abundant in the North Sea, and generally around our coast.

Ling—a northern fish, abundant on the west of Ireland, Scotland, and farther north.

The cod is probably the most useful of fishes to man. All parts of its body are of value. In addition to its prime importance as a food, both fresh and salted, oil is extracted from the liver, the head, tongue, and sounds also form a good article of food, the offal and bones are ground up into manure said to be equal to guano, the roe is used as bait in the sardine fisheries of France, and from the swim-bladder isinglass is made.

The herring family (Clupeidæ) includes the sprat, the pilchard (the young of which is so familiar in the preserved form of "sardines"), the anchovy, and, most important of all, the true herring—that wonderful fish which, as the mainstay in the fourteenth century of that powerful trading and political organization the Hanseatic League, and after that of the Dutch commercial and naval supremacy, may be said to have played its part in determining the history of nations and the fate of empires. All these Clupeoid fishes are noteworthy for the relatively large amount of fat they contain in the form of minute globules of oil disseminated through their flesh, while the cod and its allies are almost destitute of fat. The herring, however, has a very different amount of fat in its composition in different states and at different times. For example, the winter herring, in poor condition, may have only 4 or 5 per cent. of fat, while the spawning summer herring may have from 30 to 40 per cent. The average of three series of Manx herrings caught in the summer of 1917 and cured in brine gave the following analysis,[1] and may be contrasted with the composition of the cod:—

	Herring.	Cod.
Fat	22	0·3
Proteid	21	16·7
Ash (+ salt)	9	1·3
Water (+ traces) . . .	48	81·7

Other Manx herrings, however, caught in September, 1917, cured in brine and analysed in winter, gave as much as 32·72 per cent. of oil (fat).

It is this relatively large amount of easily digestible fat

[1] By Professor James Johnstone of the University of Liverpool (see, for further details, *Lancashire Sea-Fisheries Laboratory Report* for 1917).

in the flesh of the herring that gives this fish its special value as a winter food, and no effort should be spared to increase the home consumption of herrings. They are probably the cheapest form of animal food, and have a very high nutritional value. Many people will be surprised to learn that out of 12,000,000 cwts. of herring landed, nearly 10,000,000 cwts. were exported annually (90 per cent. in 1913) before the war. The total catch is far from being too much for the needs of our own country. Taking three herrings to the pound, the total catch in the United Kingdom before the war would only allow two herrings a week to each adult individual of the population.

The flat-fish of our markets (with the exception of skates and rays, which are a totally different kind of fish, and are nearly related to dogfishes and sharks) belong to the family Pleuronectidæ, the members of which undergo a remarkable transformation in their early life-history, whereby the bi-laterally symmetrical larva, with the right and left sides of the body similar, and an eye on each, undergoes in its growth a torsion of the head and some other parts, a flattening of the body from side to side, and a great extension dorso-ventrally so as to be converted into the familiar "fluke" form, with the upper (usually the *right*) side of the flat body pigmented and bearing both eyes, and the lower blind and more or less non-pigmented or white. Our best-known marketable Pleuronectids are:—

Halibut—a northern fish, of large size.

Sole—commoner in the south down to Morocco; a shallow-water fish common in the Irish Sea.

Turbot—in deeper water; a North Sea fish, but not very abundant.

Brill—more abundant than the turbot, especially in the south.

Plaice—a northern form, very abundant on the coasts of Iceland and farther north; distributed all around our coast, and important as a food of the people.

Flounder—of less importance; especially abundant in estuaries.

It is in connection with some of these more sedentary flat-fish that depletion of certain fisheries has been most clearly established, or, to put it more cautiously, that it is felt that there may be risk of the fishery being depleted on certain grounds. The more widely roaming herring, mackerel, cod, and haddock are probably safe from man's ravages; but the more local, bottom-haunting sole and plaice are less independent and more at the mercy of their immediate environment, including the fishing-fleet. It is therefore in connection mainly with such fish that attempts have been made in the United States and several European countries to compensate for the ravages of the fisherman by artificially hatching and rearing young flat-fish to add to the stock in the sea.

One of the most important and practical questions in the whole range of marine zoological investigation is—Can we increase the yield of our fisheries by cultivation ? We can cultivate shellfish, such as oysters, mussels, and cockles, on the seashore with much profit. Can we do anything towards farming our inshore or offshore fishing grounds ? The fisherman at present is a hunter of the fish. Can we reasonably hope to make him in time a farmer, reaping a harvest that, in part at least, he has sown ? These are the ideas that have led to the hatching, rearing, and transplanting operations which are carried on with more or less energy in various parts of the world.

It is by no means easy to determine whether the artificial hatching of sea-fish has as yet had any effect upon any local fishery. It is not possible to mark or brand your larval fish from the hatchery, so as to recognize them when caught as adults; nor is it practicable to devise the control experiment of both adding to and not adding to the same fishery, or two exactly similar fisheries, simultaneously, so as to secure comparable results. But it may be pointed out that much help may have been given to a depleted fishery, although no effect is noticeable. The condition of the fishery might have been far worse had no artificial help been given.

When one thinks of the enormous numbers of eggs produced naturally, in a season, by most of our common fish, as shown in the following list, one is inclined to fear that the comparatively small number of millions, or even of hundreds and thousands of millions, of young fish turned out from hatcheries, will be of little avail, and may amount to nothing more than the proverbial "drop in the bucket."

The average number of eggs spawned by a single female fish in the course of one season is:— But probably

Ling	20,000,000 to 30,000,000
Turbot	8,000,000 to 9,000,000
Cod	4,000,000 to 6,000,000
Flounder	1,000,000
Sole	600,000 to 700,000
Mackerel	600,000
Haddock	450,000
Plaice	300,000
Herring	32,000

a truer conception of the state of affairs is obtained by reflecting that, while countless millions are produced, countless millions also perish each season from natural causes (as opposed to man's operations)—that is, from their natural enemies and other adverse influences in the environment. As eggs, as embryos, as larvæ, and as post-larval young fishes, they are the food of most of the larger animals around them in the sea. Probably only a very few out of each million reach maturity, and it is out of that scanty remnant that the fisherman takes his toll, and so may in some cases "overfish" a limited area so as to reduce the population below its power of recovery. The enormous numbers produced do not, then, necessarily mean an enormous rate of increase, but they may afford man his opportunity to step in and, by adding some millions from his hatchery, do something to repair the damage and avert or delay the destruction of a local fishery.

It may be pointed out further that, even though the young fish, such as plaice, are turned out to sea soon after being hatched, say about the time of the absorption of the food-yolk, they have been protected from their natural enemies during some three or four weeks at least—about half the time from the egg to the metamorphosis—and that, moreover, is the period when, as eggs, embryos, and young larvæ, they are most feeble and defenceless and most in need of artificial protection (see Plate XXVIII).

We find at the Port Erin hatchery that, although the periods of embryonic and larval life vary to some extent—probably with the temperature of the sea-water—the average times are as follows, in the case of the plaice:—

Embryo, from fertilization of egg to hatching, in February, 24 days.
,, ,, ,, ,, ,, in March, 22 days.
,, ,, ,, ,, ,, in April, 20 days.
Larva, from hatching to absorption of yolk, about 7 or 8 days.
Post-larval, absorption of yolk to metamorphosis, 28 to 40, say 34 days.

The most significant work, and interesting experiments in connection with artificial operations, have been carried out by the United States Bureau of Fisheries and by the Fishery Board for Scotland. One example may be given from the work of each of these organizations. It has been long recognized that if a species of fish could be introduced into an area where it was previously unknown, that would be satisfactory evidence of the success of artificial operations, and the United States Bureau has shown in its successive Annual Reports of the Commissioner of Fisheries that by collecting and hatching the eggs of the shad (*Clupea sapidissima*) on the Atlantic coast and setting the larvæ free in the Pacific in the neighbourhood of the Sacramento river, a profitable shad-fishery has been established on the Californian coast. The last report published shows that

FIGS. 1 TO 3.—Three successive stages in development of Plaice larvae in the egg, magnified.

