Title: Discourses Biological and Geological Essays

Author: Thomas H. Huxley

Release Date: November 12, 2003 [EBook #10060]

Language: English

Produced by Imran Ghory, Stan Goodman, Richard Prairie and PG Distributed Proofreaders

DISCOURSES:

BIOLOGICAL & GEOLOGICAL

ESSAYS

BY

THOMAS H. HUXLEY

1894

PREFACE

The contents of the present volume, with three exceptions, are either popular lectures, or addresses delivered to scientific bodies with which I have been officially connected. I am not sure which gave me the more trouble. For I have not been one of those fortunate persons who are able to regard a popular lecture as a mere *hors d'oeuvre*, unworthy of being ranked among the serious efforts of a philosopher; and who keep their fame as scientific hierophants unsullied by attempts—at least of the successful sort—to be understanded of the people.

On the contrary, I found that the task of putting the truths learned in the field, the laboratory and the museum, into language which, without bating a jot of scientific accuracy shall be generally intelligible, taxed such scientific and literary faculty as I possessed to the uttermost; indeed my experience has furnished me with no better corrective of the tendency to scholastic pedantry which besets all those who are absorbed in pursuits remote from the common ways of men, and become habituated to think and speak in the technical dialect of their own little world, as if there were no other.

If the popular lecture thus, as I believe, finds one moiety of its justification in the self-discipline of the lecturer, it surely finds the other half in its effect on the auditory. For though various sadly comical experiences of the results of my own efforts have led me to entertain a very moderate estimate of the purely intellectual value of lectures; though I venture to doubt if more than one in ten of an average audience carries away an accurate notion of what the speaker has been driving at; yet is that not equally true of the oratory of the hustings, of the House of Commons, and even of the pulpit?

Yet the children of this world are wise in their generation; and both the politician and the priest are justified by results. The living voice has an influence over human action altogether independent of the intellectual worth of that which it utters. Many years ago, I was a guest at a great City dinner. A famous orator, endowed with a voice of rare flexibility and power; a born actor, ranging with ease through every part, from refined comedy to tragic unction, was called upon to reply to a toast. The orator was a very busy man, a charming conversationalist and by no means despised a good dinner; and, I imagine, rose without having given a thought to what he was going to say. The rhythmic roll of sound was admirable, the gestures perfect, the earnestness impressive; nothing was lacking save sense and, occasionally, grammar. When the speaker sat down the applause was terrific and one of my neighbours was especially enthusiastic. So when he had quieted down, I asked him what the orator had said. And he could not tell me.

That sagacious person John Wesley, is reported to have replied to some one who questioned the propriety of his adaptation of sacred words to extremely secular airs, that he did not see why the Devil should be left in possession of all the best tunes. And I do not see why science should not turn to account the peculiarities of human nature thus exploited by other agencies: all the more because science, by the nature of its being, cannot desire to stir the passions, or profit by the weaknesses, of human nature. The most zealous of popular lecturers can aim at nothing more than the awakening of a sympathy for abstract truth, in those who do not really follow his arguments; and of a desire to know more and better in the few who do.

At the same time it must be admitted that the popularization of science, whether by lecture or essay, has its drawbacks. Success in this department has its perils for those who succeed. The "people who fail" take their revenge, as we have recently had occasion to observe, by ignoring all the rest of a man's work and glibly labelling him a more popularizer. If the falsehood were not too glaring, they would say the same of Faraday and Helmholtz and Kelvin.

On the other hand, of the affliction caused by persons who think that what they have picked up from popular exposition qualifies them for discussing the great problems of science, it may be said, as the Radical toast said of the power of the Crown in bygone days, that it "has increased, is increasing, and ought to be diminished." The oddities of "English as she is spoke" might be abundantly paralleled by those of "Science as she is misunderstood" in the sermon, the novel, and the leading article; and a collection of the grotesque travesties of scientific conceptions, in the shape of essays on such trifles as "the Nature of Life" and the "Origin of All Things," which reach me, from time to time, might well be bound up with them.

The tenth essay in this volume unfortunately brought me, I will not say into collision, but into a position of critical remonstrance with regard to some charges of physical heterodoxy, brought by my distinguished friend Lord Kelvin, against British Geology. As President of the Geological Society of London at that time (1869), I thought I might venture to plead that we were not such heretics as we seemed to be; and that, even if we were, recantation would not affect the question of evolution.

I am glad to see that Lord Kelvin has just reprinted his reply to my plea,[1] and I refer the reader to it. I shall not presume to question anything, that on such ripe consideration, Lord Kelvin has to say upon the physical problems involved. But I may remark that no one can have asserted more strongly than I have done, the necessity of looking to physics and mathematics, for help in regard to the earliest history of the globe. (See pp. 108 and 109 of this volume.)

[Footnote 1: *Popular Lectures and Addresses.* II. Macmillan and Co. 1894.]

And I take the opportunity of repeating the opinion, that, whether what we call geological time has the lower limit assigned to it by Lord Kelvin, or the higher assumed by other philosophers; whether the germs of all living things have originated in the globe itself, or whether they have been imported on, or in, meteorites from without, the problem of the origin of those successive Faunae and Florae of the earth, the existence of which is fully demonstrated by paleontology remains exactly where it was.

For I think it will be admitted, that the germs brought to us by meteorites, if any, were not ova of elephants, nor of crocodiles; not cocoa-nuts nor acorns; not even eggs of shell-fish and corals; but only those of the lowest forms of animal and vegetable life. Therefore, since it is proved that, from a very remote epoch of geological time, the earth has been peopled by a continual succession of the higher forms of animals and plants, these either must have been created, or they have arisen by evolution. And in respect of certain groups of animals, the well-established facts of paleontology leave no rational doubt that they arose by the latter method.

In the second place, there are no data whatever, which justify the biologist in assigning any, even approximately definite, period of time, either long or short, to the evolution of one species from another by the process of variation and selection. In the ninth of the following essays, I have taken pains to prove that the change of animals has gone on at very different rates in different groups of living beings; that some types have persisted with little change from the paleozoic epoch till now, while others have changed rapidly within the limits of an epoch. In 1862 (see below p. 303, 304) in 1863 (vol. II., p. 461) and again in 1864 (ibid., p. 89-91) I argued, not as a matter of speculation, but, from paleontological facts, the bearing of which I believe, up to that time, had not been shown, that any adequate hypothesis of the causes of evolution must be consistent with progression, stationariness and retrogression, of the same type at different epochs; of different types in the same epoch; and that Darwin's hypothesis fulfilled these conditions.

According to that hypothesis, two factors are at work, variation and selection. Next to nothing is known of the causes of the former process; nothing whatever of the time required for the production of a certain amount of deviation from the existing type. And, as respects selection, which operates by extinguishing all but a small minority of variations, we have not the slightest means of estimating the rapidity with which it does its work. All that we are justified in saying is that the rate at which it takes place may vary almost indefinitely. If the famous paint- root of Florida, which kills white pigs but not black ones, were abundant and certain in its action, black pigs might be substituted for white in the course of two or three years. If, on the other hand, it was rare and uncertain in action, the white pigs might linger on for centuries.

T.H. HUXLEY.

HODESLEA, EASTBOURNE,

April, 1894.

CONTENTS

I

PALAEONTOLOGY AND THE DOCTRINE OF EVOLUTION [1870]
(Presidential Address to the Geological Society.)

I

ON A PIECE OF CHALK

[1868]

If a well were sunk at our feet in the midst of the city of Norwich, the diggers would very soon find themselves at work in that white substance almost too soft to be called rock, with which we are all familiar as "chalk."

Not only here, but over the whole county of Norfolk, the well-sinker might carry his shaft down many hundred feet without coming to the end of the chalk; and, on the sea-coast, where the waves have pared away the face of the land which breasts them, the scarped faces of the high cliffs are often wholly formed of the same material. Northward, the chalk may be followed as far as Yorkshire; on the south coast it appears abruptly in the picturesque western bays of Dorset, and breaks into the Needles of the Isle of Wight; while on the shores of Kent it supplies that long line of white cliffs to which England owes her name of Albion.

Were the thin soil which covers it all washed away, a curved band of white chalk, here broader, and there narrower, might be followed diagonally across England from Lulworth in Dorset, to Flamborough Head in Yorkshire—a distance of over 280 miles as the crow flies. From this band to the North Sea, on the east, and the Channel, on the south, the chalk is largely hidden by other deposits; but, except in the Weald of Kent and Sussex, it enters into the very foundation of all the south-eastern counties.

Attaining, as it does in some places, a thickness of more than a thousand feet, the English chalk must be admitted to be a mass of considerable magnitude. Nevertheless, it covers but an insignificant portion of the whole area occupied by the chalk formation of the globe, much of which has the same general characters as ours, and is found in detached patches, some less, and others more extensive, than the English. Chalk occurs in north-west Ireland; it stretches over a large part of France,— the chalk which underlies Paris being, in fact, a continuation of that of the London basin; it runs through Denmark and Central Europe, and extends southward to North Africa; while eastward, it appears in the Crimea and in Syria, and may be traced as far as the shores of the Sea of Aral, in Central Asia. If all the points at which true chalk occurs were circumscribed, they would lie within an irregular oval about 3,000 miles in long diameter—the area of which would be as great as that of Europe, and would many times exceed that of the largest existing inland sea—the Mediterranean.

Thus the chalk is no unimportant element in the masonry of the earth's crust, and it impresses a peculiar stamp, varying with the conditions to which it is exposed, on the scenery of the districts in which it occurs. The undulating downs and rounded coombs, covered with sweet-grassed turf, of our inland chalk country, have a peacefully domestic and mutton- suggesting prettiness, but can hardly be called either grand or beautiful. But on our southern coasts, the wall-sided cliffs, many hundred feet high, with vast needles and pinnacles standing out in the sea, sharp and solitary enough to serve as perches for the wary cormorant, confer a wonderful beauty and grandeur upon the chalk headlands. And, in the East, chalk has its share in the formation of some of the most venerable of mountain ranges, such as the Lebanon.

What is this wide-spread component of the surface of the earth? and whence did it come?

You may think this no very hopeful inquiry. You may not unnaturally suppose that the attempt to solve such problems as these can lead to no result, save that of entangling the inquirer in vague speculations, incapable of refutation and of verification. If such were really the case, I should have selected some other subject than a "piece of chalk" for my discourse. But, in truth, after much deliberation, I have been unable to think of any topic which would so well enable me to lead you to see how solid is the foundation upon which some of the most startling conclusions of physical science rest.

A great chapter of the history of the world is written in the chalk. Few passages in the history of man can be supported by such an overwhelming mass of direct and indirect evidence as that which testifies to the truth of the fragment of the history of the globe, which I hope to enable you to read, with your own eyes, to-night. Let me add, that few chapters of human history have a more profound significance for ourselves. I weigh my words well when I assert, that the man who should know the true history of the bit of chalk which every carpenter carries about in his breeches- pocket, though ignorant of all other history, is likely, if he will think his knowledge out to its ultimate results, to have a truer, and therefore a better, conception of this wonderful universe, and of man's relation to it, than the most learned student who is deep-read in the records of humanity and ignorant of those of Nature.

The language of the chalk is not hard to learn, not nearly so hard as Latin, if you only want to get at the broad features of the story it has to tell; and I propose that we now set to work to spell that story out together.

We all know that if we "burn" chalk the result is quicklime. Chalk, in fact, is a compound of carbonic acid gas, and lime, and when you make it very hot the carbonic acid flies away and the lime is left. By this method of procedure we see the lime, but we do not see the carbonic acid. If, on the other hand, you were to powder a little chalk and drop it into a good deal of strong vinegar, there would be a great bubbling and fizzing, and, finally, a clear liquid, in which no sign of chalk would appear. Here you see the carbonic acid in the bubbles; the lime, dissolved in the vinegar, vanishes from sight. There are a great many other ways of showing that chalk is essentially nothing but carbonic acid and quicklime. Chemists enunciate the result of all the experiments which prove this, by stating that chalk is almost wholly composed of "carbonate of lime."

It is desirable for us to start from the knowledge of this fact, though it may not seem to help us very far towards what we seek. For carbonate of lime is a widely-spread substance, and is met with under very various conditions. All sorts of limestones are composed of more or less pure carbonate of lime. The crust which is often deposited by waters which have drained through limestone rocks, in the form of what are called stalagmites and stalactites, is carbonate of lime. Or, to take a more familiar example, the fur on the inside of a tea-kettle is carbonate of lime; and, for anything chemistry tells us to the contrary, the chalk might be a kind of gigantic fur upon the bottom of the earth-kettle, which is kept pretty hot below.

Let us try another method of making the chalk tell us its own history. To the unassisted eye chalk looks simply like a very loose and open kind of stone. But it is possible to grind a slice of chalk down so thin that you can see through it—until it is thin enough, in fact, to be examined with any magnifying power that may be thought desirable. A thin slice of the fur of a kettle might be made in the same way. If it were examined microscopically, it would show itself to be a more or less distinctly laminated mineral substance, and nothing more.

But the slice of chalk presents a totally different appearance when placed under the microscope. The general mass of it is made up of very minute granules; but, imbedded in this matrix, are innumerable bodies, some smaller and some larger, but, on a rough average, not more than a hundredth of an inch in diameter, having a well-defined shape and structure. A cubic inch of some specimens of chalk may contain hundreds of thousands of these bodies, compacted together with incalculable millions of the granules.

The examination of a transparent slice gives a good notion of the manner in which the components of the chalk are arranged, and of their relative proportions. But, by rubbing up some chalk with a brush in water and then pouring off the milky fluid, so as to obtain sediments of different degrees of fineness, the granules and the minute rounded bodies may be pretty well separated from one another, and submitted to microscopic examination, either as opaque or as transparent objects. By combining the views obtained in these various methods, each of the rounded bodies may be proved to be a beautifully-constructed calcareous fabric, made up of a number of chambers, communicating freely with one another. The chambered bodies are of various forms. One of the commonest is something like a badly-grown raspberry, being formed of a number of nearly globular chambers of different sizes congregated together. It is called *Globigerina*, and some specimens of chalk consist of little else than *Globigerinoe* and granules. Let us fix our attention upon the *Globigerina*. It is the spoor of the game we are tracking. If we can learn what it is and what are the conditions of its existence, we shall see our way to the origin and past history of the chalk.

A suggestion which may naturally enough present itself is, that these curious bodies are the result of some process of aggregation which has taken place in the carbonate of lime; that, just as in winter, the rime on our windows simulates the most delicate and elegantly arborescent foliage—proving that the mere mineral water may, under certain conditions, assume the outward form of organic bodies—so this mineral substance, carbonate of lime, hidden away in the bowels of the earth, has taken the shape of these chambered bodies. I am not raising a merely fanciful and unreal objection. Very learned men, in former days, have even entertained the notion that all the formed things found in rocks are of this nature; and if no such conception is at present held to be admissible, it is because long and varied experience has now shown that mineral matter never does assume the form and structure we find in fossils. If any one were to try to persuade you that an oyster-shell (which is also chiefly composed of carbonate of lime) had crystallized out of sea-water, I suppose you would laugh at the absurdity. Your laughter would be justified by the fact that all experience tends to show that oyster-shells are formed by the agency of oysters, and in no other way. And if there were no better reasons, we should be justified, on like grounds, in believing that *Globigerina* is not the product of anything but vital activity.

Happily, however, better evidence in proof of the organic nature of the *Globigerinoe* than that of analogy is forthcoming. It so happens that calcareous skeletons, exactly similar to the *Globigerinoe* of the chalk, are being formed, at the present moment, by minute living creatures, which flourish in multitudes, literally more numerous than the sands of the sea-shore, over a large extent of that part of the earth's surface which is covered by the ocean.

The history of the discovery of these living *Globigerinoe*, and of the part which they play in rock building, is singular enough. It is a discovery which, like others of no less scientific importance, has arisen, incidentally, out of work devoted to very different and exceedingly practical interests. When men first took to the sea, they speedily learned to look out for shoals and rocks; and the more the burthen of their ships increased, the more imperatively necessary it became for sailors to ascertain with precision the depth of the waters they traversed. Out of this necessity grew the use of the lead and sounding line; and, ultimately, marine-surveying, which is the recording of the form of coasts and of the depth of the sea, as ascertained by the sounding-lead, upon charts.

At the same time, it became desirable to ascertain and to indicate the nature of the sea-bottom, since this circumstance greatly affects its goodness as holding ground for anchors. Some ingenious tar, whose name deserves a better fate than the oblivion into which it has fallen, attained this object by "arming" the bottom of the lead with a lump of grease, to which more or less of the sand or mud, or broken shells, as the case might be, adhered, and was brought to the surface. But, however well adapted such an apparatus might be for rough nautical purposes, scientific accuracy could not be expected from the armed lead, and to remedy its defects (especially when applied to sounding in great depths) Lieut. Brooke, of the American Navy, some years ago invented a most ingenious machine, by which a considerable portion of the superficial layer of the sea-bottom can be scooped out and brought up from any depth to which the lead descends. In 1853, Lieut. Brooke obtained mud from the bottom of the North Atlantic, between Newfoundland and the Azores, at a depth of more than 10,000 feet, or two miles, by the help of this sounding apparatus. The specimens were sent for examination to Ehrenberg of Berlin, and to Bailey of West Point, and those able microscopists found that this deep-sea mud was almost entirely composed of the skeletons of living organisms—the greater proportion of these being just like the *Globigerinoe* already known to occur in the chalk.

Thus far, the work had been carried on simply in the interests of science, but Lieut. Brooke's method of sounding acquired a high commercial value, when the enterprise of laying down the telegraph-cable between this country and the United States was undertaken. For it became a matter of immense importance to know, not only the depth of the sea over the whole line along which the cable was to be laid, but the exact nature of the bottom, so as to guard against chances of cutting or fraying the strands of that costly rope. The Admiralty consequently ordered Captain Dayman, an old friend and shipmate of mine, to ascertain the depth over the whole line of the cable, and to bring back specimens of the bottom. In former days, such a command as this might have sounded very much like one of the impossible things which the young Prince in the Fairy Tales is ordered to do before he can obtain the hand of the Princess. However, in the months of June and July, 1857, my friend performed the task assigned to him with great expedition and precision, without, so far as I know, having met with any reward of that kind. The specimens or Atlantic mud which he procured were sent to me to be examined and reported upon.[1]

[Footnote 1: See Appendix to Captain Dayman's *Deep-sea Soundings in the North Atlantic Ocean between Ireland and Newfoundland, made in H.M.S. "Cyclops*." Published by order of the Lords Commissioners of the Admiralty, 1858. They have since formed the subject of an elaborate Memoir by Messrs. Parker and Jones, published in the *Philosophical Transactions* for 1865.]

The result of all these operations is, that we know the contours and the nature of the surface-soil covered by the North Atlantic for a distance of 1,700 miles from east to west, as well as we know that of any part of the dry land. It is a prodigious plain—one of the widest and most even plains in the world. If the sea were drained off, you might drive a waggon all the way from Valentia, on the west coast of Ireland, to Trinity Bay, in Newfoundland. And, except upon one sharp incline about 200 miles from Valentia, I am not quite sure that it would even be necessary to put the skid on, so gentle are the ascents and descents upon that long route. From Valentia the road would lie down-hill for about 200 miles to the point at which the bottom is now covered by 1,700 fathoms of sea-water. Then would come the central plain, more than a thousand miles wide, the inequalities of the surface of which would be hardly perceptible, though the depth of water upon it now varies from 10,000 to 15,000 feet; and there are places in which Mont Blanc might be sunk without showing its peak above water. Beyond this, the ascent on the American side commences, and gradually leads, for about 300 miles, to the Newfoundland shore.

Almost the whole of the bottom of this central plain (which extends for many hundred miles in a north and south direction) is covered by a fine mud, which, when brought to the surface, dries into a greyish white friable substance. You can write with this on a blackboard, if you are so inclined; and, to the eye, it is quite like very soft, grayish chalk. Examined chemically, it proves to be composed almost wholly of carbonate of lime; and if you make a section of it, in the same way as that of the piece of chalk was made, and view it with the microscope, it presents innumerable *Globigerinoe* embedded in a granular matrix. Thus this deep- sea mud is substantially chalk. I say substantially, because there are a good many minor differences; but as these have no bearing on the question immediately before us,—which is the nature of the *Globigerinoe* of the chalk,—it is unnecessary to speak of them.

Globigerinoe of every size, from the smallest to the largest, are associated together in the Atlantic mud, and the chambers of many are filled by a soft animal matter. This soft substance is, in fact, the remains of the creature to which the *Globigerinoe* shell, or rather skeleton, owes its existence—and which is an animal of the simplest imaginable description. It is, in fact, a mere particle of living jelly, without defined parts of any kind—without a mouth, nerves, muscles, or distinct organs, and only manifesting its vitality to ordinary observation by thrusting out and retracting from all parts of its surface, long filamentous processes, which serve for arms and legs. Yet this amorphous particle, devoid of everything which, in the higher animals, we call organs, is capable of feeding, growing, and multiplying; of separating from the ocean the small proportion of carbonate of lime which is dissolved in sea-water; and of building up that substance into a skeleton for itself, according to a pattern which can be imitated by no other known agency.

The notion that animals can live and flourish in the sea, at the vast depths from which apparently living *Globigerinoe*; have been brought up, does not agree very well with our usual conceptions respecting the conditions of animal life; and it is not so absolutely impossible as it might at first sight appear to be, that the *Globigcrinoe* of the Atlantic sea-bottom do not live and die where they are found.

As I have mentioned, the soundings from the great Atlantic plain are almost entirely made up of *Globigerinoe*, with the granules which have been mentioned, and some few other calcareous shells; but a small percentage of the chalky mud—perhaps at most some five per cent. of it— is of a different nature, and consists of shells and skeletons composed of silex, or pure flint. These silicious bodies belong partly to the lowly vegetable organisms which are called *Diatomaceoe*, and partly to the minute, and extremely simple, animals, termed *Radiolaria*. It is quite certain that these creatures do not live at the bottom of the ocean, but at its surface—where they may be obtained in prodigious numbers by the use of a properly constructed net. Hence it follows that these silicious organisms, though they are not heavier than the lightest dust, must have fallen, in some cases, through fifteen thousand feet of water, before they reached their final resting-place on the ocean floor. And considering how large a surface these bodies expose in proportion to their weight, it is probable that they occupy a great length of time in making their burial journey from the surface of the Atlantic to the bottom.

But if the *Radiolaria* and Diatoms are thus rained upon the bottom of the sea, from the superficial layer of its waters in which they pass their lives, it is obviously possible that the *Globigerinoe* may be similarly derived; and if they were so, it would be much more easy to understand how they obtain their supply of food than it is at present. Nevertheless, the positive and negative evidence all points the other way. The skeletons of the full-grown, deep-sea *Globigerinoe* are so remarkably solid and heavy in proportion to their surface as to seem little fitted for floating; and, as a matter of fact, they are not to be found along with the Diatoms and *Radiolaria* in the uppermost stratum of the open ocean. It has been observed, again, that the abundance of *Globigerinoe*, in proportion to other organisms, of like kind, increases with the depth of the sea; and that deep-water *Globigerinoe* are larger than those which live in shallower parts of the sea; and such facts negative the supposition that these organisms have been swept by currents from the shallows into the deeps of the Atlantic. It therefore seems to be hardly doubtful that these wonderful creatures live and die at the depths in which they are found.[2]

[Footnote 2: During the cruise of H.M.S. *Bulldog*, commanded by Sir Leopold M'Clintock, in 1860, living star-fish were brought up, clinging to the lowest part of the sounding-line, from a depth of 1,260 fathoms, midway between Cape Farewell, in Greenland, and the Rockall banks. Dr. Wallich ascertained that the sea-bottom at this point consisted of the ordinary *Globigerina* ooze, and that the stomachs of the star-fishes were full of *Globigerinoe*. This discovery removes all objections to the existence of living *Globigerinoe* at great depths, which are based upon the supposed difficulty of maintaining animal life under such conditions; and it throws the burden of proof upon those who object to the supposition that the *Globigerinoe* live and die where they are found.]

However, the important points for us are, that the living *Globigerinoe* are exclusively marine animals, the skeletons of which abound at the bottom of deep seas; and that there is not a shadow of reason for believing that the habits of the *Globigerinoe* of the chalk differed from those of the existing species. But if this be true, there is no escaping the conclusion that the chalk itself is the dried mud of an ancient deep sea.

In working over the soundings collected by Captain Dayman, I was surprised to find that many of what I have called the "granules" of that mud were not, as one might have been tempted to think at first, the more powder and waste of *Globigerinoe*, but that they had a definite form and size. I termed these bodies "*coccoliths*," and doubted their organic nature. Dr. Wallich verified my observation, and added the interesting discovery that, not unfrequently, bodies similar to these "coccoliths" were aggregated together into spheroids, which lie termed "*coccospheres*." So far as we knew, these bodies, the nature of which is extremely puzzling and problematical, were peculiar to the Atlantic soundings. But, a few years ago, Mr. Sorby, in making a careful examination of the chalk by means of thin sections and otherwise, observed, as Ehrenberg had done before him, that much of its granular basis possesses a definite form. Comparing these formed particles with those in the Atlantic soundings, he found the two to be identical; and thus proved that the chalk, like the surroundings, contains these mysterious coccoliths and coccospheres. Here was a further and most interesting confirmation, from internal evidence, of the essential identity of the chalk with modern deep-sea mud. *Globigerinoe*, coccoliths, and coccospheres are found as the chief constituents of both, and testify to the general similarity of the conditions under which both have been formed.[3]

[Footnote 3: I have recently traced out the development of the "coccoliths" from a diameter of 1/7000th of an inch up to their largest size (which is about 1/1000th), and no longer doubt that they are produced by independent organisms, which, like the *Globigerinoe*, live and die at the bottom of the sea.]

The evidence furnished by the hewing, facing, and superposition of the stones of the Pyramids, that these structures were built by men, has no greater weight than the evidence that the chalk was built by *Globigerinoe*; and the belief that those ancient pyramid-builders were terrestrial and air-breathing creatures like ourselves, is not better based than the conviction that the chalk-makers lived in the sea. But as our belief in the building of the Pyramids by men is not only grounded on the internal evidence afforded by these structures, but gathers strength from multitudinous collateral proofs, and is clinched by the total absence of any reason for a contrary belief; so the evidence drawn from the *Globigerinoe* that the chalk is an ancient sea-bottom, is fortified by innumerable independent lines of evidence; and our belief in the truth of the conclusion to which all positive testimony tends, receives the like negative justification from the fact that no other hypothesis has a shadow of foundation.

It may be worth while briefly to consider a few of these collateral proofs that the chalk was deposited at the bottom of the sea. The great mass of the chalk is composed, as we have seen, of the skeletons of *Globigerinoe*, and other simple organisms, imbedded in granular matter. Here and there, however, this hardened mud of the ancient sea reveals the remains of higher animals which have lived and died, and left their hard parts in the mud, just as the oysters die and leave their shells behind them, in the mud of the present seas.

There are, at the present day, certain groups of animals which are never found in fresh waters, being unable to live anywhere but in the sea. Such are the corals; those corallines which are called *Polyzoa*; those creatures which fabricate the lamp-shells, and are called *Brachiopoda*; the pearly *Nautilus*, and all animals allied to it; and all the forms of sea-urchins and star-fishes. Not only are all these creatures confined to salt water at the present day; but, so far as our records of the past go, the conditions of their existence have been the same: hence, their occurrence in any deposit is as strong evidence as can be obtained, that that deposit was formed in the sea. Now the remains of animals of all the kinds which have been enumerated, occur in the chalk, in greater or less abundance; while not one of those forms of shell-fish which are characteristic of fresh water has yet been observed in it.

When we consider that the remains of more than three thousand distinct species of aquatic animals have been discovered among the fossils of the chalk, that the great majority of them are of such forms as are now met with only in the sea, and that there is no reason to believe that any one of them inhabited fresh water—the collateral evidence that the chalk represents an ancient sea-bottom acquires as great force as the proof derived from the nature of the chalk itself. I think you will now allow that I did not overstate my case when I asserted that we have as strong grounds for believing that all the vast area of dry land, at present occupied by the chalk, was once at the bottom of the sea, as we have for any matter of history whatever; while there is no justification for any other belief.

No less certain it is that the time during which the countries we now call south-east England, France, Germany, Poland, Russia, Egypt, Arabia, Syria, were more or less completely covered by a deep sea, was of considerable duration. We have already seen that the chalk is, in places, more than a thousand feet thick. I think you will agree with me, that it must have taken some time for the skeletons of animalcules of a hundredth of an inch in diameter to heap up such a mass as that. I have said that throughout the thickness of the chalk the remains of other animals are scattered. These remains are often in the most exquisite state of preservation. The valves of the shell-fishes are commonly adherent; the long spines of some of the sea-urchins, which would be detached by the smallest jar, often remain in their places. In a word, it is certain that these animals have lived and died when the place which they now occupy was the surface of as much of the chalk as had then been deposited; and that each has been covered up by the layer of *Globigerina* mud, upon which the creatures imbedded a little higher up have, in like manner, lived and died. But some of these remains prove the existence of reptiles of vast size in the chalk sea. These lived their time, and had their ancestors and descendants, which assuredly implies time, reptiles being of slow growth.

There is more curious evidence, again, that the process of covering up, or, in other words, the deposit of *Globigerina* skeletons, did not go on very fast. It is demonstrable that an animal of the cretaceous sea might die, that its skeleton might lie uncovered upon the sea-bottom long enough to lose all its outward coverings and appendages by putrefaction; and that, after this had happened, another animal might attach itself to the dead and naked skeleton, might grow to maturity, and might itself die before the calcareous mud had buried the whole.

Cases of this kind are admirably described by Sir Charles Lyell. He speaks of the frequency with which geologists find in the chalk a fossilized sea-urchin, to which is attached the lower valve of a *Crania*. This is a kind of shell-fish, with a shell composed of two pieces, of which, as in the oyster, one is fixed and the other free.

"The upper valve is almost invariably wanting, though occasionally found in a perfect state of preservation in the white chalk at some distance. In this case, we see clearly that the sea-urchin first lived from youth to age, then died and lost its spines, which were carried away. Then the young *Crania* adhered to the bared shell, grew and perished in its turn; after which, the upper valve was separated from the lower, before the Echinus became enveloped in chalky mud."[4]

A specimen in the Museum of Practical Geology, in London, still further prolongs the period which must have elapsed between the death of the sea- urchin, and its burial by the *Globigerinoe*. For the outward face of the valve of a *Crania*, which is attached to a sea-urchin, (*Micraster*), is itself overrun by an incrusting coralline, which spreads thence over more or less of the surface of the sea-urchin. It follows that, after the upper valve of the *Crania* fell off, the surface of the attached valve must have remained exposed long enough to allow of the growth of the whole coralline, since corallines do not live embedded in mud.[4]

[Footnote 4: *Elements of Geology*, by Sir Charles Lyell, Bart. F.B.S., p. 23.]