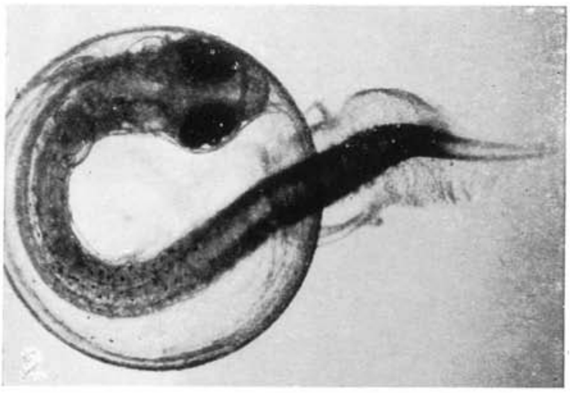


FIG. 4.—Plaice larva hatching from egg, tail first.

[*Photo by* DR. F. WARD.

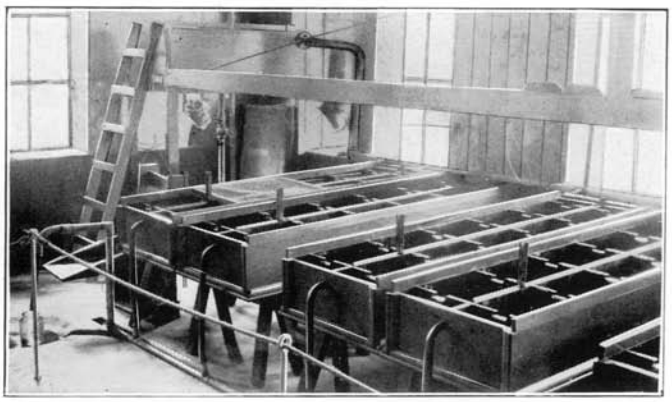


FIG. 5.—Plaice Hatching-boxes at the Port Erin Biological Station.

in 1915, the latest year for which statistics are completed, the Pacific shad-fishery yielded over 7½ millions of pounds, valued at over 75,000 dollars.

In addition, extensive operations in the hatching and setting free of fry are conducted on the Atlantic coast. Over 52½ millions of shad-fry from the hatcheries were distributed in 1918 in the Eastern States. In the Commissioner's report for 1921 (published in 1922) it is stated that the two hatcheries then working were distributing all their fry locally in Maryland and North Carolina, and the report adds: "In view of the conditions that exist in other shad-streams where artificial propagation is not conducted, it seems but just to assume that the hatcheries have been a factor in maintaining the shad-fisheries in their vicinity."

The Fishery Board for Scotland carried on for some years an interesting experiment in adding artificially hatched plaice larvæ to a circumscribed sea-area (Upper Loch Fyne) with the view of determining whether an increase was noticeable in the number of young fish present. Positive results seem to have been obtained. During a period of six years, millions of larvæ were hatched at Aberdeen and deposited in Loch Fyne, and during the next six years none were added; while during the whole period of twelve years experimental hauls of the net were made on certain selected beaches where the young metamorphosed plaice congregate. The statistical results apparently indicate that during the years when larvæ were added the number of young fish caught, per hour of fishing, was more than double the number caught in the succeeding period of six years. Or, to put it another way, the figures given in the report show that the addition of about 20 millions of plaice larvæ a year doubled the number of young metamorphosed fish on the shallow beaches of Loch Fyne.

It has sometimes been said that the young fish turned out from hatcheries may possibly be weaklings, which, on account of having been reared under artificial conditions, may die in their early youth, perhaps even before undergoing metamorphosis. Experience shows that all such fears are groundless. In the hatchery at the Port Erin Biological Station young plaice have been reared up to their fourth year, when they had become sexually mature, and had, a year before, in their turn produced spawn for the hatchery. In 1917 there were three generations of plaice living together in the institution—the grandparent spawners, which had been originally wild fish; the parents, which were hatched in the spring of 1914 and were then spawning (in March, 1917); and the young of the third generation, which were developing as normal larvæ. The following year (March, 1918) some of the fish hatched in 1914 had again produced fertile spawn—there can be no doubt that they were perfectly normal healthy fish.

In addition to such operations in hatching and rearing, a further experiment that has been tried with the object of restocking depleted fisheries is the transplanting of young fish from shallow waters where they are present in great quantities ("nurseries"), and perhaps overcrowded, to other deeper fishing-grounds where there is abundance of food and where growth will probably be more rapid. Professor Walter Garstang first showed, some years ago, that small plaice caught in spring on the Dutch inshore grounds and transferred to the richer feeding-ground of the Dogger Bank, in the centre of the North Sea, grew very much more quickly than those left inshore. The following statement as to the result of this experiment is quoted from a recent article by Dr. E. J. Allen:—

"Plaice 7¾ inches long, when captured in April on the inshore grounds, were on the average 13 3/8 inches long by the following November when transplanted to the Dogger Bank, whereas those that remained on the inshore grounds were only 9 1/8 inches long at the same date. Expressed as weights, the differences are still more striking. Fish of 2½ ounces increased in seven months to 15 ounces on the Dogger Bank, but only to 4½ ounces on the inshore grounds.

"The cost of catching the small plaice and transporting them to the feeding-grounds is not excessive if large numbers are dealt with, and an experiment on a commercial scale would, in the opinion of most fishery naturalists, be now fully justified. It must be remembered, however, that for all projects which aim at increasing the supply of marketable fishes in the high seas international co-operation is almost essential, as the grounds are open to all nations and all would benefit by any improvement effected."

Apart from these and many other experiments in practical fisheries exploitation and cultivation—in which the United States of America certainly led the way—modern fisheries research is directed towards finding out the conditions under which the food-fishes live, feed, migrate, and reproduce their kind, so as to determine the possibilities and methods of preserving them from destruction, increasing their numbers, and even eventually of predicting when and where profitable fisheries may take place.

And, in regard to all these characteristics—feeding, spawning, etc.—a special study has to be made of each kind of fish. Many of them differ very notably. To take an example of this from the spawning habits and the early stages of life, the eggs of the herring are laid upon stones and sea-weeds on the bottom of the sea in shallow water, and there they remain undergoing their embryonic development until the young herrings are hatched out; but this is quite exceptional amongst common edible fish. Most of the others, such as the cod, the plaice, and all their relations, produce eggs that float and remain near the surface of the sea throughout their further development, as was discovered in 1864 by Professor G. O. Sars in the case of the cod.

The various kinds of edible fish are caught, some by hooks on long lines (such as the cod), some by trains or long lengths of nets (the herring), and some by beam- or otter-trawls dragged along the sea-bottom (the flat-fish). The methods of fishing vary from place to place and from time to time throughout the year.

Many sea-fisheries are local and seasonal. This is due to the movements or periodic migrations of the fish, and one of the most important practical applications of oceanography is to determine what causes these migrations in each particular case—why it is that one kind of fish is more abundant in one locality than in another, why the fish is present at one season and absent at others, or is more plentiful one year so as to give rise to a good fishery. We are beginning to understand some of the causes of these movements of fish and the variations in their abundance, but much has still to be learned in regard to all.

The movements may be classified into:—

1. Those caused by physical characters of the water (temperature, salinity, currents, etc.).
2. Those due to feeding needs.
3. Those explained by breeding or spawning habits.

As examples of the influence of the environment, we may take the case of the cod, which is a northern or cold water fish, so in Norway it constitutes 80 per cent. of the total fish-catch, and in our seas it is a winter fishery; while its relation, the hake, is a southern fish, frequenting warmer water and making up 65 per cent. of the catch in the Bay of Biscay. The case of the haddock, which is 50 per cent. of the total catch in the North Sea and only 3 per cent. in Norwegian seas, has been explained as due to the absence of large areas of soft bottom at a suitable depth for that fish on the coast of Norway.