The progress of knowledge may, one day, enable us to deduce from such facts as these the maximum rate at which the chalk can have accumulated, and thus to arrive at the minimum duration of the chalk period. Suppose that the valve of the *Cronia* upon which a coralline has fixed itself in the way just described, is so attached to the sea-urchin that no part of it is more than an inch above the face upon which the sea-urchin rests. Then, as the coralline could not have fixed itself, if the *Crania* had been covered up with chalk mud, and could not have lived had itself been so covered, it follows, that an inch of chalk mud could not have accumulated within the time between the death and decay of the soft parts of the sea-urchin and the growth of the coralline to the full size which it has attained. If the decay of the soft parts of the sea-urchin; the attachment, growth to maturity, and decay of the *Crania*; and the subsequent attachment and growth of the coralline, took a year (which is a low estimate enough), the accumulation of the inch of chalk must have taken more than a year: and the deposit of a thousand feet of chalk must, consequently, have taken more than twelve thousand years.

The foundation of all this calculation is, of course, a knowledge of the length of time the *Crania* and the coralline needed to attain their full size; and, on this head, precise knowledge is at present wanting. But there are circumstances which tend to show, that nothing like an inch of chalk has accumulated during the life of a *Crania*; and, on any probable estimate of the length of that life, the chalk period must have had a much longer duration than that thus roughly assigned to it.

Thus, not only is it certain that the chalk is the mud of an ancient sea- bottom; but it is no less certain, that the chalk sea existed during an extremely long period, though we may not be prepared to give a precise estimate of the length of that period in years. The relative duration is clear, though the absolute duration may not be definable. The attempt to affix any precise date to the period at which the chalk sea began, or ended, its existence, is baffled by difficulties of the same kind. But the relative age of the cretaceous epoch may be determined with as great ease and certainty as the long duration of that epoch.

You will have heard of the interesting discoveries recently made, in various parts of Western Europe, of flint implements, obviously worked into shape by human hands, under circumstances which show conclusively that man is a very ancient denizen of these regions. It has been proved that the whole populations of Europe, whose existence has been revealed to us in this way, consisted of savages, such as the Esquimaux are now; that, in the country which is now France, they hunted the reindeer, and were familiar with the ways of the mammoth and the bison. The physical geography of France was in those days different from what it is now—the river Somme, for instance, having cut its bed a hundred feet deeper between that time and this; and, it is probable, that the climate was more like that of Canada or Siberia, than that of Western Europe.

The existence of these people is forgotten even in the traditions of the oldest historical nations. The name and fame of them had utterly vanished until a few years back; and the amount of physical change which has been effected since their day renders it more than probable that, venerable as are some of the historical nations, the workers of the chipped flints of Hoxne or of Amiens are to them, as they are to us, in point of antiquity. But, if we assign to these hoar relics of long-vanished generations of men the greatest age that can possibly be claimed for them, they are not older than the drift, or boulder clay, which, in comparison with the chalk, is but a very juvenile deposit. You need go no further than your own sea-board for evidence of this fact. At one of the most charming spots on the coast of Norfolk, Cromer, you will see the boulder clay forming a vast mass, which lies upon the chalk, and must consequently have come into existence after it. Huge boulders of chalk are, in fact, included in the clay, and have evidently been brought to the position they now occupy by the same agency as that which has planted blocks of syenite from Norway side by side with them.

The chalk, then, is certainly older than the boulder clay. If you ask how much, I will again take you no further than the same spot upon your own coasts for evidence. I have spoken of the boulder clay and drift as resting upon the chalk. That is not strictly true. Interposed between the chalk and the drift is a comparatively insignificant layer, containing vegetable matter. But that layer tells a wonderful history. It is full of stumps of trees standing as they grew. Fir-trees are there with their cones, and hazel-bushes with their nuts; there stand the stools of oak and yew trees, beeches and alders. Hence this stratum is appropriately called the "forest-bed."

It is obvious that the chalk must have been upheaved and converted into dry land, before the timber trees could grow upon it. As the bolls of some of these trees are from two to three feet in diameter, it is no less clear that the dry land thus formed remained in the same condition for long ages. And not only do the remains of stately oaks and well-grown firs testify to the duration of this condition of things, but additional evidence to the same effect is afforded by the abundant remains of elephants, rhinoceroses, hippopotamuses, and other great wild beasts, which it has yielded to the zealous search of such men as the Rev. Mr. Gunn. When you look at such a collection as he has formed, and bethink you that these elephantine bones did veritably carry their owners about, and these great grinders crunch, in the dark woods of which the forest- bed is now the only trace, it is impossible not to feel that they are as good evidence of the lapse of time as the annual rings of the tree stumps.

Thus there is a writing upon the wall of cliffs at Cromer, and whoso runs may read it. It tells us, with an authority which cannot be impeached, that the ancient sea-bed of the chalk sea was raised up, and remained dry land, until it was covered with forest, stocked with the great game the spoils of which have rejoiced your geologists. How long it remained in that condition cannot be said; but "the whirligig of time brought its revenges" in those days as in these. That dry land, with the bones and teeth of generations of long-lived elephants, hidden away among the gnarled roots and dry leaves of its ancient trees, sank gradually to the bottom of the icy sea, which covered it with huge masses of drift and boulder clay. Sea-beasts, such as the walrus, now restricted to the extreme north, paddled about where birds had twittered among the topmost twigs of the fir-trees. How long this state of things endured we know not, but at length it came to an end. The upheaved glacial mud hardened into the soil of modern Norfolk. Forests grew once more, the wolf and the beaver replaced the reindeer and the elephant; and at length what we call the history of England dawned.

Thus you have, within the limits of your own county, proof that the chalk can justly claim a very much greater antiquity than even the oldest physical traces of mankind. But we may go further and demonstrate, by evidence of the same authority as that which testifies to the existence of the father of men, that the chalk is vastly older than Adam himself. The Book of Genesis informs us that Adam, immediately upon his creation, and before the appearance of Eve, was placed in the Garden of Eden. The problem of the geographical position of Eden has greatly vexed the spirits of the learned in such matters, but there is one point respecting which, so far as I know, no commentator has ever raised a doubt. This is, that of the four rivers which are said to run out of it, Euphrates and Hiddekel are identical with the rivers now known by the names of Euphrates and Tigris. But the whole country in which these mighty rivers take their origin, and through which they run, is composed of rocks which are either of the same age as the chalk, or of later date. So that the chalk must not only have been formed, but, after its formation, the time required for the deposit of these later rocks, and for their upheaval into dry land, must have elapsed, before the smallest brook which feeds the swift stream of "the great river, the river of Babylon," began to flow.

Thus, evidence which cannot be rebutted, and which need not be strengthened, though if time permitted I might indefinitely increase its quantity, compels you to believe that the earth, from the time of the chalk to the present day, has been the theatre of a series of changes as vast in their amount, as they were slow in their progress. The area on which we stand has been first sea and then land, for at least four alternations; and has remained in each of these conditions for a period of great length.

Nor have these wonderful metamorphoses of sea into land, and of land into sea, been confined to one corner of England. During the chalk period, or "cretaceous epoch," not one of the present great physical features of the globe was in existence. Our great mountain ranges, Pyrenees, Alps, Himalayas, Andes, have all been upheaved since the chalk was deposited, and the cretaceous sea flowed over the sites of Sinai and Ararat. All this is certain, because rocks of cretaceous, or still later, date have shared in the elevatory movements which gave rise to these mountain chains; and may be found perched up, in some cases, many thousand feet high upon their flanks. And evidence of equal cogency demonstrates that, though, in Norfolk, the forest-bed rests directly upon the chalk, yet it does so, not because the period at which the forest grew immediately followed that at which the chalk was formed, but because an immense lapse of time, represented elsewhere by thousands of feet of rock, is not indicated at Cromer.

I must ask you to believe that there is no less conclusive proof that a still more prolonged succession of similar changes occurred, before the chalk was deposited. Nor have we any reason to think that the first term in the series of these changes is known. The oldest sea-beds preserved to us are sands, and mud, and pebbles, the wear and tear of rocks which were formed in still older oceans.

But, great as is the magnitude of these physical changes of the world, they have been accompanied by a no less striking series of modifications in its living inhabitants. All the great classes of animals, beasts of the field, fowls of the air, creeping things, and things which dwell in the waters, flourished upon the globe long ages before the chalk was deposited. Very few, however, if any, of these ancient forms of animal life were identical with those which now live. Certainly not one of the higher animals was of the same species as any of those now in existence. The beasts of the field, in the days before the chalk, were not our beasts of the field, nor the fowls of the air such as those which the eye of men has seen flying, unless his antiquity dates infinitely further back than we at present surmise. If we could be carried back into those times, we should be as one suddenly set down in Australia before it was colonized. We should see mammals, birds, reptiles, fishes, insects, snails, and the like, clearly recognizable as such, and yet not one of them would be just the same as those with which we are familiar, and many would be extremely different.

From that time to the present, the population of the world has undergone slow and gradual, but incessant, changes. There has been no grand catastrophe—no destroyer has swept away the forms of life of one period, and replaced them by a totally new creation: but one species has vanished and another has taken its place; creatures of one type of structure have diminished, those of another have increased, as time has passed on. And thus, while the differences between the living creatures of the time before the chalk and those of the present day appear startling, if placed side by side, we are led from one to the other by the most gradual progress, if we follow the course of Nature through the whole series of those relics of her operations which she has left behind. It is by the population of the chalk sea that the ancient and the modern inhabitants of the world are most completely connected. The groups which are dying out flourish, side by side, with the groups which are now the dominant forms of life. Thus the chalk contains remains of those strange flying and swimming reptiles, the pterodactyl, the ichthyosaurus, and the plesiosaurus, which are found in no later deposits, but abounded in preceding ages. The chambered shells called ammonites and belemnites, which are so characteristic of the period preceding the cretaceous, in like manner die with it.

But, amongst these fading remainders of a previous state of things, are some very modern forms of life, looking like Yankee pedlars among a tribe of Red Indians. Crocodiles of modern type appear; bony fishes, many of them very similar to existing species, almost supplant the forms of fish which predominate in more ancient seas; and many kinds of living shell- fish first become known to us in the chalk. The vegetation acquires a modern aspect. A few living animals are not even distinguishable as species, from those which existed at that remote epoch. The *Globigerina* of the present day, for example, is not different specifically from that of the chalk; and the same maybe said of many other *Foraminifera*. I think it probable that critical and unprejudiced examination will show that more than one species of much higher animals have had a similar longevity; but the only example which I can at present give confidently is the snake's-head lampshell (*Terebratulina caput serpentis*), which lives in our English seas and abounded (as *Terebratulina striata* of authors) in the chalk.

The longest line of human ancestry must hide its diminished head before the pedigree of this insignificant shell-fish. We Englishmen are proud to have an ancestor who was present at the Battle of Hastings. The ancestors of

Terebratulina caput serpentis may have been present at a battle of *Ichthyosauria* in that part of the sea which, when the chalk was forming, flowed over the site of Hastings. While all around has changed, this *Terebratulina* has peacefully propagated its species from generation to generation, and stands to this day, as a living testimony to the continuity of the present with the past history of the globe.

Up to this moment I have stated, so far as I know, nothing but well- authenticated facts, and the immediate conclusions which they force upon the mind. But the mind is so constituted that it does not willingly rest in facts and immediate causes, but seeks always after a knowledge of the remoter links in the chain of causation.

Taking the many changes of any given spot of the earth's surface, from sea to land and from land to sea, as an established fact, we cannot refrain from asking ourselves how these changes have occurred. And when we have explained them—as they must be explained—by the alternate slow movements of elevation and depression which have affected the crust of the earth, we go still further back, and ask, Why these movements?

I am not certain that any one can give you a satisfactory answer to that question. Assuredly I cannot. All that can be said, for certain, is, that such movements are part of the ordinary course of nature, inasmuch as they are going on at the present time. Direct proof may be given, that some parts of the land of the northern hemisphere are at this moment insensibly rising and others insensibly sinking; and there is indirect, but perfectly satisfactory, proof, that an enormous area now covered by the Pacific has been deepened thousands of feet, since the present inhabitants of that sea came into existence. Thus there is not a shadow of a reason for believing that the physical changes of the globe, in past times, have been effected by other than natural causes. Is there any more reason for believing that the concomitant modifications in the forms of the living inhabitants of the globe have been brought about in other ways?

Before attempting to answer this question, let us try to form a distinct mental picture of what has happened in some special case. The crocodiles are animals which, as a group, have a very vast antiquity. They abounded ages before the chalk was deposited; they throng the rivers in warm climates, at the present day. There is a difference in the form of the joints of the back-bone, and in some minor particulars, between the crocodiles of the present epoch and those which lived before the chalk; but, in the cretaceous epoch, as I have already mentioned, the crocodiles had assumed the modern type of structure. Notwithstanding this, the crocodiles of the chalk are not identically the same as those which lived in the times called "older tertiary," which succeeded the cretaceous epoch; and the crocodiles of the older tertiaries are not identical with those of the newer tertiaries, nor are these identical with existing forms. I leave open the question whether particular species may have lived on from epoch to epoch. But each epoch has had its peculiar crocodiles; though all, since the chalk, have belonged to the modern type, and differ simply in their proportions, and in such structural particulars as are discernible only to trained eyes.

How is the existence of this long succession of different species of crocodiles to be accounted for? Only two suppositions seem to be open to us—Either each species of crocodile has been specially created, or it has arisen out of some pre-existing form by the operation of natural causes. Choose your hypothesis; I have chosen mine. I can find no warranty for believing in the distinct creation of a score of successive species of crocodiles in the course of countless ages of time. Science gives no countenance to such a wild fancy; nor can even the perverse ingenuity of a commentator pretend to discover this sense, in the simple words in which the writer of Genesis records the proceedings of the fifth and six days of the Creation.

On the other hand, I see no good reason for doubting the necessary alternative, that all these varied species have been evolved from pre- existing crocodilian forms, by the operation of causes as completely a part of the common order of nature as those which have effected the changes of the inorganic world. Few will venture to affirm that the reasoning which applies to crocodiles loses its force among other animals, or among plants. If one series of species has come into existence by the operation of natural causes, it seems folly to deny that all may have arisen in the same way.

A small beginning has led us to a great ending. If I were to put the bit of chalk with which we started into the hot but obscure flame of burning hydrogen, it would presently shine like the sun. It seems to me that this physical metamorphosis is no false image of what has been the result of our subjecting it to a jet of fervent, though nowise brilliant, thought to-night. It has become luminous, and its clear rays, penetrating the abyss of the remote past, have brought within our ken some stages of the evolution of the earth. And in the shifting "without haste, but without rest" of the land and sea, as in the endless variation of the forms assumed by living beings, we have observed nothing but the natural product of the forces originally possessed by the substance of the universe.

II

THE PROBLEMS OF THE DEEP SEA

[1873]

On the 21st of December, 1872, H.M.S. *Challenger*, an eighteen gun corvette, of 2,000 tons burden, sailed from Portsmouth harbour for a three, or perhaps four, years' cruise. No man-of-war ever left that famous port before with so singular an equipment. Two of the eighteen sixty-eight pounders of the *Challenger's* armament remained to enable her to speak with effect to sea-rovers, haply devoid of any respect for science, in the remote seas for which she is bound; but the main-deck was, for the most part, stripped of its war-like gear, and fitted up with physical, chemical, and biological laboratories; Photography had its dark cabin; while apparatus for dredging, trawling, and sounding; for photometers and for thermometers, filled the space formerly occupied by guns and gun-tackle, pistols and cutlasses.

The crew of the *Challenger* match her fittings. Captain Nares, his officers and men, are ready to look after the interests of hydrography, work the ship, and, if need be, fight her as seamen should; while there is a staff of scientific civilians, under the general direction of Dr. Wyville Thomson, F.R.S. (Professor of Natural History in Edinburgh University by rights, but at present detached for duty *in partibus*), whose business it is to turn all the wonderfully packed stores of appliances to account, and to accumulate, before the ship returns to England, such additions to natural knowledge as shall justify the labour and cost involved in the fitting out and maintenance of the expedition.