Nearly fifty years ago, Moebius and Heincke first showed, from their investigations of 1877 and subsequent years, that in the case of the Baltic and Kattegat there were annual immigrations of northern fishes in spring and of southern fishes in autumn; and in their expedition of 1890, Otto Pettersson and Ekman proved that these seasonal movements of fish from outside were caused by an inflow of Atlantic (Gulf Stream) water in autumn, and of more northerly waters in spring. Since then it has been established by the work of many investigators that these inflows of outside water into the North Sea are only part of a wider annual periodicity in the system of currents of the North Atlantic. In summer there is a great increase in the amount of Gulf Stream water flowing over the Wyville Thomson ridge towards the Shetlands and the North Sea. Below this warmer and more saline water lies the cold Arctic water of the Norwegian Sea, and it is about the line of junction of these two bodies of water, at about 100 fathoms or more, that we have what Sir John Murray called the "mud-line," where detritus accumulates and where fishes and crustacea (such as *Calanus*) are present in quantity. This region is the feeding-ground of the cod and other fishes, and the site of important spring and summer fisheries. In addition to this annual periodicity, which floods the Norwegian Channel and North Sea with Gulf Stream water, Otto Pettersson has shown that there is also a secular periodicity, which after an interval of years results in a diminution of the pulse of the Gulf Stream, so that for some months the inflow of Atlantic water becomes much less, and as a result there is an increased flow in the autumn of northern water into the Norwegian Channel, etc., causing changes in the spawning of the herring and in the consequent fisheries. This was notably the case, for example, in November 1893 (see Otto Pettersson, *Ur Svenska,* vii, 1922).

Again, take the case of an interesting oceanographic observation which, if established, may be found to explain the variations in time and amount of important fisheries. Otto Pettersson in 1910 discovered by his observations in the Gullmar Fjord the presence of periodic submarine waves of deeper salter water in the Kattegat and the fjords of the west coast of Sweden, which draw in with them from the Jutland banks vast shoals of the herrings which congregate there in autumn. The deeper layer consists of "bank-water" of salinity 32 to 34 per thousand, and as this rolls in along the bottom as a series of huge undulations it forces out the overlying fresher water, and so the herrings living in the bankwater outside are sucked into the Kattegat and neighbouring fjords and give rise to important local fisheries. Pettersson connects the crests of the submarine waves with the phases of the moon. Two great waves of salter water which reached up to the surface took place in November, 1910, one near the time of full moon and the other about new moon, and the latter was at the time when the shoals of herring appeared inshore and provided a profitable fishery. The coincidence of the oceanic phenomena with the lunar phases is not, however, very exact, and doubts have been expressed as to the connection; but if established, and even if found to be due not to the moon but to prevalent winds or the influence of ocean currents, this would be a case of the migration of fishes depending upon mechanical causes.

A correlation seems to be established between the Cornish pilchard fisheries and periodic variations in the physical characters (probably the salinity) of the water in the English Channel, and between Dutch anchovies and the temperature the previous year; also between the prevalence of coastal water and the Norwegian fisheries. The summer catches of mackerel on the south coast have been shown to vary with the amount of sunshine earlier in the year—the connecting link being probably the large Copepod *Calanus,* upon which we know the mackerel feeds. The herring, again, in our summer fisheries is apparently affected in its movements by the temperature of the water, the catches being heavier in seasons when the water is colder, up to a limit, for the shoals break up and the fishery comes to an end when the temperature falls below 54·5° F.

The characteristics of the environment affect not merely the movements, but also the nourishment and growth of the fish. In an assemblage of fish caught together in the trawl, we generally find fish of several different ages, and are able from the sizes to separate them into age-groups. It is believed that we can also determine exactly the age of many of the bony fish by examining the otoliths, or the scales, where the successive annual rings of growth show more rapid increase in summer and much less in winter; and even the growth in different summers is found to vary according to the temperature. It is curious to think we may be able to pronounce upon the climate of past years by examining with a microscope the scales of a fish caught to-day.

Amongst examples of movements due to spawning needs, an extraordinary case is that of the common eels, which live in fresh-water streams and lakes and other shallow fresh waters for years without breeding, and then towards the end of their lives change their appearance (acquiring a silvery sheen and large eyes), and, giving up all their previous habits, migrate to the deep sea and spawn in mid-Atlantic, west of the Azores, beyond the 2,000-fathom line. From there the leptocephalus-larvæ are carried by the Gulf Stream drift to the coasts of North-West Europe, taking three years to the journey, and as elvers they migrate up the rivers to people the inland waters, where no sexually mature individuals, no eggs, and no larvæ have ever been found. The herring furnishes another good example of spawning migrations, and comes into shallow water at various points on our coast and in the Baltic, etc., to deposit its eggs on suitable ground.

Feeding migrations or movements may be local and small in amount and more or less irregular, as when a shoal of plaice invade a bed of young mussels and move off again when they have exhausted the food; or may be greater in amount, and periodic, as in the case of the mackerel and the herring following their planktonic food.

Scientific investigations bearing on sea-fisheries questions have hitherto dealt with the fish as they live in the sea—their structure and habits, their reproduction and life-history, their food and general relations to their environment—with the object of discovering the best means of conserving the fisheries or even of increasing the supply of fish. But it is now coming to be recognized that there is need also of biologico-chemical investigations on the fish after they are caught, on the post-mortem changes that they undergo in different circumstances, and on how best to preserve them with their nutrient and other desirable qualities unimpaired until they are put on the market and used as food.

Such investigations will teach us how best to deal with the occasional, unexpected, superabundant catches which glut the markets, and may even result in much good food being wasted as field-manure. But they will also lead to a more equitable distribution and a more profitable use of the periodic profusion of such local fisheries as those of herrings, mackerel and sprats. The best use, economically, that can be made, for example, of the summer herring fishery in the Irish Sea, or in the Hebrides, is to cure in various ways (kippering, salting, etc.) the great bulk of the catch. Distribution can thus be controlled, consumption can be spread over a longer period, the product may be improved as a food and local industries are established. As Dr. James Johnstone has pointed out, "A clamant need of the present time, and indeed of normal times, is the curing of summer-caught herrings for consumption in winter, when fat-rich foods are more useful than in the warmer months."[1]

A minor, but still quite typical, example of such occasional or even periodic glut of fishes, difficult to deal with and leading to waste of good food, is the winter sprat fishery in Morecambe Bay. During the height of a recent fishery fully seventy tons of fish were landed each day, and the value to the fishermen of such a catch was over £300. A ton of sprats contains, on the average, 130,000 fish. In a

[1] *Lancashire Sea-Fisheries Laboratory Report* for 1916, p. 23.

day's fishing, therefore, nine millions of sprats may be captured, and this goes on day after day without making any appreciable difference to the abundance of the fish. The question has naturally occurred in connection with this and other similar fisheries elsewhere, whether it would not be desirable, with a view to a more perfect distribution and more economic utilization of this food product, to establish curing or canning industries for the purpose of converting the temporary superabundance of the fresh perishable fish into a more permanent and highly nutritious article of diet. It is satisfactory to know that the matter is now being investigated from both the scientific and the commercial points of view and that experiments are being made which it is hoped will lead to such preservation industries being established.

The United States Bureau of Fisheries with its very extensive organization and ample resources sets an example to the civilized world in the promotion and utilization of their important fisheries—both marine and fresh-water. Their experts seem to be equally successful in devising new methods and in conducting an active propaganda. The establishment of a new fishery, the provision of the necessary markets and the all-important demand on the part of the public are promoted simultaneously. The method seems to be to boom one fish at a time: in 1916 it was the tile-fish, and in 1917 the dog-fish under a new name. Our European food-fishes have been known to the public for centuries, and their names, such as herring, cod and plaice, are very old; but the "tile-fish" is new to the markets and the name is a recent invention. When, as the result of scientific exploration, the fish was found in quantity and introduced to the fishermen and the public, and it became necessary to find a name shorter than the zoological designation *Lopholatilus chamoeleonticeps,* the terminal part ("tile") [1]

[1] And possibly also because of the tile-like markings on the head.

of the generic title was taken and is now firmly established in common use. When the fishery had been in existence for twelve months (1916) the known catch amounted to upwards of 10,250,000 pounds, valued at more than $400,000. During the fiscal year 1917 the tile-fish landed reached 11,641,500 pounds, and the receipts of the fishermen exceeded $477,730.