Under the able and zealous superintendence of the Hydrographer, Admiral Richards, every precaution which experience and forethought could devise has been taken to provide the expedition with the material conditions of success; and it would seem as if nothing short of wreck or pestilence, both most improbable contingencies, could prevent the *Challenger* from doing splendid work, and opening up a new era in the history of scientific voyages.

The dispatch of this expedition is the culmination of a series of such enterprises, gradually increasing in magnitude and importance, which the Admiralty, greatly to its credit, has carried out for some years past; and the history of which is given by Dr. Wyville Thomson in the beautifully illustrated volume entitled "The Depths of the Sea," published since his departure.

"In the spring of the year 1868, my friend Dr. W.B. Carpenter, at that time one of the Vice-Presidents of the Royal Society, was with me in Ireland, where we were working out together the structure and development of the Crinoids. I had long previously had a profound conviction that the land of promise for the naturalist, the only remaining region where there were endless novelties of extraordinary interest ready to the hand which had the means of gathering them, was the bottom of the deep sea. I had even had a glimpse of some of these treasures, for I had seen, the year before, with Prof. Sars, the forms which I have already mentioned dredged by his son at a depth of 300 to 400 fathoms off the Loffoten Islands. I propounded my views to my fellow-labourer, and we discussed the subject many times over our microscopes. I strongly urged Dr. Carpenter to use his influence at head-quarters to induce the Admiralty, probably through the Council of the Royal Society, to give us the use of a vessel properly fitted with dredging gear and all necessary scientific apparatus, that many heavy questions as to the state of things in the depths of the ocean, which were still in a state of uncertainty, might be definitely settled. After full consideration, Dr. Carpenter promised his hearty co- operation, and we agreed that I should write to him on his return to London, indicating generally the results which I anticipated, and sketching out what I conceived to be a promising line of inquiry. The Council of the Royal Society warmly supported the proposal; and I give here in chronological order the short and eminently satisfactory correspondence which led to the Admiralty placing at the disposal of Dr. Carpenter and myself the gunboat *Lightninq*, under the command of Staff- Commander May, R.N., in the summer of 1868, for a trial cruise to the North of Scotland, and afterwards to the much wider surveys in H.M.S. *Porcupine*, Captain Calver, R.N., which were made with the additional association of Mr. Gwyn Jeffreys, in the summers of the years 1869 and 1870."[1]

[Footnote 1: The Depths of the Sea, pp. 49-50.]

Plain men may be puzzled to understand why Dr. Wyville Thomson, not being a cynic, should relegate the "Land of Promise" to the bottom of the deep sea, they may still more wonder what manner of "milk and honey" the *Challenger* expects to find; and their perplexity may well rise to its maximum, when they seek to divine the manner in which that milk and honey are to be got out of so inaccessible a Canaan. I will, therefore, endeavour to give some answer to these questions in an order the reverse of that in which I have stated them.

Apart from hooks, and lines, and ordinary nets, fishermen have, from time immemorial, made use of two kinds of implements for getting at sea- creatures which live beyond tide-marks—these are the "dredge" and the "trawl." The dredge is used by oyster-fishermen. Imagine a large bag, the mouth of which has the shape of an elongated parallelogram, and is fastened to an iron frame of the same shape, the two long sides of this rim being fashioned into scrapers. Chains attach the ends of the frame to a stout rope, so that when the bag is dragged along by the rope the edge of one of the scrapers rests on the ground, and scrapes whatever it touches into the bag. The oyster-dredger takes one of these machines in his boat, and when he has reached the oyster-bed the dredge is tossed overboard; as soon as it has sunk to the bottom the rope is paid out sufficiently to prevent it from pulling the dredge directly upwards, and is then made fast while the boat goes ahead. The dredge is thus dragged along and scrapes oysters and other sea-animals and plants, stones, and mud into the bag. When the dredger judges it to be full he hauls it up, picks out the oysters, throws the rest overboard, and begins again.

Dredging in shallow water, say ten to twenty fathoms, is an easy operation enough; but the deeper the dredger goes, the heavier must be his vessel, and the stouter his tackle, while the operation of hauling up becomes more and more laborious. Dredging in 150 fathoms is very hard work, if it has to be carried on by manual labour; but by the use of the donkey-engine to supply power,[2] and of the contrivances known as "accumulators," to diminish the risk of snapping the dredge rope by the rolling and pitching of the vessel, the dredge has been worked deeper and deeper, until at last, on the 22nd of July, 1869, H.M.S. *Porcupine* being in the Bay of Biscay, Captain Calver, her commander, performed the unprecedented feat of dredging in 2,435 fathoms, or 14,610 feet, a depth nearly equal to the height of Mont Blanc. The dredge "was rapidly hauled on deck at one o'clock in the morning of the 23rd, after an absence of 7-1/4 hours, and a journey of upwards of eight statute miles," with a hundred weight and a half of solid contents.

[Footnote 2: The emotional side of the scientific nature has its singularities. Many persons will call to mind a certain philosopher's tenderness over his watch—"the little creature"—which was so singularly lost and found again. But Dr. Wyville Thomson surpasses the owner of the watch in his loving-kindness towards a donkey-engine. "This little engine was the comfort of our lives. Once or twice it was overstrained, and then we pitied the willing little thing, panting like an overtaxed horse."]

The trawl is a sort of net for catching those fish which habitually live at the bottom of the sea, such as soles, plaice, turbot, and gurnett. The mouth of the net may be thirty or forty feet wide, and one edge of its mouth is fastened to a beam of wood of the same length. The two ends of the beam are supported by curved pieces of iron, which raise the beam and the edge of the net which is fastened to it, for a short distance, while the other edge of the mouth of the net trails upon the ground. The closed end of the net has the form of a great pouch; and, as the beam is dragged along, the fish, roused from the bottom by the sweeping of the net, readily pass into its mouth and accumulate in the pouch at its end. After drifting with the tide for six or seven hours the trawl is hauled up, the marketable fish are picked out, the others thrown away, and the trawl sent overboard for another operation.

More than a thousand sail of well-found trawlers are constantly engaged in sweeping the seas around our coast in this way, and it is to them that we owe a very large proportion of our supply of fish. The difficulty of trawling, like that of dredging, rapidly increases with the depth at which the operation is performed; and, until the other day, it is probable that trawling at so great a depth as 100 fathoms was something unheard of. But the first news from the *Challenger* opens up new possibilities for the trawl.

Dr. Wyville Thomson writes ("Nature," March 20, 1873):—

"For the first two or three hauls in very deep water off the coast of Portugal, the dredge came up filled with the usual 'Atlantic ooze,' tenacious and uniform throughout, and the work of hours, in sifting, gave the very smallest possible result. We were extremely anxious to get some idea of the general character of the Fauna, and particularly of the distribution of the higher groups; and after various suggestions for modification of the dredge, it was proposed to try the ordinary trawl. We had a compact trawl, with a 15-feet beam, on board, and we sent it down off Cape St. Vincent at a depth of 600 fathoms. The experiment looked hazardous, but, to our great satisfaction, the trawl came up all right and contained, with many of the larger invertebrate, several fishes…. After the first attempt we tried the trawl several times at depths of 1090, 1525, and, finally, 2125 fathoms, and always with success."

To the coral-fishers of the Mediterranean, who seek the precious red coral, which grows firmly fixed to rocks at a depth of sixty to eighty fathoms, both the dredge and the trawl would be useless. They, therefore, have recourse to a sort of frame, to which are fastened long bundles of loosely netted hempen cord, and which is lowered by a rope to the depth at which the hempen cords can sweep over the surface of the rocks and break off the coral, which is brought up entangled in the cords. A similar contrivance has arisen out of the necessities of deep-sea exploration.

In the course of the dredging of the *Porcupine*, it was frequently found that, while few objects of interest were brought up within the dredge, many living creatures came up sticking to the outside of the dredge-bag, and even to the first few fathoms of the dredge-rope. The mouth of the dredge doubtless rapidly filled with mud, and thus the things it should have brought up were shut out. To remedy this inconvenience Captain Calver devised an arrangement not unlike that employed by the coral- fishers. He fastened half a dozen swabs, such as are used for drying decks, to the dredge. A swab is something like what a birch-broom would be if its twigs were made of long, coarse, hempen yarns. These dragged along after the dredge over the surface of the mud, and entangled the creatures living there—multitudes of which, twisted up in the strands of the swabs, were brought to the surface with the dredge. A further improvement was made by attaching a long iron bar to the bottom of the dredge bag, and fastening large bunches of teased-out hemp to the end of this bar. These "tangles" bring up immense quantities of such animals as have long arms, or spines, or prominences which readily become caught in the hemp, but they are very destructive to the fragile organisms which they imprison; and, now that the trawl can be successfully worked at the greatest depths, it may be expected to supersede them; at least, wherever the ground is soft enough to permit of trawling.

It is obvious that between the dredge, the trawl, and the tangles, there is little chance for any organism, except such as are able to burrow rapidly, to remain safely at the bottom of any part of the sea which the *Challenger* undertakes to explore. And, for the first time in the history of scientific exploration, we have a fair chance of learning what the population of the depths of the sea is like in the most widely different parts of the world.

And now arises the next question. The means of exploration being fairly adequate, what forms of life may be looked for at these vast depths?

The systematic study of the Distribution of living beings is the most modern branch of Biological Science, and came into existence long after Morphology and Physiology had attained a considerable development. This naturally does not imply that, from the time men began to observe natural phenomena, they were ignorant of the fact that the animals and plants of one part of the world are different from those in other regions; or that those of the hills are different from those of the plains in the same region; or finally that some marine creatures are found only in the shallows, while others inhabit the deeps. Nevertheless, it was only after the discovery of America that the attention of naturalists was powerfully drawn to the wonderful differences between the animal population of the central and southern parts of the new world and that of those parts of the old world which lie under the same parallels of latitude. So far back as 1667 Abraham Mylius, in his treatise "De Animalium origine et migratione, populorum," argues that, since there are innumerable species of animals in America which do not exist elsewhere, they must have been made and placed there by the Deity: Buffon no less forcibly insists upon the difference between the Faunae of the old and new world. But the first attempt to gather facts of this order into a whole, and to coordinate them into a series of generalizations, or laws of Geographical Distribution, is not a century old, and is contained in the "Specimen Zoologiae Geographicae Quadrupedum Domicilia et Migrationes sistens," published, in 1777, by the learned Brunswick Professor, Eberhard Zimmermann, who illustrates his work by what he calls a "Tabula Zoographica," which is the oldest distributional map known to me.

In regard to matters of fact, Zimmermann's chief aim is to show that among terrestrial mammals, some occur all over the world, while others are restricted to particular areas of greater or smaller extent; and that the abundance of species follows temperature, being greatest in warm and least in cold climates. But marine animals, he thinks, obey no such law. The Arctic and Atlantic seas, he says, are as full of fishes and other animals as those of the tropics. It is, therefore, clear that cold does not affect the dwellers in the sea as it does land animals, and that this must be the case follows from the fact that sea water, "propter varias quas continet bituminis spiritusque particulas," freezes with much more difficulty than fresh water. On the other hand, the heat of the Equatorial sun penetrates but a short distance below the surface of the ocean. Moreover, according to Zimmermann, the incessant disturbance of the mass of the sea by winds and tides, so mixes up the warm and the cold that life is evenly diffused and abundant throughout the ocean.

In 1810, Risso, in his work on the Ichthyology of Nice, laid the foundation of what has since been termed "bathymetrical" distribution, or distribution in depth, by showing that regions of the sea bottom of different depths could be distinguished by the fishes which inhabit them. There was the *littoral region* between tide marks with its sand-eels, pipe fishes, and blennies: the *seaweed region*, extending from low- water-mark to a depth of 450 feet, with its wrasses, rays, and flat fish; and the *deep-sea region*, from 450 feet to 1500 feet or more, with its file-fish, sharks, gurnards, cod, and sword-fish.

More than twenty years later, M.M. Audouin and Milne Edwards carried out the principle of distinguishing the Faunae of different zones of depth much more minutely, in their "Recherches pour servir à l'Histoire Naturelle du Littoral de la France," published in 1832.

They divide the area included between highwater-mark and lowwater-mark of spring tides (which is very extensive, on account of the great rise and fall of the tide on the Normandy coast about St. Malo, where their observations were made) into four zones, each characterized by its peculiar invertebrate inhabitants. Beyond the fourth region they distinguish a fifth, which is never uncovered, and is inhabited by oysters, scallops, and large starfishes and other animals. Beyond this they seem to think that animal life is absent.[3]

[Footnote 3: "Enfin plus has encore, c'est-à-dire alors loin des côtes, le fond des eaux ne paraît plus être habité, du moms dans nos mers, par aucun de ces animaux" (1. c. tom. i. p. 237). The "ces animaux" leaves the meaning of the authors doubtful.]

Audouin and Milne Edwards were the first to see the importance of the bearing of a knowledge of the manner in which marine animals are distributed in depth, on geology. They suggest that, by this means, it will be possible to judge whether a fossiliferous stratum was formed upon the shore of an ancient sea, and even to determine whether it was deposited in shallower or deeper water on that shore; the association of shells of animals which live in different zones of depth will prove that the shells have been transported into the position in which they are found; while, on the other hand, the absence of shells in a deposit will not justify the conclusion that the waters in which it was formed were devoid of animal inhabitants, inasmuch as they might have been only too deep for habitation.

The new line of investigation thus opened by the French naturalists was followed up by the Norwegian, Sars, in 1835, by Edward Forbes, in our own country, in 1840,[4] and by Oersted, in Denmark, a few years later. The genius of Forbes, combined with his extensive knowledge of botany, invertebrate zoology, and geology, enabled him to do more than any of his compeers, in bringing the importance of distribution in depth into notice; and his researches in the Aegean Sea, and still more his remarkable paper "On the Geological Relations of the existing Fauna and Flora of the British Isles," published in 1846, in the first volume of the "Memoirs of the Geological Survey of Great Britain," attracted universal attention.

[Footnote 4: In the paper in the *Memoirs of the Survey* cited further on, Forbes writes:—

"In an essay 'On the Association of Mollusca on the British Coasts, considered with reference to Pleistocene Geology,' printed in [the *Edinburgh Academic Annual* for] 1840, I described the mollusca, as distributed on our shores and seas, in four great zones or regions, usually denominated 'The Littoral zone,' 'The region of Laminariae,' 'The region of Coral-lines,' and 'The region of Corals.' An extensive series of researches, chiefly conducted by the members of the committee appointed by the British Association to investigate the marine geology of Britain by means of the dredge, have not invalidated this classification, and the researches of Professor Lovén, in the Norwegian and Lapland seas, have borne out their correctness The first two of the regions above mentioned had been previously noticed by Lamoureux, in his account of the distribution (vertically) of sea-weeds, by Audouin and Milne Edwards in their *Observations on the Natural History of the coast of France*, and by Sars in the preface to his *Beskrivelser og Jagttayelser*."]