Having established this fishery, the Bureau then entered on a campaign to convert one of the most destructive and neglected fishes of the Atlantic coast, the spiny dog-fish, into a valuable asset; and the first step taken was to suggest a change in the name of the fish for trade purposes. We are told that people in all parts of the country will eat "cat-fish," but are prejudiced against "dog-fish," so the Bureau altered the name of the latter to "gray-fish," which "is descriptive, not pre-occupied, and altogether unobjectionable." (Commissioner's Report for 1917.)

There was apparently at first much prejudice and opposition to be overcome, but the Commissioner tells us that "an early feature of the campaign was the complete change in the fishermen's attitude after they had become fully informed as to the Bureau's plans; and the autumn of 1916 witnessed the extraordinary sight of New England fishermen going out specially for gray-fish and selling their catch at remunerative prices for food." It soon became evident that the demand far surpassed the supply. The canned fish met with a ready sale, and were soon all disposed of as "the goods proved to be not only one of the best canned products on the market, but also one of the most economical to the consumer, who could buy at retail for 10 cents a can containing 14 ounces net weight of fish." Again— "Although the canned product had been known to the trade and public only since October, in April, 1917, it was known to be handled by dealers in 128 cities and towns in New York and Pennsylvania alone, and by May the fish was on sale by retailers in 30 states and the District of Columbia."

Many other instances of the energetic and successful exploitation of American fisheries—in the interests both of the fishermen and the public—might be given, but these two examples, both bearing newly-coined names which have rapidly become familiar to the public, must suffice.

Thus we have seen that sea-fisheries investigation and promotion may be approached from many points of view, and with the great advances that have been made of recent years, the aspects and prospects of successful sea-fisheries research have undergone changes which encourage the hope that a combination of the work now carried on by hydrographers and biologists in most civilized countries on fundamental problems of the ocean may result in a more rational exploitation and administration of the fishing industries.

Edward Forbes long ago (1847) denounced Government apathy and strongly urged that such scientific fisheries work should be undertaken "for the good of the country and for the better proving that the true interests of Government are those linked with and inseparable from Science." All will most cordially approve of these last words, while recognizing that our Government Department of Fisheries is now being organized on better lines, is itself carrying on scientific work of national importance, and is, I am happy to think, in complete sympathy with the work of independent scientific investigators of the sea and desirous of closer co-operation with university laboratories and biological stations.

CHAPTER XVII
FOOD-MATTERS IN THE SEA

We arrive finally at these very fundamental questions: What is the manner of nutrition of all living organisms of the oceans? and What are the ultimate food-matters in the water ?

It will be agreed that the food of the economic animals in the sea, such as fishes, shell-fish and crustaceans, must always be of interest and importance to man, and it is commonly supposed that the larger marine animals feed upon the smaller and simpler until organisms of microscopic size are reached, which in their turn are nourished upon inorganic substances dissolved in the sea-water. It has frequently been pointed out that, in addition to the great feeding-grounds on the sea-bottom where molluscs and worms and zoophytes abound, the plankton (small floating organisms of many kinds, both plants and animals) which is abundant in most seas at nearly all times must be a valuable constituent of the food both of young fishes of various kinds and also of adult pelagic or migratory fishes such as the herring and the mackerel. Of the innumerable organisms in the plankton, two groups are of primary importance in this connection: viz. (1) the Copepod Crustacea, small animals on the average perhaps a tenth of an inch in length, forming an excellent food like lobsters or shrimps, and sometimes present in summer in great abundance locally so as to constitute shoals upon which mackerel, herring and other fishes are known to feed; and

(2) the Diatoms,[1] minute unicellular plants with siliceous coverings, much smaller than the Copepoda and of a totally different nature, and probably not so suitable for food in the case of a higher animal such as a fish, but available as good vegetable food for many lower invertebrate animals.

The Copepoda (being animals) feed upon the Diatoms and other allied minute organisms. The Diatoms, being plants, are, however, able to nourish themselves and build up their bodies from the carbon-dioxide and the soluble salts and other substances dissolved in sea-water. Diatoms are therefore one of the *producing* groups in the sea, being able to produce or build organic matters such as starch and protoplasm from inorganic materials; while Copepoda are *consumers,* as they require and use up already formed organic matter (such as the Diatoms) for their nutriment. Bacteria (plants without chlorophyll) in the sea are intermediate in this respect. They no doubt require organic food, but probably obtain it from dissolved organic matter derived from sewage and the washings of the land, and from any decomposing animal or vegetable matters in the sea, and other products of the metabolism of higher organisms. Such dissolved organic matter must vary in amount very greatly in different places and in different circumstances, and although constantly renewed it is also constantly being used up or broken down by bacterial action into inorganic matters. It is quite reasonable to suppose that many minute and simple organisms in the sea which have no mouth or other mechanism for taking in solid food, may be able to obtain nutriment from the dissolved organic matter in the water. It may therefore be said that the sea is to some slight extent a nutritive medium, as was pointed out long ago by Dr. W. B. Carpenter; but very different views have been expressed of late years as to the amount of such possible source of nutriment in the form of dissolved organic

[1] There are other still smaller organisms in sea-water, but the Diatoms may be taken as a type of all the micro-phyto-plankton.

carbon that may be present, and estimates have varied from less than one to over ninety milligrammes per litre of sea-water.

The general result of the work initiated by Hensen and carried out by the Kiel school of investigators has certainly been to emphasize the importance of the plankton as supplying the nutriment that is necessary for the existence of other marine animals. The extreme view put forward by some was that we could actually estimate from a few small samples the total amount of food available in wide oceanic areas, and therefore the number of fishes or other animals that could be supported.

Possibly as a reaction against the views of the Hensen school, the physiologist Professor August Pütter of Bonn, in a series of remarkable papers from 1907 to 1912, attempted to prove that the plankton in the sea is utterly insufficient to nourish the animals which are supposed to feed upon it, and that not only simple and minute organisms but also large highly organized animals with a well-developed alimentary canal, such as Crustacea, Mollusca and even true fishes, could and do obtain most of their nutriment from the dissolved organic matter in the water. He holds (1) that the mass of plankton in sea-water is much too small in amount to meet the food requirements of the larger animals, and (2) that an abundant source of food is present in the form of the dissolved organic compounds in the water, and that it is on these that the sea-animals are nourished. This view was referred to, briefly, in the chapter on plankton; but, though very improbable, it deals with such important fundamental matters that it must be discussed at greater length here.

According to Pütter, then, the living plankton is of comparatively slight importance as a food material, and many animals of the sea are nourished, somewhat like endoparasites in the bodies of higher animals, by the dissolved organic substances resulting from the decay and metabolism of other organisms—such as the algæ of the plankton, and the other larger marine algæ. Pütter based this conclusion upon figures which he published showing that there was a surprisingly large amount of dissolved organic carbon in the sea-water of the Bay of Naples, where his work was carried out, and that the nutritive requirements of some of the higher marine invertebrate animals could not be met by the amount of lower organisms (the plankton) contained in the volume of water available for their use.