On the coasts of the British Islands, Forbes distinguishes four zones or regions, the Littoral (between tide marks), the Laminarian (between lowwater-mark and 15 fathoms), the Coralline (from 15 to 50 fathoms), and the Deep sea or Coral region (from 50 fathoms to beyond 100 fathoms). But, in the deeper waters of the Aegean Sea, between the shore and a depth of 300 fathoms, Forbes was able to make out no fewer than eight zones of life, in the course of which the number and variety of forms gradually diminished until, beyond 300 fathoms, life disappeared altogether. Hence it appeared as if descent in the sea had much the same effect on life, as ascent on land. Recent investigations appear to show that Forbes was right enough in his classification of the facts of distribution in depth as they are to be observed in the Aegean; and though, at the time he wrote, one or two observations were extant which might have warned him not to generalize too extensively from his Aegean experience, his own dredging work was so much more extensive and systematic than that of any other naturalist, that it is not wonderful he should have felt justified in building upon it. Nevertheless, so far as the limit of the range of life in depth goes, Forbes' conclusion has been completely negatived, and the greatest depths yet attained show not even an approach to a "zero of life":—

"During the several cruises of H.M. ships *Lightning* and *Porcupine* in the years 1868, 1869, and 1870," says Dr. Wyville Thomson, "fifty-seven hauls of the dredge were taken in the Atlantic at depths beyond 500 fathoms, and sixteen at depths beyond 1,000 fathoms, and, in all cases, life was abundant. In 1869, we took two casts in depths greater than 2,000 fathoms. In both of these life was abundant; and with the deepest cast, 2,435 fathoms, off the month of the Bay of Biscay, we took living, well-marked and characteristic examples of all the five invertebrate sub- kingdoms. And thus the question of the existence of abundant animal life at the bottom of the sea has been finally settled and for all depths, for there is no reason to suppose that the depth anywhere exceeds between three and four thousand fathoms; and if there be nothing in the conditions of a depth of 2,500 fathoms to prevent the full development of a varied Fauna, it is impossible to suppose that even an additional thousand fathoms would make any great difference."[5]

[Footnote 5: *The Depths of the Sea*, p. 30. Results of a similar kind, obtained by previous observers, are stated at length in the sixth chapter, pp. 267-280. The dredgings carried out by Count Pourtales, under the authority of Professor Peirce, the Superintendent of the United States Coast Survey, in the years 1867, 1868, and 1869, are particularly noteworthy, and it is probably not too much to say, in the words of Professor Agassiz, "that we owe to the coast survey the first broad and comprehensive basis for an exploration of the sea bottom on a large scale, opening a new era in zoological and geological research."]

As Dr. Wyville Thomson's recent letter, cited above, shows, the use of the trawl, at great depths, has brought to light a still greater diversity of life. Fishes came up from a depth of 600 to more than 1,000 fathoms, all in a peculiar condition from the expansion of the air contained in their bodies. On their relief from the extreme pressure, their eyes, especially, had a singular appearance, protruding like great globes from their heads. Bivalve and univalve mollusca seem to be rare at the greatest depths; but starfishes, sea urchins and other echinoderms, zoophytes, sponges, and protozoa abound.

It is obvious that the *Challenger* has the privilege of opening a new chapter in the history of the living world. She cannot send down her dredges and her trawls into these virgin depths of the great ocean without bringing up a discovery. Even though the thing itself may be neither "rich nor rare," the fact that it came from that depth, in that particular latitude and longitude, will be a new fact in distribution, and, as such, have a certain importance.

But it may be confidently assumed that the things brought up will very frequently be zoological novelties; or, better still, zoological antiquities, which, in the tranquil and little-changed depths of the ocean, have escaped the causes of destruction at work in the shallows, and represent the predominant population of a past age.

It has been seen that Audouin and Milne Edwards foresaw the general influence of the study of distribution in depth upon the interpretation of geological phenomena. Forbes connected the two orders of inquiry still more closely; and in the thoughtful essay "On the connection between the distribution of the existing Fauna and Flora of the British Isles, and the geological changes which have affected their area, especially during the epoch of the Northern drift," to which reference has already been made, he put forth a most pregnant suggestion.

In certain parts of the sea bottom in the immediate vicinity of the British Islands, as in the Clyde district, among the Hebrides, in the Moray Firth, and in the German Ocean, there are depressed areas, forming a kind of submarine valleys, the centres of which are from 80 to 100 fathoms, or more, deep. These depressions are inhabited by assemblages of marine animals, which differ from those found over the adjacent and shallower region, and resemble those which are met with much farther north, on the Norwegian coast. Forbes called these Scandinavian detachments "Northern outliers."

How did these isolated patches of a northern population get into these deep places? To explain the mystery, Forbes called to mind the fact that, in the epoch which immediately preceded the present, the climate was much colder (whence the name of "glacial epoch" applied to it); and that the shells which are found fossil, or sub-fossil, in deposits of that age are precisely such as are now to be met with only in the Scandinavian, or still more Arctic, regions. Undoubtedly, during the glacial epoch, the general population of our seas had, universally, the northern aspect which is now presented only by the "northern outliers"; just as the vegetation of the land, down to the sea-level, had the northern character which is, at present, exhibited only by the plants which live on the tops of our mountains. But, as the glacial epoch passed away, and the present climatal conditions were developed, the northern plants were able to maintain themselves only on the bleak heights, on which southern forms could not compete with them. And, in like manner, Forbes suggested that, after the glacial epoch, the northern animals then inhabiting the sea became restricted to the deeps in which they could hold their own against invaders from the south, better fitted than they to flourish in the warmer waters of the shallows. Thus depth in the sea corresponded in its effect upon distribution to height on the land.

The same idea is applied to the explanation of a similar anomaly in the
Fauna of the Aegean:—

"In the deepest of the regions of depth of the Aegean, the representation of a Northern Fauna is maintained, partly by identical and partly by representative forms…. The presence of the latter is essentially due to the law (of representation of parallels of latitude by zones of depth), whilst that of the former species depended on their transmission from their parent seas during a former epoch, and subsequent isolation. That epoch was doubtless the newer Pliocene or Glacial Era, when the *Mya truncata* and other northern forms now extinct in the Mediterranean, and found fossil in the Sicilian tertiaries, ranged into that sea. The changes which there destroyed the *shallow water* glacial forms, did not affect those living in the depths, and which still survive."[6]

[Footnote 6: *Memoirs of the Geological Survey of Great Britain*, Vol. i. p. 390.]

The conception that the inhabitants of local depressions of the sea bottom might be a remnant of the ancient population of the area, which had held their own in these deep fastnesses against an invading Fauna, as Britons and Gaels have held out in Wales and in Scotland against encroaching Teutons, thus broached by Forbes, received a wider application than Forbes had dreamed of when the sounding machine first brought up specimens of the mud of the deep sea. As I have pointed out elsewhere,[7] it at once became obvious that the calcareous sticky mud of the Atlantic was made up, in the main, of shells of *Globigerina* and other *Foraminifera*, identical with those of which the true chalk is composed, and the identity extended even to the presence of those singular bodies, the Coccoliths and Coccospheres, the true nature of which is not yet made out. Here then were organisms, as old as the cretaceous epoch, still alive, and doing their work of rock-making at the bottom of existing seas. What if *Globigerina* and the Coccoliths should not be the only survivors of a world passed away, which are hidden beneath three miles of salt water? The letter which Dr. Wyville Thomson wrote to Dr. Carpenter in May, 1868, out of which all these expeditions have grown, shows that this query had become a practical problem in Dr. Thomson's mind at that time; and the desirableness of solving the problem is put in the foreground of his reasons for urging the Government to undertake the work of exploration:—

[Footnote 7: See above, "On a Piece of Chalk," p. 13.]

"Two years ago, M. Sars, Swedish Government Inspector of Fisheries, had an opportunity, in his official capacity, of dredging off the Loffoten Islands at a depth of 300 fathoms. I visited Norway shortly after his return, and had an opportunity of studying with his father, Professor Sars, some of his results. Animal forms were *abundant*; many of them were new to science; and among them was one of surpassing interest, the small crinoid, of which you have a specimen, and which we at once recognised as a degraded type of the *Apiocrinidoe*, an order hitherto regarded as extinct, which attained its maximum in the Pear Encrinites of the Jurassic period, and whose latest representative hitherto known was the *Bourguettocrinus* of the chalk. Some years previously, Mr. Absjornsen, dredging in 200 fathoms in the Hardangerfjord, procured several examples of a Starfish (*Brisinga*), which seems to find its nearest ally in the fossil genus *Protaster*. These observations place it beyond a doubt that animal life is abundant in the ocean at depths varying from 200 to 300 fathoms, that the forms at these great depths differ greatly from those met with in ordinary dredgings, and that, at all events in some cases, these animals are closely allied to, and would seem to be directly descended from, the Fauna of the early tertiaries.

"I think the latter result might almost have been anticipated; and, probably, further investigation will largely add to this class of data, and will give us an opportunity of testing our determinations of the zoological position of some fossil types by an examination of the soft parts of their recent representatives. The main cause of the destruction, the migration, and the extreme modification of animal types, appear to be change of climate, chiefly depending upon oscillations of the earth's crust. These oscillations do not appear to have ranged, in the Northern portion of the Northern Hemisphere, much beyond 1,000 feet since the commencement of the Tertiary Epoch. The temperature of deep waters seems to be constant for all latitudes at 39°; so that an immense area of the North Atlantic must have had its conditions unaffected by tertiary or post-tertiary oscillations."[8]

[Footnote 8: The Depths of the Sea, pp. 51-52.]

As we shall see, the assumption that the temperature of the deep sea is everywhere 39° F. (4° Cent.) is an error, which Dr. Wyville Thomson adopted from eminent physical writers; but the general justice of the reasoning is not affected by this circumstance, and Dr. Thomson's expectation has been, to some extent, already verified.

Thus besides *Globigerina*, there are eighteen species of deep-sea *Foraminifera* identical with species found in the chalk. Imbedded in the chalky mud of the deep sea, in many localities, are innumerable cup- shaped sponges, provided with six-rayed silicious spicula, so disposed that the wall of the cup is formed of a lacework of flinty thread. Not less abundant, in some parts of the chalk formation, are the fossils known as *Ventriculites*, well described by Dr. Thomson as "elegant vases or cups, with branching root-like bases, or groups of regularly or irregularly spreading tubes delicately fretted on the surface with an impressed network like the finest lace"; and he adds, "When we compare such recent forms as *Aphrocallistes, Iphiteon, Holtenia*, and *Askonema*, with certain series of the chalk *Ventriculites*, there cannot be the slightest doubt that they belong to the same family—in some cases to very nearly allied genera."[9]

[Footnote 9: *The Depths of the Sea*, p. 484.]

Professor Duncan finds "several corals from the coast of Portugal more nearly allied to chalk forms than to any others."

The Stalked Crinoids or Feather Stars, so abundant in ancient times, are now exclusively confined to the deep sea, and the late explorations have yielded forms of old affinity, the existence of which has hitherto been unsuspected. The general character of the group of star fishes imbedded in the white chalk is almost the same as in the modern Fauna of the deep Atlantic. The sea urchins of the deep sea, while none of them are specifically identical with any chalk form, belong to the same general groups, and some closely approach extinct cretaceous genera.

Taking these facts in conjunction with the positive evidence of the existence, during the Cretaceous epoch, of a deep ocean where now lies the dry land of central and southern Europe, northern Africa, and western and southern Asia; and of the gradual diminution of this ocean during the older tertiary epoch, until it is represented at the present day by such teacupfuls as the Caspian, the Black Sea, and the Mediterranean; the supposition of Dr. Thomson and Dr. Carpenter that what is now the deep Atlantic, was the deep Atlantic (though merged in a vast easterly extension) in the Cretaceous epoch, and that the *Globigerina* mud has been accumulating there from that time to this, seems to me to have a great degree of probability. And I agree with Dr. Wyville Thomson against Sir Charles Lyell (it takes two of us to have any chance against his authority) in demurring to the assertion that "to talk of chalk having been uninterruptedly formed in the Atlantic is as inadmissible in a geographical as in a geological sense."

If the word "chalk" is to be used as a stratigraphical term and restricted to *Globigerina* mud deposited during the Cretaceous epoch, of course it is improper to call the precisely similar mud of more recent date, chalk. If, on the other hand, it is to be used as a mineralogical term, I do not see how the modern and the ancient chalks are to be separated—and, looking at the matter geographically, I see no reason to doubt that a boring rod driven from the surface of the mud which forms the floor of the mid-Atlantic would pass through one continuous mass of *Globigerina* mud, first of modern, then of tertiary, and then of mesozoic date; the "chalks" of different depths and ages being distinguished merely by the different forms of other organisms associated with the *Globigerinoe*.

On the other hand, I think it must be admitted that a belief in the continuity of the modern with the ancient chalk has nothing to do with the proposition that we can, in any sense whatever, be said to be still living in the Cretaceous epoch. When the *Challenger's* trawl brings up an *Ichthyosaurus*, along with a few living specimens of *Belemnites* and *Turrilites*, it may be admitted that she has come upon a cretaceous "outlier." A geological period is characterized not only by the presence of those creatures which lived in it, but by the absence of those which have only come into existence later; and, however large a proportion of true cretaceous forms may be discovered in the deep sea, the modern types associated with them must be abolished before the Fauna, as a whole, could, with any propriety, be termed Cretaceous.

I have now indicated some of the chief lines of Biological inquiry, in which the *Challenger* has special opportunities for doing good service, and in following which she will be carrying out the work already commenced by the *Lightning* and *Porcupine* in their cruises of 1868 and subsequent years.

But biology, in the long run, rests upon physics, and the first condition for arriving at a sound theory of distribution in the deep sea, is the precise ascertainment of the conditions of life; or, in other words, a full knowledge of all those phenomena which are embraced under the head of the Physical Geography of the Ocean.

Excellent work has already been done in this direction, chiefly under the superintendence of Dr. Carpenter, by the *Lightning* and the *Porcupine*,[10] and some data of fundamental importance to the physical geography of the sea have been fixed beyond a doubt.

[Footnote 10: *Proceedings of the Royal Society*, 1870 and 1872]

Thus, though it is true that sea-water steadily contracts as it cools down to its freezing point, instead of expanding before it reaches its freezing point as fresh water does, the truth has been steadily ignored by even the highest authorities in physical geography, and the erroneous conclusions deduced from their erroneous premises have been widely accepted as if they were ascertained facts. Of course, if sea-water, like fresh water, were heaviest at a temperature of 39° F. and got lighter as it approached 32° F., the water of the bottom of the deep sea could not be colder than 39°. But one of the first results of the careful ascertainment of the temperature at different depths, by means of thermometers specially contrived for the avoidance of the errors produced by pressure, was the proof that, below 1000 fathoms in the Atlantic, down to the greatest depths yet sounded, the water has a temperature always lower than 38° Fahr., whatever be the temperature of the water at the surface. And that this low temperature of the deepest water is probably the universal rule for the depths of the open ocean is shown, among others, by Captain Chimmo's recent observations in the Indian ocean, between Ceylon and Sumatra, where, the surface water ranging from 85°-81° Fahr., the temperature at the bottom, at a depth of 2270 to 2656 fathoms, was only from 34° to 32° Fahr.

As the mean temperature of the superficial layer of the crust of the earth may be taken at about 50° Fahr., it follows that the bottom layer of the deep sea in temperate and hot latitudes, is, on the average, much colder than either of the bodies with which it is in contact; for the temperature of the earth is constant, while that of the air rarely falls so low as that of the bottom water in the latitudes in question; and even when it does, has time to affect only a comparatively thin stratum of the surface water before the return of warm weather.

How does this apparently anomalous state of things come about? If we suppose the globe to be covered with a universal ocean, it can hardly be doubted that the cold of the regions towards the poles must tend to cause the superficial water of those regions to contract and become specifically heavier. Under these circumstances, it would have no alternative but to descend and spread over the sea bottom, while its place would be taken by warmer water drawn from the adjacent regions. Thus, deep, cold, polar-equatorial currents, and superficial, warmer, equatorial-polar currents, would be set up; and as the former would have a less velocity of rotation from west to east than the regions towards which they travel, they would not be due southerly or northerly currents, but south-westerly in the northern hemisphere, and north-westerly in the southern; while, by a parity of reasoning, the equatorial-polar warm currents would be north-easterly in the northern hemisphere, and south-easterly in the southern. Hence, as a north-easterly current has the same direction as a south-westerly wind, the direction of the northern equatorial-polar current in the extra-tropical part of its course would pretty nearly coincide with that of the anti-trade winds. The freezing of the surface of the polar sea would not interfere with the movement thus set up. For, however bad a conductor of heat ice may be, the unfrozen sea-water immediately in contact with the undersurface of the ice must needs be colder than that further off; and hence will constantly tend to descend through the subjacent warmer water.