Taking certain common marine animals—he calculated from the consumption of oxygen the minimal value of the carbon required per unit of time for an animal of a given body weight, then taking certain figures for the amount of plankton strained from a given volume of water (by Lohmann off Syracuse, during December) he calculated the amount of water that the animal in question would require to strain in order to obtain the required carbon, and declared it to be an impossibly large amount. For example: In the case of the common marine sponge *Suberites domuncula* at Naples, he calculated that with a body-weight of 60 grammes (about 2 oz.) it required 0.9 milligrammes of carbon per hour. Taking Lohmann's results as to the plankton in the Mediterranean it followed that the sponge, in order to obtain that amount of carbon from the plankton, would require to filter 242 litres of sea-water per hour—about 4,000 times its own volume. This amount of water he showed could not pass in the time through the openings and water passages of the sponge. On the other hand, he finds that the sea-water he analysed contains sufficient of the dissolved organic-carbon compounds to supply the needs of the sponge from an amount of water that could easily pass through the sponge cavities in an hour. He obtained similar conclusions in the case of the Holothurian *Cucumaria grubei,* and subsequently extended his investigations to an ascidian, a sea-anemone and a fish, with like results.

Other competent observers, however, on repeating Pütter's experiments, have arrived at very different conclusions. Thus while Pütter found in the Bay of Naples as much as 65 to 92 milligrammes of dissolved organic carbon per litre of water, Henze in his investigation found only from 6 down to 3 milligrammes, and even less in some samples; and Raben, with better methods, found at Kiel, where the water may be polluted, an average of about 12 milligrammes per litre, and in the open Baltic only 3 milligrammes. Even this, however, is a large amount of carbon compared with what Pütter and others state can be supplied by the plankton. It must be remembered, however, that all methods of collecting the smaller but immensely abundant organisms of the plankton are still very defective, and that even the finest silk nets, with which most of the data have been obtained, allow a very large proportion of the nanno-plankton to escape. But other estimates of the quantities of plankton present are much larger than those made use of by Pütter, and we know that localities and seasons differ greatly.

Pütter's other figures, in regard to the food-requirements of various animals, and therefore the volumes of water they must strain, have also been controverted, and some of the other independent estimates of the food-requirements of various animals that have been made are as follows:

Professor E. Prince of the Canadian Sea-fisheries Department states that if the sponge *Suberites,* one ounce in weight, had such requirements that would mean nearly 1½ billions of a Diatom like *Skeletonema,* or more than 7 billions of *Thalassiosira* daily; that similarly a Copepod (*Calocalanus*) might require daily 9,750,000,000 *Thalassiosira*; and that an oyster 5 inches long would consume $\frac{1}{12}$ cub. in. of solid food daily, and therefore would need to filter 8 or 9 gallons of water, nearly 2,000 times its own bulk. Kishinouye states that the Japanese Sardine would require to swim nine miles to catch the ¾ gram of food needed daily, as only one gram of Diatoms and other similar organisms is contained in 1,000 litres of the water. But Prof. G. H. Parker has recently shown that the sponge *Spinosella* at Bermuda, with about twenty exhalant openings can strain in a day about 1,575 litres, or over 415 gallons of sea-water.

In addition to the plankton and the nanno-plankton, Professor Prince draws attention to the "Demerson," sinking clouds of dead plankton, which settle on the botton as a colloidal stratum, recalling the now discredited "Bathybius" of pre- "Challenger" times. This demerson is an important source of nutriment for animals at all depths from coast to abyss. Petersen and others have also recognized this potential food-matter under the name "detritus."

The various estimates differ widely. It is probable that different animals differ in their food-requirements according to their habits, and probably localities also vary. It is evident that further data are required, as the calculations of food requirements on our present data must be regarded as of very doubtful value. The food requirements cannot be expected to be proportional to the animal's weight, as exoskeletal and some other structures that add materially to the weight are not active in metabolism. Nor can the surface area be taken as a guide, as surfaces vary greatly in absorbing power.

Professor B. Moore and several other bio-chemists, in a series of investigations made at the Port Erin Biological Station from 1910 onwards, have shown conclusively that the amount of dissolved organic carbon present in the sea-water of the Irish Sea is almost negligible (lying well below 1 mgr. per litre of water), and that Pütter's figures are very incorrect; his original figure of sixty-five having been brought down by Henze and Raben to six, and then three, and now by Moore to one, which is within the limit of experimental error. Moore has also shown, however, that the amount of plankton normally present and generally distributed throughout the water, avoiding special swarms, is insufficient to provide food for the larger animals if these merely filter the water as it comes. In fact, according to the latest investigations, the organic matter in solution and the generally distributed plankton taken together do not seem sufficient for the nutrition of actively swimming marine animals, although they may suffice for the fixed or sedentary forms, such as sponges, ascidians and lamellibranch molluscs. Moore estimates that the sedentary sponge requires to filter only fifteen times its own volume per hour, while the active Crustacean requires 250 times. The active animals, however, such as Crustacea and fishes, probably hunt their food and follow up shoals of plankton or frequent those zones in which the plankton is especially abundant, and so are able to obtain a great deal more than the average amount which is distributed through the water in general at the time. This result accords well with our many observations at Port Erin on the irregularity in the distribution of the plankton, and the corresponding variations in the occurrence of the migratory fishes which may be regarded as following and feeding upon the swarms of planktonic organisms.

We have, moreover, direct evidence that the larger and more active members of the plankton, such as Copepoda, do feed upon the minute algæ of the plankton. W. J. Dakin's original observations made at Kiel have been corroborated and extended by Esterly in California, who has shown conclusively that in a number of different species of Copepoda he examined, particles such as Diatoms and other minute members of the plankton are ingested and can be traced through the intestine. Some individual Copepoda may be found with the alimentary canal empty, or containing only a greenish amorphous mass, but that may well be because soft-bodied organisms have been eaten and have been or are being rapidly digested. Further observations must, however, be made into the food and the feeding habits of all plankton feeders in the living condition, and when actually feeding. I may add that during the last twenty years I have myself examined in the living condition about 10,000 samples of freshly caught plankton, and I have no doubt whatever, from what I have seen, that the Copepoda and other larger and more active animals are habitually feeding upon the smaller forms.

Putting aside the detritus or demerson, and other plant and animal food on the sea-bottom, and considering only what is free in the water, as yet we have discovered no other more abundant source of food for larger marine animals than the organisms of the plankton, and if this is really insufficient, as Pütter and others have tried to prove, then we have here one of the most important problems of marine biology still unsolved, and one which requires further research, both observational and experimental, upon the feeding habits of many common animals—work which can only be carried on at sea or in the laboratories of marine biological stations.

The problem is, in part, a bio-chemical one; and that brings us to Pütter's further assertion that, as he was able to keep large invertebrates and even fish in water containing no obvious or particulate food during long periods when they were daily absorbing oxygen and losing carbon, they must have been living on dissolved carbon in the water. This has been answered by Moore and his fellow-workers at Port Erin, who have conducted a long series of experiments ranging over seven months (235 days) on the nutrition and metabolism of various marine animals, during which they kept such large animals as lobsters, octopus and fish. Each experiment ran for a long period, during which the animals were not fed, but their consumption of oxygen and output of carbon-dioxide was determined daily. At the end the animals showed no serious result and no loss in weight. They were apparently healthy and lively. The explanation was found to be that the loss of organic matter from the tissues is made good or replaced by an equivalent amount of sea-water taken in. The proteins of the animals' tissues were found to be much reduced, and the loss was sufficient to account for all the energy required for the metabolism of the fasting animal.

The bearing of this result upon Pütter's views is that when a marine animal does not lose weight on being kept without food, it need not be supposed that it is obtaining carbon from hypothetical dissolved compounds in the water, but is merely replacing the loss from its tissues by storing up water. It is evident, however, that this process cannot go on indefinitely.

Notwithstanding Pütter's statements, which have undergone so many corrections, until further evidence is forthcoming we may continue to believe that aquatic animals are nourished chiefly by particulate food taken in at the mouth and digested in the alimentary canal.

The further and final contribution that Professor Moore and the other bio-chemists at Port Erin have made to our knowledge of the metabolism of the sea and the nutrition of marine animals, is that the green plant cell, such as that of the phyto-plankton, is not dependent for either its nitrogen or its carbon upon the amount that may be present in the form of nitrogen salts and as carbon dioxide in the water. They have shown in recent papers before the Royal Society[1] that elemental nitrogen can be obtained from the air through the water, and the very small quantities of nitrates, nitrites and ammonia salts may remain in the water unconsumed.

In regard to the carbon supply their experiments show that the bicarbonates of magnesium and calcium can be broken up and used by the green plant cell in its nutrition, until the whole stock of bicarbonates in the water has been exhausted. This latest result cuts at the root not only of Pütter's views as to the source of carbon, but also of the law of the minimum (so far as regards nitrogen), as expounded by Brandt and others—to the effect that the amount of

[1] *Proc. Roy. Soc.,* B 91 and 92 (1920). See also Moore's book *Biochemistry* (1921).

possible organic life in the sea is limited by the quantity of whatever necessary substance is present in minimal amount—it being supposed, for example, that the necessary nitrogen has to be obtained from the small quantities present in the form of ammonia salts, nitrates and nitrites. But these recent experiments show that, to quote the words of Moore's Royal Society paper:—

"The source of the nitrogen is the atmospheric elemental nitrogen dissolved in the sea-water, and not ammonia, nitrates or nitrites. The source of the carbon is the carbon dioxide of the bicarbonates of calcium and magnesium dissolved in sea-water."

This reaction is so large in amount in the sea, in spring at the time of the plankton maximum, that if it takes place to the same extent down to a depth of 100 metres, then the carbon made available would suffice for a crop of phyto-plankton amounting to at least ten tons of moist vegetation per acre.

In the application of oceanographic investigations to sea-fisheries problems, one ultimate aim, whether frankly admitted or not, must be to obtain some kind of a rough approximation to a census or valuation of the sea—of the fishes that form the food of man, of the lower animals of the sea-bottom on which many of the fishes feed, and of the planktonic contents of the upper waters which form the ultimate organized food of the sea—and many attempts have been made in different ways to attain the desired end.

Our knowledge of the number of animals living in different regions of the sea is for the most part relative only. We know that one haul of the dredge is larger than another, or that one locality seems richer than another, but we have very little information as to the actual numbers of any kind of animal per square foot or per acre in the sea. Hensen, as we have seen, attempted to estimate the number of food-fishes in the North Sea from the number of their eggs caught in a comparatively small series of hauls of the tow-net, but the data were probably quite insufficient and the conclusions may be erroneous. It is an interesting speculation to which we cannot attach any economic importance. His own colleague, Heincke, says of it: “This method appears theoretically feasible, but presents in practice so many serious difficulties that no positive results of real value have as yet been obtained.”

All biologists must agree that to determine even approximately the number of individuals of any particular species living in a known area is a contribution to knowledge which may be of great economic value in the case of the edible fishes, but it may be doubted whether Hensen’s methods, even with greatly increased data, will ever give us the required information. Petersen’s method, of setting free marked plaice and then assuming that the proportion of these recaught is to the total number marked as the fishermen’s catch in the same district is to the total population, will only hold good in circumscribed areas where there is practically no migration and where the fish are fairly evenly distributed. This method gives us what has been called “the fishing coefficient,” applicable to the North Sea for those sizes of fish which are caught by the trawl. Heincke,[1] from an actual examination of samples of the stock on the ground obtained by experimental trawling (“the catch coefficient”), supplemented by the market returns of the various countries, estimates the adult plaice at about 1,500 millions, of which about 500 millions are caught or destroyed by the fishermen annually.

It is difficult to imagine any further method which will enable us to estimate any such case as, say, the number of plaice in the North Sea, where the individuals are so far beyond our direct observation and are liable to change their positions at any moment. But a beginning can be made

[1]F. Heincke, *Cons. Per. Internat. Explor. de la Mer,* “Investigations on the Plaice,” Copenhagen, 1913.

on more accessible ground with more sedentary animals, and Dr. C. G. Joh. Petersen, of the Danish Biological Station, has for some years been pursuing the subject in a series of interesting reports on the "Evaluation of the Sea."[1] He uses a bottom-sampler, or grab, which can be lowered down open and then closed on the bottom so as to bring up a sample square foot or square metre (or in deep water one-tenth of a square metre) of the sand or mud and its inhabitants. With this apparatus, modified in size and weight for different depths and bottoms, Petersen and his fellow-workers have made a very thorough examination of the Danish waters, and especially of the Kattegat and the Limfjord, have described a series of "animal communities" characteristic of different zones and regions of shallow water, and have arrived at certain numerical results as to the quantity of animals in the Kattegat expressed in tons—such as 5,000 tons of plaice requiring as food 50,000 tons of "useful animals" (mollusca and polychæt worms), and 25,000 tons of starfish using up 200,000 tons of useful animals which might otherwise serve as food for fishes, and the dependence of all these animals directly or indirectly upon the great Beds of Zostera, which make up 24,000,000 tons in the Kattegat. Such estimates are obviously of great biological interest, and, even if only rough approximations, are a valuable contribution to our understanding of the metabolism of the sea and of the possibility of increasing the yield of local fisheries.

But on studying these Danish results in the light of what we know of our own marine fauna, although none of our seas have been examined in the same detail by the bottom-sampler method, it seems probable that the animal communities as defined by Petersen are not exactly applicable on our coasts, and that the estimates of relative and absolute abundance may be very different in different seas

[1] See *Reports of the Danish Biological Station,* and especially the *Report* for 1918, "The Sea Bottom and its Production of Fish Food."

under different conditions. The work will have to be done in each great area, such as the North Sea, the English Channel, and the Irish Sea, independently. This is a necessary investigation, both biological and physical, which lies before the oceanographers of the future, upon the results of which the future preservation and further cultivation of our national sea-fisheries may depend.

It has been shown by Johnstone and others that the common edible animals of the shore may exist in such abundance that an area of the sea may be more productive of food for man than a similar area of pasture or crops on land. A Lancashire mussel-bed has been shown to have as many as 16,000 young mussels per square foot, and it is estimated that in the shallow waters of Liverpool Bay there are from 20 to 200 animals of sizes varying from an amphipod to a plaice on each square metre of the bottom. Shelford, in America, states that 4 square feet of the sea will support one human life.

From these and similar data which can be readily obtained, it is not difficult to calculate totals by estimating the number of square yards in areas of similar character between tide-marks or in shallow water. And from weighings of samples some approximation to the number of tons of available food may be computed. But one must not go too far. Let all the figures be based upon actual observation. Imagination is necessary in science, but in calculating a population of even a very limited area it is best to believe only what one can see and measure.

Countings and weighings, however, do not give us all the information we need. It is something to know even approximately the number of millions of animals on a mile of shore and the number of millions of tons of possible food in a sea-area, but that is not sufficient. All food-fishes are not equally nourishing to man, and all plankton and bottom invertebrata are not equally nourishing to a fish. At this point the biologist requires the assistance of the physiologist and the bio-chemist. We want to know next the value of our food matters in proteids, carbohydrates, and fats, and the resulting calories. We have already seen how markedly a fat summer herring differs in essential constitution from the ordinary white fish, such as the cod, which is almost destitute of fat.

Professor Brandt, at Kiel, Professor Benjamin Moore, at Port Erin, and others, have similarly shown that plankton gatherings may vary greatly in their nutrient value according as they are composed mainly of Diatoms, of Dinoflagellates, or of Copepoda. And, no doubt, the animals of the "benthos," the common invertebrates of our shores, will show similar differences in analysis.[1] It is obvious that some contain more solid flesh, others more water in their tissues, others more calcareous matter in the exoskeleton, and that therefore, weight for weight, we may be sure that some are more nutritious than the others; and this is probably at least one cause of that preference we see in some of our bottom-feeding fish for certain kinds of food, such as polychæt worms, in which there is relatively little waste, and thin-shelled lamellibranch molluscs, such as young mussels, which have a highly nutrient body in a comparatively thin and brittle shell.