In this way, it would seem inevitable that the surface waters of the northern and southern frigid zones must, sooner or later, find their way to the bottom of the rest of the ocean; and there accumulate to a thickness dependent on the rate at which they absorb heat from the crust of the earth below, and from the surface water above.

If this hypothesis be correct, it follows that, if any part of the ocean in warm latitudes is shut off from the influence of the cold polar underflow, the temperature of its deeps should be less cold than the temperature of corresponding depths in the open sea. Now, in the Mediterranean, Nature offers a remarkable experimental proof of just the kind needed. It is a landlocked sea which runs nearly east and west, between the twenty-ninth and forty-fifth parallels of north latitude. Roughly speaking, the average temperature of the air over it is 75° Fahr. in July and 48° in January.

This great expanse of water is divided by the peninsula of Italy (including Sicily), continuous with which is a submarine elevation carrying less than 1,200 feet of water, which extends from Sicily to Cape Bon in Africa, into two great pools—an eastern and a western. The eastern pool rapidly deepens to more than 12,000 feet, and sends off to the north its comparatively shallow branches, the Adriatic and the Aegean Seas. The western pool is less deep, though it reaches some 10,000 feet. And, just as the western end of the eastern pool communicates by a shallow passage, not a sixth of its greatest depth, with the western pool, so the western pool is separated from the Atlantic by a ridge which runs between Capes Trafalgar and Spartel, on which there is hardly 1,000 feet of water. All the water of the Mediterranean which lies deeper than about 150 fathoms, therefore, is shut off from that of the Atlantic, and there is no communication between the cold layer of the Atlantic (below 1,000 fathoms) and the Mediterranean. Under these circumstances, what is the temperature of the Mediterranean? Everywhere below 600 feet it is about 55° Fahr.; and consequently, at its greatest depths, it is some 20° warmer than the corresponding depths of the Atlantic.

It seems extremely difficult to account for this difference in any other way, than by adopting the views so strongly and ably advocated by Dr. Carpenter, that, in the existing distribution of land and water, such a circulation of the water of the ocean does actually occur, as theoretically must occur, in the universal ocean, with which we started.

It is quite another question, however, whether this theoretic circulation, true cause as it may be, is competent to give rise to such movements of sea-water, in mass, as those currents, which have commonly been regarded as northern extensions of the Gulf-stream. I shall not venture to touch upon this complicated problem; but I may take occasion to remark that the cause of a much simpler phenomenon—the stream of Atlantic water which sets through the Straits of Gibraltar, eastward, at the rate of two or three miles an hour or more, does not seem to be so clearly made out as is desirable.

The facts appear to be that the water of the Mediterranean is very slightly denser than that of the Atlantic (1.0278 to 1.0265), and that the deep water of the Mediterranean is slightly denser than that of the surface; while the deep water of the Atlantic is, if anything, lighter than that of the surface. Moreover, while a rapid superficial current is setting in (always, save in exceptionally violent easterly winds) through the Straits of Gibraltar, from the Atlantic to the Mediterranean, a deep undercurrent (together with variable side currents) is setting out through the Straits, from the Mediterranean to the Atlantic.

Dr. Carpenter adopts, without hesitation, the view that the cause of this indraught of Atlantic water is to be sought in the much more rapid evaporation which takes place from the surface of the Mediterranean than from that of the Atlantic; and thus, by lowering the level of the former, gives rise to an indraught from the latter.

But is there any sound foundation for the three assumptions involved here? Firstly, that the evaporation from the Mediterranean, as a whole, is much greater than that from the Atlantic under corresponding parallels; secondly, that the rainfall over the Mediterranean makes up for evaporation less than it does over the Atlantic; and thirdly, supposing these two questions answered affirmatively: Are not these sources of loss in the Mediterranean fully covered by the prodigious quantity of fresh water which is poured into it by great rivers and submarine springs? Consider that the water of the Ebro, the Rhine, the Po, the Danube, the Don, the Dnieper, and the Nile, all flow directly or indirectly into the Mediterranean; that the volume of fresh water which they pour into it is so enormous that fresh water may sometimes be baled up from the surface of the sea off the Delta of the Nile, while the land is not yet in sight; that the water of the Black Sea is half fresh, and that a current of three or four miles an hour constantly streams from it Mediterraneanwards through the Bosphorus;—consider, in addition, that no fewer than ten submarine springs of fresh water are known to burst up in the Mediterranean, some of them so large that Admiral Smyth calls them "subterranean rivers of amazing volume and force"; and it would seem, on the face of the matter, that the sun must have enough to do to keep the level of the Mediterranean down; and that, possibly, we may have to seek for the cause of the small superiority in saline contents of the Mediterranean water in some condition other than solar evaporation.

Again, if the Gibraltar indraught is the effect of evaporation, why does it go on in winter as well as in summer?

All these are questions more easily asked than answered; but they must be answered before we can accept the Gibraltar stream as an example of a current produced by indraught with any comfort.

The Mediterranean is not included in the *Challenger's* route, but she will visit one of the most promising and little explored of hydrographical regions—the North Pacific, between Polynesia and the Asiatic and American shores; and doubtless the store of observations upon the currents of this region, which she will accumulate, when compared with what we know of the North Atlantic, will throw a powerful light upon the present obscurity of the Gulf-stream problem.

III

ON SOME OF THE RESULTS OF THE EXPEDITION OF H.M.S. *CHALLLENGER*

[1875]

In May, 1873, I drew attention[1] to the important problems connected with the physics and natural history of the sea, to the solution of which there was every reason to hope the cruise of H.M.S. *Challenger* would furnish important contributions. The expectation then expressed has not been disappointed. Reports to the Admiralty, papers communicated to the Royal Society, and large collections which have already been sent home, have shown that the *Challenger's* staff have made admirable use of their great opportunities; and that, on the return of the expedition in 1874, their performance will be fully up to the level of their promise. Indeed, I am disposed to go so far as to say, that if nothing more came of the *Challengers* expedition than has hitherto been yielded by her exploration of the nature of the sea bottom at great depths, a full scientific equivalent of the trouble and expense of her equipment would have been obtained.

[Footnote 1: See the preceding Essay.]

In order to justify this assertion, and yet, at the same time, not to claim more for Professor Wyville Thomson and his colleagues than is their due, I must give a brief history of the observations which have preceded their exploration of this recondite field of research, and endeavour to make clear what was the state of knowledge in December, 1872, and what new facts have been added by the scientific staff of the *Challenger*. So far as I have been able to discover, the first successful attempt to bring up from great depths more of the sea bottom than would adhere to a sounding-lead, was made by Sir John Ross, in the voyage to the Arctic regions which he undertook in 1818. In the Appendix to the narrative of that voyage, there will be found an account of a very ingenious apparatus called "clams"—a sort of double scoop—of his own contrivance, which Sir John Ross had made by the ship's armourer; and by which, being in Baffin's Bay, in 72° 30' N. and 77° 15' W., he succeeded in bringing up from 1,050 fathoms (or 6,300 feet), "several pounds" of a "fine green mud," which formed the bottom of the sea in this region. Captain (now Sir Edward) Sabine, who accompanied Sir John Ross on this cruise, says of this mud that it was "soft and greenish, and that the lead sunk several feet into it." A similar "fine green mud" was found to compose the sea bottom in Davis Straits by Goodsir in 1845. Nothing is certainly known of the exact nature of the mud thus obtained, but we shall see that the mud of the bottom of the Antarctic seas is described in curiously similar terms by Dr. Hooker, and there is no doubt as to the composition of this deposit.

In 1850, Captain Penny collected in Assistance Bay, in Kingston Bay, and in Melville Bay, which lie between 73° 45' and 74° 40' N., specimens of the residuum left by melted surface ice, and of the sea bottom in these localities. Dr. Dickie, of Aberdeen, sent these materials to Ehrenberg, who made out[2] that the residuum of the melted ice consisted for the most part of the silicious cases of diatomaceous plants, and of the silicious spicula of sponges; while, mixed with these, were a certain number of the equally silicious skeletons of those low animal organisms, which were termed *Polycistineoe* by Ehrenberg, but are now known as *Radiolaria*.

[Footnote 2: *Ueber neue Anschauungen des kleinsten nördlichen Polarlebens*.—Monatsberichte d. K. Akad. Berlin, 1853.]

In 1856, a very remarkable addition to our knowledge of the nature of the sea bottom in high northern latitudes was made by Professor Bailey of West Point. Lieutenant Brooke, of the United States Navy, who was employed in surveying the Sea of Kamschatka, had succeeded in obtaining specimens of the sea bottom from greater depths than any hitherto reached, namely from 2,700 fathoms (16,200 feet) in 56° 46' N., and 168° 18' E.; and from 1,700 fathoms (10,200 feet) in 60° 15' N. and 170° 53' E. On examining these microscopically, Professor Bailey found, as Ehrenberg had done in the case of mud obtained on the opposite side of the Arctic region, that the fine mud was made up of shells of *Diatomacoe*, of spicula of sponges, and of *Radiolaria*, with a small admixture of mineral matters, but without a trace of any calcareous organisms.

Still more complete information has been obtained concerning the nature of the sea bottom in the cold zone around the south pole. Between the years 1839 and 1843, Sir James Clark Ross executed his famous Antarctic expedition, in the course of which he penetrated, at two widely distant points of the Antarctic zone, into the high latitudes of the shores of Victoria Land and of Graham's Land, and reached the parallel of 80° S. Sir James Ross was himself a naturalist of no mean acquirements, and Dr. Hooker,[3] the present President of the Royal Society, accompanied him as naturalist to the expedition, so that the observations upon the fauna and flora of the Antarctic regions made during this cruise were sure to have a peculiar value and importance, even had not the attention of the voyagers been particularly directed to the importance of noting the occurrence of the minutest forms of animal and vegetable life in the ocean.

[Footnote 3: Now Sir Joseph Hooker. 1894.]

Among the scientific instructions for the voyage drawn up by a committee of the Royal Society, however, there is a remarkable letter from Von Humboldt to Lord Minto, then First Lord of the Admiralty, in which, among other things, he dwells upon the significance of the researches into the microscopic composition of rocks, and the discovery of the great share which microscopic organisms take in the formation of the crust of the earth at the present day, made by Ehrenberg in the years 1836-39. Ehrenberg, in fact, had shown that the extensive beds of "rotten-stone" or "Tripoli" which occur in various parts of the world, and notably at Bilin in Bohemia, consisted of accumulations of the silicious cases and skeletons of *Diatomaceoe*, sponges, and *Radiolaria*; he had proved that similar deposits were being formed by *Diatomaceoe*, in the pools of the Thiergarten in Berlin and elsewhere, and had pointed out that, if it were commercially worth while, rotten-stone might be manufactured by a process of diatom-culture. Observations conducted at Cuxhaven in 1839, had revealed the existence, at the surface of the waters of the Baltic, of living Diatoms and *Radiolaria* of the same species as those which, in a fossil state, constitute extensive rocks of tertiary age at Caltanisetta, Zante, and Oran, on the shores of the Mediterranean.

Moreover, in the fresh-water rotten-stone beds of Bilin, Ehrenberg had traced out the metamorphosis, effected apparently by the action of percolating water, of the primitively loose and friable deposit of organized particles, in which the silex exists in the hydrated or soluble condition. The silex, in fact, undergoes solution and slow redeposition, until, in ultimate result, the excessively fine-grained sand, each particle of which is a skeleton, becomes converted into a dense opaline stone, with only here and there an indication of an organism.

From the consideration of these facts, Ehrenberg, as early as the year 1839, had arrived at the conclusion that rocks, altogether similar to those which constitute a large part of the crust of the earth, must be forming, at the present day, at the bottom of the sea; and he threw out the suggestion that even where no trace of organic structure is to be found in the older rocks, it may have been lost by metamorphosis.[4]

[Footnote 4: *Ueber die noch jetzt zahlreich lebende Thierarten der Kreidebildung und den Organismus der Polythalamien. Abhandlungen der Kön. Akad. der Wissenchaften.* 1839. *Berlin*. 1841. I am afraid that this remarkable paper has been somewhat overlooked in the recent discussions of the relation of ancient rocks to modern deposits.]

The results of the Antarctic exploration, as stated by Dr. Hooker in the "Botany of the Antarctic Voyage," and in a paper which he read before the British Association in 1847, are of the greatest importance in connection with these views, and they are so clearly stated in the former work, which is somewhat inaccessible, that I make no apology for quoting them at length—

"The waters and the ice of the South Polar Ocean were alike found to abound with microscopic vegetables belonging to the order *Diatomaceoe*. Though much too small to be discernible by the naked eye, they occurred in such countless myriads as to stain the berg and the pack ice wherever they were washed by the swell of the sea; and, when enclosed in the congealing surface of the water, they imparted to the brash and pancake ice a pale ochreous colour. In the open ocean, northward of the frozen zone, this order, though no doubt almost universally present, generally eludes the search of the naturalist; except when its species are congregated amongst that mucous scum which is sometimes seen floating on the waves, and of whose real nature we are ignorant; or when the coloured contents of the marine animals who feed on these Algae are examined. To the south, however, of the belt of ice which encircles the globe, between the parallels of 50° and 70° S., and in the waters comprised between that belt and the highest latitude ever attained by man, this vegetation is very conspicuous, from the contrast between its colour and the white snow and ice in which it is imbedded. Insomuch, that in the eightieth degree, all the surface ice carried along by the currents, the sides of every berg and the base of the great Victoria Barrier itself, within reach of the swell, were tinged brown, as if the polar waters were charged with oxide of iron.