Such investigations of foods and their values seem a natural and useful extension of faunistic work, for the purpose of obtaining some approximation to a quantitative estimate of the more important animals of our shores and shallow water, and their relative values as either the immediate or the ultimate food of marketable fishes.

Each such fish has its "food-chain" or series of alternative chains, leading back from the food of man to the

[1] Moore and others have made analyses of the protein, fat, etc., in the soft parts of Sponge, Ascidian, Aplysia, Fusus, Echinus, and Cancer at Port Erin, and find considerable differences—the protein ranging, for example, from 8 to 51 per cent., and the fat from 2 to 14 per cent. (see *Bio-Chemical Journ.,* vi. p. 291).

invertebrates upon which it preys and then to the food of these, and so down to the smallest and simplest organisms in the sea, and each such chain must have all its links fully worked out as to seasonal and quantitative occurrence back to the Diatoms and Flagellates which depend upon physical conditions and take us beyond the range of biology—but not beyond that of oceanography. The Diatoms and the Flagellates are probably more important than the more obvious sea-weeds, not only as food, but also in supplying to the water the oxygen necessary for the respiration of living protoplasm. In addition to the numbers present at any time, the further object must be to estimate the rate of production and rate of destruction of all organic substances in the sea. Lohmann has estimated that at Kiel, throughout the year, the plants make up 56 per cent. and the animals 44 per cent. of the plankton, and that the plants have an average daily accession of 30 per cent. (in volume) which is consumed by the animals.

To attain to an approximate census and valuation of the sea—remote though it may seem—is a great aim, but it is not sufficient. We want not only to record and to count natural objects, but also to understand them. We require to know not merely what an organism is—in the fullest detail of structure and development and affinities—and also where it occurs—again in full detail—and in what abundance under different circumstances, but also *how* it lives, and what all its relations are to both its physical and its biological environment, and that is where the physiologist, and especially the bio-chemist, can help us. In the best interests of biological progress the day of the naturalist who merely collects, the day of the anatomist and histologist who merely describe, is over, and the future is with the observer and the experimenter animated by a divine curiosity to enter into the life of the organism and understand how it lives and moves and has its being— “Felix qui potuit rerum cognoscere causas.”

Thus we catch glimpses—it is not yet a finished picture—of the endless changes of the ocean; of both earth and air contributing necessary materials to the water so that those of minimal amount never become exhausted; of the fishes we eat feeding upon smaller animals, the cod on the hermit and other crabs, the plaice on cockles and mussels, the herring on the larger Copepods of the plankton, and these in their turn on microscopic organisms; of the carbon dioxide and the silica becoming stored up in winter to be used by the phyto-plankton which has been called into activity by the increasing radiant energy of the sunlight in spring, just in time to nourish the newly hatched post-larval fishes; of the zoo-plankton that follows, feeding on the phyto-plankton and itself falling prey to the migratory fishes in summer, and the dead remains of everything falling to the bottom to form the demerson upon which hordes of benthonic animals can browse. And we recognize that all are links in a series of interlacing chains where nothing is lost, nothing wasted, substances disappearing only to reappear in another form: the carbon and calcium now free in the water as dissociated ions, now locked up in the shell of a mollusc, buried in Globigerina ooze or fossilized as a coral reef; the silica once in a flint, now in a Radiolarian shell, a Sponge spicule, or a Diatom frustule, to be redissolved in the water when required by the inexorable laws of nature to pass to another phase of the beneficent, never-ending cycle of events that constitutes the metabolism of the oceans.

The appeal which such researches in pure science make to university laboratories, and to all who desire to advance knowledge, ought to be irresistible; but there is also a wider appeal, on economic grounds, not to the scientific world alone, but to the whole population of these islands, a maritime people who owe everything to the sea. I urge them to become better informed in regard to our national sea-fisheries and take a more enlightened interest in the basal principles that underlie a rational regulation and exploitation of these important industries. National efficiency depends to a very great extent upon the degree in which scientific results and methods are appreciated by the people and scientific investigation is promoted by the Government and other administrative authorities. The principles and discoveries of science apply to aquiculture no less than to agriculture. To increase the harvest of the sea the fisheries must be continuously investigated, and such cultivation as is possible must be applied, and all this is clearly a natural application of the biological and hydrographical work now united under the science of oceanography.

May I hope that the foregoing chapters have given the reader an impression of a young science-in-the-making, where there are curious facts to verify, interesting theories to discuss and plenty of unsolved problems ?

Mr. J. Y. Buchanan has claimed that the science of oceanography was born at sea on February 15, 1873, at the first official dredging station of the "Challenger" expedition, when everything that came up in the dredge was new and led to fundamental discoveries as to the deposits forming on the floor of the ocean. That was exactly half a century ago, and although much has been done in the interval by Government expeditions and by individual explorers, nothing so comprehensive as the voyage of the "Challenger," or yielding such a body of scientific results, has yet been achieved.

In the Presidential Address to the British Association at Cardiff, in 1920, the question was asked, "Has not the time come for a new 'Challenger' expedition?"—and during the succeeding days of the meeting the question was answered over and over again in the affirmative. The suggestion was taken up with such enthusiasm by the various scientific sections of the Association that the Council appointed a special committee of experts to draw up a reasoned report on the need of a national expedition for the further exploration of the oceans, the objects to be attained, and the probable cost. The memorandum which resulted from the work of this committee is printed here (by permission of the British Association) as an appendix, in the hope that it may be of interest and possibly of use in the future; but in the meantime the project remains in abeyance. After consultation with high authorities, the Council of the Association, in March, 1921, reluctantly decided that, although not abandoned, the matter must be postponed in deference to the pressing need for economy in national expenditure.

In the report of the Council for 1920–21 it is stated:—

"The scheme, however, is retained under consideration, and the Council hopes that the expedition is only postponed for a season, and that the interval may be usefully employed in perfecting plans and making other essential preparations.

"Meanwhile the memorandum has been communicated to the Cabinet Secretariat of H.M. Government, the Admiralty, and the Department of Scientific and Industrial Research."

It must suffice to add that all the sciences concerned—Physics, Chemistry, Geology, Zoology, Botany, Physiology, and Geography—have problems for the oceanographer awaiting solution, a number of the investigations proposed are of the highest direct practical importance, and there are many reasons why it is urgent that the scheme should be revived and preparations organized with as little delay as possible. In view of our maritime position, of the relations of our Empire to the oceans, of the pre-eminence of our Navy, of our great mercantile marine, and of our sea-fisheries, Great Britain should undoubtedly lead the world in oceanographical research.

APPENDIX

MEMORANDUM ON PROPOSED NATIONAL EXPEDITION FOR THE EXPLORATION OF THE SEA[1]

I

ORIGIN OF PROPOSAL

At the Annual Meeting of the British Association for the Advancement of Science in August, 1920, the President, Dr. W. A. Herdman, F.R.S., Professor of Oceanography in the University of Liverpool, delivered an address dealing with some of the problems of oceanography, and suggested that the time had come for a new British expedition to explore the great oceans of the globe. This suggestion was afterwards put forward more definitely and with further detail in the discussion "On the Need for the Scientific Investigation of the Ocean" at a joint meeting of the Sections of Zoology and Geography. The proposal then made was, in brief, that there was now urgent need for another great exploring expedition like that of the "Challenger" (1872–76), national in character, world-wide in scope, to investigate further the science of the sea, in all departments, by modern methods, under the best expert advice and control.

ACTION BY COMMITTEES AND COUNCIL OF THE ASSOCIATION

This proposal was received with such favour that at the next meeting of the Committee of Section D (Zoology) a resolution was unanimously passed:— "

That Section D is profoundly impressed with the importance of urging the initiation of a further National Expedition for the Exploration of the Ocean, and requests the

[1]Reprinted, by permission, from the *Report of the Council of the British Association,* for 1920–21.

Council of the British Association to appoint a Committee to take the necessary steps to impress this need upon His Majesty's Government and the nation.
"

This resolution was supported by the Committees of all the other Sections of the Association interested in such an exploration. The Committee of Recommendations and the General Committee on the following day passed a resolution "pointing out the importance of urging the initiation of a national expedition for the exploration of the ocean, and requesting that the Council of the British Association should take the necessary steps to impress this need upon His Majesty's Government and the nation." The Council of the Association thereupon appointed a Committee, representative of all the departments of science concerned, to prepare and take steps for the presentation of the present statement; while, following upon a reference from the Association, the Council of the Royal Society also appointed a Committee to confer with that appointed by the Council of the Association.

Many men of science, both British and foreign, wrote expressing the hope that the cogent scientific reasons for the expedition may be pressed without delay upon the Government, so as to induce the nation to undertake this great enterprise.

II

"CHALLENGER" EXPEDITION

The "Challenger" expedition, the great British circumnavigating and deep-sea exploring expedition under Sir George Nares and Sir Wyville Thomson in 1872–76, brought back collections and results unrivalled either before or since, which added enormously to our scientific and practical knowledge of the oceans. Our knowledge of the science of the sea, however, has undergone great changes during the last half-century. Physics, Chemistry, Geology, Zoology, Botany, Physiology, and Geography all have problems awaiting solution,[1] and there are many modern methods of investigation of the ocean depths which have been devised or improved since the days of the "Challenger." All civilized nations of the world have contributed by means of expeditions during the last quarter-century to the advance of oceanography,

[1] See schedule appended (p. 334, for a summary of the proposed investigations.

and it is remarkable that our country, considering the relations of our Empire to the oceans, has done comparatively little. In view of our maritime position, of the pre-eminence of our Navy, of our great mercantile marine, and of our sea-fisheries, Great Britain should undoubtedly lead the world in oceanographical research.

III

SCOPE AND PERIOD OF PROPOSED EXPEDITION

Such an expedition as is contemplated ought, in order to make worthy contributions to science, to be at least as extensive in duration and as comprehensive in scope as the "Challenger" expedition. It ought to explore all the great oceans during a period of three or four years. It ought to be prepared to establish landing parties on oceanic islands, coral reefs, and other places where special detailed explorations on shore or in shallow water are required. Special scientific apparatus may have to be devised, and young scientific men may have to be trained to fit them for the work of such an expedition. At least one year, therefore, would have to be devoted to the work of preparation. It will be apparent from the Schedule to this statement that a number of the investigations proposed are of the highest direct practical importance, and there are many reasons why it is important that the scheme should be initiated and preparations organized with as little delay as possible.

SHIP

Preliminary inquiries lead tentatively to the belief that a vessel of the mercantile marine, of about 3,000 tons, chartered by H.M. Government for the occasion, would best suit the general purposes of the expedition; with the possible exception, as already indicated, of certain investigations which might be carried out independently of the main body.

SCIENTIFIC PERSONNEL

It is estimated that the scientific staff of such an expedition should consist of a director with ten or twelve assistants, exclusive of landing parties and any officers of the Royal Navy who might be detailed for special investigations for Admiralty purposes.

COST

While it is difficult under present conditions, and in the present preliminary stage of inquiry into the possibility and scope of the expedition, to form any near estimate of its cost, it is believed that (apart from the provision of the ship, which it is hoped would be undertaken by the Admiralty) this should lie between £200,000 and £300,000, with a bias toward the higher figure. It is to be observed that the expenditure would be spread over a number of years.

PUBLICATION OF RESULTS

In this connection suitable arrangements for the adequate publication of the results of the expedition must be borne in mind. The working out and publication of the results of the "Challenger" expedition are stated to have cost about as much as the expedition itself, and a similar expenditure may be anticipated in the present case.

PRESERVATION OF SPECIMENS

The natural repository of type specimens collected during the expedition would be the British Museum (Natural History Department), while duplicate specimens should be offered to museums, universities, etc., in various parts of the Empire.

SCHEDULE

SUBJECTS FOR INVESTIGATION

To give some idea of the amount and variety of scientific work that might be undertaken by such an expedition, the following may be mentioned as some of the chief recommendations which have been received from representatives of the various Sections of the British Association concerned:—

1. In the departments of marine biology and physiology extensive investigations are required of fish and fisheries in the interest of food supplies. These include a very wide range of inquiry, which may be summarized thus: the effects of temperature and other conditions on the distribution and life of organisms; the distribution of the plankton (which includes organisms of first-rate importance as food for fishes which supply food for man); ocean currents in relation to fisheries (just enough is known as to the influence of variations in the great oceanic currents upon the movements and abundance of migratory fishes to make evident the need for further and more complete investigation of the subject);

the physiology of deep-sea and other oceanic animals; the investigation of marine algæ, both coastal and planktonic; marine bacteria; bio-chemical investigation of the metabolism of the sea (this is perhaps the department of oceanography which deals with the most fundamental problems and which is most in need of immediate investigation); the question of the abundance of tropical plankton as compared with that of temperate and polar seas, the distribution and action of denitrifying bacteria, the variations of the plankton in relation to environmental conditions, the factors which determine uniformity of conditions over a large sea-area from the point of view of plankton distribution, the supply of the necessary minimal substances such as nitrogen, silica, and phosphorus to the living organisms, and the determination of the rate of production and rate of destruction of all organic substances in the sea—these are some of the fundamental problems of the metabolism of the ocean; all of them require investigation, and bear, directly or indirectly, upon the harvest of the sea for man's use, just as agricultural researches bear upon the harvest of the land.

2. In the appropriate departments of chemistry observations are required on the temperature, salinity, and chemistry of sea-water, the hydrogen-ion concentration, and the source and distribution of nitrogen in the sea.

3. In the department of physics there is need for investigation of meteorological problems, the distribution of oceanic temperature, atmospheric electricity, long-distance transmission of electro-magnetic waves, and other problems of wireless telegraphy at sea. The study of the variation in the force of gravity over the great ocean basins is also suggested, and bears upon the problem of the figure of the earth, and the density of materials of which it is composed. It may be stated here that such an investigation might need to be carried out on a larger and steadier ship than that which would most probably be detailed for the expedition. On the other hand, there is no reason why the whole of the investigations associated with the expedition should be confined to a single vessel, for the opportunity might be made for collateral investigations on other vessels in the ordinary course of navigation. Similarly, the investigation of the phenomena of tides, one of the most urgent on the physical

side, could most profitably be begun in shallow seas, and not on the vessel carrying the main expedition over the deep oceans.

4. In the departments of geology and geography there are indicated as subjects for study both shallow and deep water deposits, and the various methods of deposition; sediments on the sea-bottom in relation to the movement (rising or sinking) of adjacent land areas (a matter which in turn bears upon the encroachments of the sea upon the land, or the reverse); borings on the floor of the sea for the extension of knowledge of the rocks composing the crust of the earth; the physical conditions of oceanic islands; the growth and other problems of coral reefs and islands.
5. In the department of anthropology it is pointed out that the opportunity for landing parties on oceanic islands (especially in the Pacific) would give occasion for observations on the ethnography, habits, and life of native populations; any medical officer attached to such parties would find matter for study in the physical characters and diseases of natives.

It is not suggested that the foregoing summary by any means covers a complete list of the problems of the ocean requiring investigation, nor, on the other hand, that these need all be undertaken by one expedition; but they are sufficient to show that there is still much to be found out in all branches of oceanography, and that a further scientific exploration of the oceans will add to knowledge in many branches of science, and should also aid in the advancement of various industries based upon marine products of economic importance.

It may be desirable to refer to the relations between the work of such an expedition as is here proposed—work which, while temporary in character, would be world-wide in scope—and that carried on under the International Council for the Study of the Sea in the North Atlantic and adjoining European seas. This latter work, while restricted in scope, is permanent, and the proposed oceanographic expedition covers a wider range in science, and would offer an unsurpassable opportunity of qualifying investigators to take part in future oceanographical and fisheries research under a permanent organization.

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