"As the majority of these plants consist of very simple vegetable cells, enclosed in indestructible silex (as other Algae are in carbonate of lime), it is obvious that the death and decomposition of such multitudes must form sedimentary deposits, proportionate in their extent to the length and exposure of the coast against which they are washed, in thickness to the power of such agents as the winds, currents, and sea, which sweep them more energetically to certain positions, and in purity, to the depth of the water and nature of the bottom. Hence we detected their remains along every icebound shore, in the depths of the adjacent ocean, between 80 and 400 fathoms. Off Victoria Barrier (a perpendicular wall of ice between one and two hundred feet above the level of the sea) the bottom of the ocean was covered with a stratum of pure white or green mud, composed principally of the silicious shells of the *Diatomaceoe*. These, on being put into water, rendered it cloudy like milk, and took many hours to subside. In the very deep water off Victoria and Graham's Land, this mud was particularly pure and fine; but towards the shallow shores there existed a greater or less admixture of disintegrated rock and sand; so that the organic compounds of the bottom frequently bore but a small proportion to the inorganic." …

"The universal existence of such an invisible vegetation as that of the Antarctic Ocean, is a truly wonderful fact, and the more from its not being accompanied by plants of a high order. During the years we spent there, I had been accustomed to regard the phenomena of life as differing totally from what obtains throughout all other latitudes, for everything living appeared to be of animal origin. The ocean swarmed with *Mollusca*, and particularly entomostracous *Crustacea*, small whales, and porpoises; the sea abounded with penguins and seals, and the air with birds; the animal kingdom was ever present, the larger creatures preying on the smaller, and these again on smaller still; all seemed carnivorous. The herbivorous were not recognised, because feeding on a microscopic herbage, of whose true nature I had formed an erroneous impression. It is, therefore, with no little satisfaction that I now class the *Diatomaceoe* with plants, probably maintaining in the South Polar Ocean that balance between the vegetable and the animal kingdoms which prevails over the surface of our globe. Nor is the sustenance and nutrition of the animal kingdom the only function these minute productions may perform; they may also be the purifiers of the vitiated atmosphere, and thus execute in the Antarctic latitudes the office of our trees and grass turf in the temperate regions, and the broad leaves of the palm, &c., in the tropics." …

With respect to the distribution of the *Diatomaceoe*, Dr. Hooker remarks:—

"There is probably no latitude between that of Spitzbergen and Victoria Land, where some of the species of either country do not exist: Iceland, Britain, the Mediterranean Sea, North and South America, and the South Sea Islands, all possess Antarctic *Diatomaceoe*. The silicious coats of species only known living in the waters of the South Polar Ocean, have, during past ages, contributed to the formation of rocks; and thus they outlive several successive creations of organized beings. The phonolite stones of the Rhine, and the Tripoli stone, contain species identical with what are now contributing to form a sedimentary deposit (and perhaps, at some future period, a bed of rock) extending in one continuous stratum for 400 measured miles. I allude to the shores of the Victoria Barrier, along whose coast the soundings examined were invariably charged with diatomaceous remains, constituting a bank which stretches 200 miles north from the base of Victoria Barrier, while the average depth of water above it is 300 fathoms, or 1,800 feet. Again, some of the Antarctic species have been detected floating in the atmosphere which overhangs the wide ocean between Africa and America. The knowledge of this marvellous fact we owe to Mr. Darwin, who, when he was at sea off the Cape de Verd Islands, collected an impalpable powder which fell on Captain Fitzroy's ship. He transmitted this dust to Ehrenberg, who ascertained it to consist of the silicious coats, chiefly of American *Diatomaceoe*, which were being wafted through the upper region of the air, when some meteorological phenomena checked them in their course and deposited them on the ship and surface of the ocean.

"The existence of the remains of many species of this order (and amongst them some Antarctic ones) in the volcanic ashes, pumice, and scoriae of active and extinct volcanoes (those of the Mediterranean Sea and Ascension Island, for instance) is a fact bearing immediately upon the present subject. Mount Erebus, a volcano 12,400 feet high, of the first class in dimensions and energetic action, rises at once from the ocean in the seventy-eighth degree of south latitude, and abreast of the *Diatomaceoe* bank, which reposes in part on its base.

Hence it may not appear preposterous to conclude that, as Vesuvius receives the waters of the Mediterranean, with its fish, to eject them by its crater, so the subterranean and subaqueous forces which maintain Mount Erebus in activity may occasionally receive organic matter from the bank, and disgorge it, together with those volcanic products, ashes and pumice.

"Along the shores of Graham's Land and the South Shetland Islands, we have a parallel combination of igneous and aqueous action, accompanied with an equally copious supply of *Diatomaceoe*. In the Gulf of Erebus and Terror, fifteen degrees north of Victoria Land, and placed on the opposite side of the globe, the soundings were of a similar nature with those of the Victoria Land and Barrier, and the sea and ice as full of *Diatomaceoe*. This was not only proved by the deep sea lead, but by the examination of bergs which, once stranded, had floated off and become reversed, exposing an accumulation of white friable mud frozen to their bases, which abounded with these vegetable remains."

The *Challenger* has explored the Antarctic seas in a region intermediate between those examined by Sir James Ross's expedition; and the observations made by Dr. Wyville Thomson and his colleagues in every respect confirm those of Dr. Hooker:—

"On the 11th of February, lat. 60° 52' S., long. 80° 20' E., and March 3, lat. 53° 55' S., long. 108° 35' E., the sounding instrument came up filled with a very fine cream-coloured paste, which scarcely effervesced with acid, and dried into a very light, impalpable, white powder. This, when examined under the microscope, was found to consist almost entirely of the frustules of Diatoms, some of them wonderfully perfect in all the details of their ornament, and many of them broken up. The species of Diatoms entering into this deposit have not yet been worked up, but they appear to be referable chiefly to the genera *Fragillaria, Coscinodiscus, Choetoceros, Asteromphalus*, and *Dictyocha*, with fragments of the separated rods of a singular silicious organism, with which we were unacquainted, and which made up a large proportion of the finer matter of this deposit. Mixed with the Diatoms there were a few small *Globigerinoe*, some of the tests and spicules of Radiolarians, and some sand particles; but these foreign bodies were in too small proportion to affect the formation as consisting practically of Diatoms alone. On the 4th of February, in lat. 52°, 29' S., long., 71° 36" E., a little to the north of the Heard Islands, the tow-net, dragging a few fathoms below the surface, came up nearly filled with a pale yellow gelatinous mass. This was found to consist entirely of Diatoms of the same species as those found at the bottom. By far the most abundant was the little bundle of silicious rods, fastened together loosely at one end, separating from one another at the other end, and the whole bundle loosely twisted into a spindle. The rods are hollow, and contain the characteristic endochrome of the *Diatomaceoe*. Like the *Globigerina* ooze, then, which it succeeds to the southward in a band apparently of no great width, the materials of this silicious deposit are derived entirely from the surface and intermediate depths. It is somewhat singular that Diatoms did not appear to be in such large numbers on the surface over the Diatom ooze as they were a little further north. This may perhaps be accounted for by our not having struck their belt of depth with the tow-net; or it is possible that when we found it on the 11th of February the bottom deposit was really shifted a little to the south by the warm current, the excessively fine flocculent *débris* of the Diatoms taking a certain time to sink. The belt of Diatom ooze is certainly a little further to the southward in long. 83° E., in the path of the reflux of the Agulhas current, than in long. 108° E.

"All along the edge of the ice-pack—everywhere, in fact, to the south of the two stations—on the 11th of February on our southward voyage, and on the 3rd of March on our return, we brought up fine sand and grayish mud, with small pebbles of quartz and felspar, and small fragments of mica- slate, chlorite-slate, clay-slate, gneiss, and granite. This deposit, I have no doubt, was derived from the surface like the others, but in this case by the melting of icebergs and the precipitation of foreign matter contained in the ice.

"We never saw any trace of gravel or sand, or any material necessarily derived from land, on an iceberg. Several showed vertical or irregular fissures filled with discoloured ice or snow; but, when looked at closely, the discoloration proved usually to be very slight, and the effect at a distance was usually due to the foreign material filling the fissure reflecting light less perfectly than the general surface of the berg. I conceive that the upper surface of one of these great tabular southern icebergs, including by far the greater part of its bulk, and culminating in the portion exposed above the surface of the sea, was formed by the piling up of successive layers of snow during the period, amounting perhaps to several centuries, during which the ice-cap was slowly forcing itself over the low land and out to sea over a long extent of gentle slope, until it reached a depth considerably above 200 fathoms, when the lower specific weight of the ice caused an upward strain which at length overcame the cohesion of the mass, and portions were rent off and floated away. If this be the true history of the formation of these icebergs, the absence of all land *débris* in the portion exposed above the surface of the sea is readily understood. If any such exist, it must be confined to the lower part of the berg, to that part which has at one time or other moved on the floor of the ice-cap.

"The icebergs, when they are first dispersed, float in from 200 to 250 fathoms. When, therefore, they have been drifted to latitudes of 65° or 64° S., the bottom of the berg just reaches the layer at which the temperature of the water is distinctly rising, and it is rapidly melted, and the mud and pebbles with which it is more or less charged are precipitated. That this precipitation takes place all over the area where the icebergs are breaking up, constantly, and to a considerable extent, is evident from the fact of the soundings being entirely composed of such deposits; for the Diatoms, *Globigerinoe*, and radiolarians are present on the surface in large numbers; and unless the deposit from the ice were abundant it would soon be covered and masked by a layer of the exuvia of surface organisms."

The observations which have been detailed leave no doubt that the Antarctic sea bottom, from a little to the south of the fiftieth parallel, as far as 80° S., is being covered by a fine deposit of silicious mud, more or less mixed, in some parts, with the ice-borne *débris* of polar lands and with the ejections of volcanoes. The silicious particles which constitute this mud, are derived, in part, from the diatomaceous plants and radiolarian animals which throng the surface, and, in part, from the spicula of sponges which live at the bottom. The evidence respecting the corresponding Arctic area is less complete, but it is sufficient to justify the conclusion that an essentially similar silicious cap is being formed around the northern pole.

There is no doubt that the constituent particles of this mud may agglomerate into a dense rock, such as that formed at Oran on the shores of the Mediterranean, which is made up of similar materials. Moreover, in the case of freshwater deposits of this kind it is certain that the action of percolating water may convert the originally soft and friable, fine-grained sandstone into a dense, semi-transparent opaline stone, the silicious organized skeletons being dissolved, and the silex re-deposited in an amorphous state. Whether such a metamorphosis as this occurs in submarine deposits, as well as in those formed in fresh water, does not appear; but there seems no reason to doubt that it may. And hence it may not be hazardous to conclude that very ordinary metamorphic agencies may convert these polar caps into a form of quartzite.

In the great intermediate zone, occupying some 110° of latitude, which separates the circumpolar Arctic and Antarctic areas of silicious deposit, the Diatoms and *Radiolaria* of the surface water and the sponges of the bottom do not die out, and, so far as some forms are concerned, do not even appear to diminish in total number; though, on a rough estimate, it would appear that the proportion of *Radiolaria* to Diatoms is much greater than in the colder seas. Nevertheless the composition of the deep-sea mud of this intermediate zone is entirely different from that of the circumpolar regions.

The first exact information respecting the nature of this mud at depths greater than 1,000 fathoms was given by Ehrenberg, in the account which he published in the "Monatsberichte" of the Berlin Academy for the year 1853, of the soundings obtained by Lieut. Berryman, of the United States Navy, in the North Atlantic, between Newfoundland and the Azores.

Observations which confirm those of Ehrenberg in all essential respects have been made by Professor Bailey, myself, Dr. Wallich, Dr. Carpenter, and Professor Wyville Thomson, in their earlier cruises; and the continuation of the *Globigerina* ooze over the South Pacific has been proved by the recent work of the *Challenger*, by which it is also shown, for the first time, that, in passing from the equator to high southern latitudes, the number and variety of the *Foraminifera* diminishes, and even the *Globigerinoe* become dwarfed. And this result, it will be observed, is in entire accordance with the fact already mentioned that, in the sea of Kamschatka, the deep-sea mud was found by Bailey to contain no calcareous organisms.

Thus, in the whole of the "intermediate zone," the silicious deposit which is being formed there, as elsewhere, by the accumulation of sponge- spicula, *Radiolaria*, and Diatoms, is obscured and overpowered by the immensely greater amount of calcareous sediment, which arises from the aggregation of the skeletons of dead *Foraminifera*.

The similarity of the deposit, thus composed of a large percentage of carbonate of lime, and a small percentage of silex, to chalk, regarded merely as a kind of rock, which was first pointed out by Ehrenberg,[5] is now admitted on all hands; nor can it be reasonably doubted, that ordinary metamorphic agencies are competent to convert the "modern chalk" into hard limestone or even into crystalline marble.

[Footnote 5: The following passages in Ehrenberg's memoir on *The Organisms in the Chalk which are still living* (1839), are conclusive:—

"7. The dawning period of the existing living organic creation, if such a period is distinguishable (which is doubtful), can only be supposed to have existed on the other side of, and below, the chalk formation; and thus, either the chalk, with its widespread and thick beds, must enter into the series of newer formations; or some of the accepted four great geological periods, the quaternary, tertiary, and secondary formations, contain organisms which still live. It is more probable, in the proportion of 3 to 1, that the transition or primary period is not different, but that it is only more difficult to examine and understand, by reason of the gradual and prolonged chemical decomposition and metamorphosis of many of its organic constituents."

"10. By the mass-forming *Infasoria* and *Polythalamia*, secondary are not distinguishable from tertiary formations; and, from what has been said, it is possible that, at this very day, rock masses are forming in the sea, and being raised by volcanic agencies, the constitution of which, on the whole, is altogether similar to that of the chalk. The chalk remains distinguishable by its organic remains as a formation, but not as a kind of rock."]

Ehrenberg appears to have taken it for granted that the *Globigerinoe* and other *Foraminifera* which are found in the deep-sea mud, live at the great depths in which their remains are found; and he supports this opinion by producing evidence that the soft parts of these organisms are preserved, and may be demonstrated by removing the calcareous matter with dilute acids. In 1857, the evidence for and against this conclusion appeared to me to be insufficient to warrant a positive conclusion one way or the other, and I expressed myself in my report to the Admiralty on Captain Dayman's soundings in the following terms:—

"When we consider the immense area over which this deposit is spread, the depth at which its formation is going on, and its similarity to chalk, and still more to such rocks as the marls of Caltanisetta, the question, whence are all these organisms derived? becomes one of high scientific interest.

"Three answers have suggested themselves:—

"In accordance with the prevalent view of the limitation of life to comparatively small depths, it is imagined either: 1, that these organisms have drifted into their present position from shallower waters; or 2, that they habitually live at the surface of the ocean, and only fall down into their present position.

"1. I conceive that the first supposition is negatived by the extremely marked zoological peculiarity of the deep-sea fauna.

"Had the *Globigerinoe* been drifted into their present position from shallow water, we should find a very large proportion of the characteristic inhabitants of shallow waters mixed with them, and this would the more certainly be the case, as the large *Globigerinoe*, so abundant in the deep-sea soundings, are, in proportion to their size, more solid and massive than almost any other *Foraminifera*. But the fact is that the proportion of other *Foraminifera* is exceedingly small, nor have I found as yet, in the deep-sea deposits, any such matters as fragments of molluscous shells, of *Echini*, &c., which abound in shallow waters, and are quite as likely to be drifted as the heavy *Globigerinoe*. Again, the relative proportions of young and fully formed *Globigerinoe* seem inconsistent with the notion that they have travelled far. And it seems difficult to imagine why, had the deposit been accumulated in this way, *Coscinodisci* should so almost entirely represent the *Diatomaceoe*.

"2. The second hypothesis is far more feasible, and is strongly supported by the fact that many *Polycistineoe [Radiolaria]* and *Coscinodisci* are well known to live at the surface of the ocean. Mr. Macdonald, Assistant-Surgeon of H.M.S. *Herald*, now in the South-Western Pacific, has lately sent home some very valuable observations on living forms of this kind, met with in the stomachs of oceanic mollusks, and therefore certainly inhabitants of the superficial layer of the ocean. But it is a singular circumstance that only one of the forms figured by Mr. Macdonald is at all like a *Globigerina*, and there are some peculiarities about even this which make me greatly doubt its affinity with that genus. The form, indeed, is not unlike that of a *Globigerina*, but it is provided with long radiating processes, of which I have never seen any trace in *Globigerina*. Did they exist, they might explain what otherwise is a great objection to this view, viz., how is it conceivable that the heavy *Globigerina* should maintain itself at the surface of the water?

"If the organic bodies in the deep-sea soundings have neither been drifted, nor have fallen from above, there remains but one alternative— they must have lived and died where they are.

"Important objections, however, at once suggest themselves to this view. How can animal life be conceived to exist under such conditions of light, temperature, pressure, and aeration as must obtain at these vast depths?

"To this one can only reply that we know for a certainty that even very highly-organized animals do continue to live at a depth of 300 and 400 fathoms, inasmuch as they have been dredged up thence; and that the difference in the amount of light and heat at 400 and at 2,000 fathoms is probably, so to speak, very far less than the difference in complexity of organisation between these animals and the humbler *Protozoa* and *Protophyta* of the deep-sea soundings.

"I confess, though as yet far from regarding it proved that the *Globigerinoe* live at these depths, the balance of probabilities seems to me to incline in that direction. And there is one circumstance which weighs strongly in my mind. It may be taken as a law that any genus of animals which is found far back in time is capable of living under a great variety of circumstances as regards light, temperature, and pressure. Now, the genus *Globigerina* is abundantly represented in the cretaceous epoch, and perhaps earlier.

"I abstain, however, at present from drawing any positive conclusions, preferring rather to await the result of more extended observations."[6]

[Footnote 6: Appendix to Report on Deep-sea Soundings in the Atlantic
Ocean, by Lieut.-Commander Joseph Dayman. 1857.]

Dr. Wallich, Professor Wyville Thomson, and Dr. Carpenter concluded that the *Globigerinoe* live at the bottom. Dr. Wallich writes in 1862—"By sinking very fine gauze nets to considerable depths, I have repeatedly satisfied myself that *Globigerina* does not occur in the superficial strata of the ocean."[7] Moreover, having obtained certain living star- fish from a depth of 1,260 fathoms, and found their stomachs full of "fresh-looking *Globigerinoe*" and their *débris*—he adduces this fact in support of his belief that the *Globigerinoe* live at the bottom.

[Footnote 7: The *North Atlantic Sea-bed*, p. 137.]

On the other hand, Müller, Haeckel, Major Owen, Mr. Gwyn Jeffries, and other observers, found that *Globigerinoe*, with the allied genera *Orbulina* and *Pulvinulina*, sometimes occur abundantly at the surface of the sea, the shells of these pelagic forms being not unfrequently provided with the long spines noticed by Macdonald; and in 1865 and 1866, Major Owen more especially insisted on the importance of this fact. The recent work of the *Challenger* fully confirms Major Owen's statement. In the paper recently published in the proceedings of the Royal Society,[8] from which a quotation has already been made, Professor Wyville Thomson says:—

"I had formed and expressed a very strong opinion on the matter. It seemed to me that the evidence was conclusive that the *Foraminifera* which formed the *Globigerina* ooze lived on the bottom, and that the occurrence of individuals on the surface was accidental and exceptional; but after going into the thing carefully, and considering the mass of evidence which has been accumulated by Mr. Murray, I now admit that I was in error; and I agree with him that it may be taken as proved that all the materials of such deposits, with the exception, of course, of the remains of animals which we now know to live at the bottom at all depths, which occur in the deposit as foreign bodies, are derived from the surface.

[Footnote 8: "Preliminary Notes on the Nature of the Sea-bottom procured by the soundings of H.M.S. *Challenger* during her cruise in the Southern Seas, in the early part of the year 1874."—*Proceedings of the Royal Society*, Nov. 26, 1874.]

"Mr. Murray has combined with a careful examination of the soundings a constant use of the tow-net, usually at the surface, but also at depths of from ten to one hundred fathoms; and he finds the closest relation to exist between the surface fauna of any particular locality and the deposit which is taking place at the bottom. In all seas, from the equator to the polar ice, the tow-net contains *Globigerinoe*. They are more abundant and of a larger size in warmer seas; several varieties, attaining a large size and presenting marked varietal characters, are found in the intertropical area of the Atlantic. In the latitude of Kerguelen they are less numerous and smaller, while further south they are still more dwarfed, and only one variety, the typical *Globigerina bulloides*, is represented. The living *Globigerinoe* from the tow-net are singularly different in appearance from the dead shells we find at the bottom. The shell is clear and transparent, and each of the pores which penetrate it is surrounded by a raised crest, the crest round adjacent pores coalescing into a roughly hexagonal network, so that the pores appear to lie at the bottom of a hexagonal pit. At each angle of this hexagon the crest gives off a delicate flexible calcareous spine, which is sometimes four or five times the diameter of the shell in length. The spines radiate symmetrically from the direction of the centre of each chamber of the shell, and the sheaves of long transparent needles crossing one another in different directions have a very beautiful effect. The smaller inner chambers of the shell are entirely filled with an orange-yellow granular sarcode; and the large terminal chamber usually contains only a small irregular mass, or two or three small masses run together, of the same yellow sarcode stuck against one side, the remainder of the chamber being empty. No definite arrangement and no approach to structure was observed in the sarcode, and no differentiation, with the exception of round bright-yellow oil-globules, very much like those found in some of the radiolarians, which are scattered, apparently irregularly, in the sarcode. We never have been able to detect, in any of the large number of *Globigerinoe* which we have examined, the least trace of pseudopodia, or any extension, in any form, of the sarcode beyond the shell.

* * * * *

"In specimens taken with the tow-net the spines are very usually absent; but that is probably on account of their extreme tenuity; they are broken off by the slightest touch. In fresh examples from the surface, the dots indicating the origin of the lost spines may almost always be made out with a high power. There are never spines on the *Globigerinoe* from the bottom, even in the shallowest water."

There can now be no doubt, therefore, that *Globigerinoe* live at the top of the sea; but the question may still be raised whether they do not also live at the bottom. In favour of this view, it has been urged that the shells of the *Globigerinoe* of the surface never possess such thick walls as those which are fouled at the bottom, but I confess that I doubt the accuracy of this statement. Again, the occurrence of minute *Globigerinoe* in all stages of development, at the greatest depths, is brought forward as evidence that they live *in situ*. But considering the extent to which the surface organisms are devoured, without discrimination of young and old, by *Salpoe* and the like, it is not wonderful that shells of all ages should be among the rejectamenta. Nor can the presence of the soft parts of the body in the shells which form the *Globigerina* ooze, and the fact, if it be one, that animals living at the bottom use them as food, be considered as conclusive evidence that the *Globigerinoe* live at the bottom. Such as die at the surface, and even many of those which are swallowed by other animals, may retain much of their protoplasmic matter when they reach the depths at which the temperature sinks to 34° or 32° Fahrenheit, where decomposition must become exceedingly slow.

Another consideration appears to me to be in favour of the view that the *Globigerinoe* and their allies are essentially surface animals. This is the fact brought out by the *Challenger's* work, that they have a southern limit of distribution, which can hardly depend upon anything but the temperature of the surface water. And it is to be remarked that this southern limit occurs at a lower latitude in the Antarctic seas than it does in the North Atlantic. According to Dr. Wallich ("The North Atlantic Sea Bed," p. 157) *Globigerina* is the prevailing form in the deposits between the Faroe Islands and Iceland, and between Iceland and East Greenland—or, in other words, in a region of the sea-bottom which lies altogether north of the parallel of 60° N.; while in the southern seas, the *Globigerinoe* become dwarfed and almost disappear between 50° and 55° S. On the other hand, in the sea of Kamschatka, the *Globigerinoe* have vanished in 56° N., so that the persistence of the *Globigerina* ooze in high latitudes, in the North Atlantic, would seem to depend on the northward curve of the isothermals peculiar to this region; and it is difficult to understand how the formation of *Globigerina* ooze can be affected by this climatal peculiarity unless it be effected by surface animals.

Whatever may be the mode of life of the *Foraminifera*, to which the calcareous element of the deep-sea "chalk" owes its existence, the fact that it is the chief and most widely spread material of the sea-bottom in the intermediate zone, throughout both the Atlantic and Pacific Oceans, and the Indian Ocean, at depths from a few hundred to over two thousand fathoms, is established. But it is not the only extensive deposit which is now taking place. In 1853, Count Pourtalès, an officer of the United States Coast Survey, which has done so much for scientific hydrography, observed, that the mud forming the sea-bottom at depths of one hundred and fifty fathoms, in 31° 32' N., 79° 35' W., off the Coast of Florida, was "a mixture, in about equal proportions, of *Globigerinoe* and black sand, probably greensand, as it makes a green mark when crushed on paper." Professor Bailey, examining these grains microscopically, found that they were casts of the interior cavities of *Foraminifera*, consisting of a mineral known as *Glauconite*, which is a silicate of iron and alumina. In these casts the minutest cavities and finest tubes in the Foraminifer were sornetilnes reproduced in solid counterparts of the glassy mineral, while the calcareous original had been entirely dissolved away.

Contemporaneously with these observations, the indefatigable Ehrenberg had discovered that the "greensands" of the geologist were largely made up of casts of a similar character, and proved the existence of *Foraminifera* at a very ancient geological epoch, by discovering such casts in a greensand of Lower Silurian age, which occurs near St. Petersburg.

Subsequently, Messrs. Parker and Jones discovered similar casts in process of formation, the original shell not having disappeared, in specimens of the sea-bottom of the Australian seas, brought home by the late Professor Jukes. And the *Challenger* has observed a deposit of a similar character in the course of the Agulhas current, near the Cape of Good Hope, and in some other localities not yet defined.

It would appear that this infiltration of *Foraminifera* shells with *Glauconite* does not take place at great depths, but rather in what may be termed a sublittoral region, ranging from a hundred to three hundred fathoms. It cannot be ascribed to any local cause, for it takes place, not only over large areas in the Gulf of Mexico and the Coast of Florida, but in the South Atlantic and in the Pacific. But what are the conditions which determine its occurrence, and whence the silex, the iron, and the alumina (with perhaps potash and some other ingredients in small quantity) of which the *Glauconite* is composed, proceed, is a point on which no light has yet been thrown. For the present we must be content with the fact that, in certain areas of the "intermediate zone," greensand is replacing and representing the primitively calcareo- silicious ooze.

The investigation of the deposits which are now being formed in the basin of the Mediterranean, by the late Professor Edward Forbes, by Professor Williamson and more recently by Dr. Carpenter, and a comparison of the results thus obtained with what is known of the surface fauna, have brought to light the remarkable fact, that while the surface and the shallows abound with *Foraminifera* and other calcareous shelled organisms, the indications of life become scanty at depths beyond 500 or 600 fathoms, while almost all traces of it disappear at greater depths, and at 1,000 to 2,000 fathoms the bottom is covered with a fine clay.

Dr. Carpenter has discussed the significance of this remarkable fact, and he is disposed to attribute the absence of life at great depths, partly to the absence of any circulation of the water of the Mediterranean at such depths, and partly to the exhaustion of the oxygen of the water by the organic matter contained in the fine clay, which he conceives to be formed by the finest particles of the mud brought down by the rivers which flow into the Mediterranean.

However this may be, the explanation thus offered of the presence of the fine mud, and of the absence of organisms which ordinarily live at the bottom, does not account for the absence of the skeletons of the organisms which undoubtedly abound at the surface of the Mediterranean; and it would seem to have no application to the remarkable fact discovered by the *Challenger*, that in the open Atlantic and Pacific Oceans, in the midst of the great intermediate zone, and thousands of miles away from the embouchure of any river, the sea-bottom, at depths approaching to and beyond 3,000 fathoms, no longer consists of *Globigerina* ooze, but of an excessively fine red clay.

Professor Thomson gives the following account of this capital discovery:—

"According to our present experience, the deposit of *Globigerina* ooze is limited to water of a certain depth, the extreme limit of the pure characteristic formation being placed at a depth of somewhere about 2,250 fathoms. Crossing from these shallower regions occupied by the ooze into deeper soundings, we find, universally, that the calcareous formation gradually passes into, and is finally replaced by, an extremely fine pure clay, which occupies, speaking generally, all depths below 2,500 fathoms, and consists almost entirely of a silicate of the red oxide of iron and alumina. The transition is very slow, and extends over several hundred fathoms of increasing depth; the shells gradually lose their sharpness of outline, and assume a kind of 'rotten' look and a brownish colour, and become more and more mixed with a fine amorphous red-brown powder, which increases steadily in proportion until the lime has almost entirely disappeared. This brown matter is in the finest possible state of subdivision, so fine that when, after sifting it to separate any organisms it might contain, we put it into jars to settle, it remained for days in suspension, giving the water very much the appearance and colour of chocolate.

"In indicating the nature of the bottom on the charts, we came, from experience and without any theoretical considerations, to use three terms for soundings in deep water. Two of these, Gl. oz. and r. cl., were very definite, and indicated strongly-marked formations, with apparently but few characters in common; but we frequently got soundings which we could not exactly call '*Globigerina* ooze' or 'red clay,' and before we were fully aware of the nature of these, we were in the habit of indicating them as 'grey ooze' (gr. oz.) We now recognise the 'grey ooze' as an intermediate stage between the *Globigerina* ooze and the red clay; we find that on one side, as it were, of an ideal line, the red clay contains more and more of the material of the calcareous ooze, while on the other, the ooze is mixed with an increasing proportion of 'red clay.'

"Although we have met with the same phenomenon so frequently, that we were at length able to predict the nature of the bottom from the depth of the soundings with absolute certainty for the Atlantic and the Southern Sea, we had, perhaps, the best opportunity of observing it in our first section across the Atlantic, between Teneriffe and St. Thomas. The first four stations on this section, at depths from 1,525 to 2,220 fathoms, show *Globigerina* ooze. From the last of these, which is about 300 miles from Teneriffe, the depth gradually increases to 2,740 fathoms at 500, and 2,950 fathoms at 750 miles from Teneriffe. The bottom in these two soundings might have been called 'grey ooze,' for although its nature has altered entirely from the *Globigerina* ooze, the red clay into which it is rapidly passing still contains a considerable admixture of carbonate of lime.

"The depth goes on increasing to a distance of 1,150 miles from Teneriffe, when it reaches 3,150 fathoms; there the clay is pure and smooth, and contains scarcely a trace of lime. From this great depth the bottom gradually rises, and, with decreasing depth, the grey colour and the calcareous composition of the ooze return. Three soundings in 2,050, 1,900, and 1,950 fathoms on the 'Dolphin Rise' gave highly characteristic examples of the *Globigerina* formation. Passing from the middle plateau of the Atlantic into the western trough, with depths a little over 3,000 fathoms, the red clay returned in all its purity; and our last sounding, in 1,420 fathoms, before reaching Sombrero, restored the *Globigerina* ooze with its peculiar associated fauna.

"This section shows also the wide extension and the vast geological importance of the red clay formation. The total distance from Teneriffe to Sombrero is about 2,700 miles. Proceeding from east to west, we have—

About 80 miles of volcanic mud and sand, " 350 " *Globigerina* ooze, " 1,050 " red clay, " 330 " *Globigerina* ooze, " 850 " red clay, " 40 " *Globigerina* ooze;

giving a total of 1,900 miles of red clay to 720 miles of *Globigerina* ooze.

"The nature and origin of this vast deposit of clay is a question of the very greatest interest; and although I think there can be no doubt that it is in the main solved, yet some matters of detail are still involved in difficulty. My first impression was that it might be the most minutely divided material, the ultimate sediment produced by the disintegration of the land, by rivers and by the action of the sea on exposed coasts, and held in suspension and distributed by ocean currents, and only making itself manifest in places unoccupied by the *Globigerina* ooze. Several circumstances seemed, however, to negative this mode of origin. The formation seemed too uniform: wherever we met with it, it had the same character, and it only varied in composition in containing less or more carbonate of lime.

"Again, the were gradually becoming more and more convinced that all the important elements of the *Globigerina* ooze lived on the surface, and it seemed evident that, so long as the condition on the surface remained the same, no alteration of contour at the bottom could possibly prevent its accumulation; and the surface conditions in the Mid-Atlantic were very uniform, a moderate current of a very equal temperature passing continuously over elevations and depressions, and everywhere yielding to the tow-net the ooze-forming *Foraminifera* in the same proportion. The Mid-Atlantic swarms with pelagic *Mollusca*, and, in moderate depths, the shells of these are constantly mixed with the *Globigerina* ooze, sometimes in number sufficient to make up a considerable portion of its bulk. It is clear that these shells must fall in equal numbers upon the red clay, but scarcely a trace of one of them is ever brought up by the dredge on the red clay area. It might be possible to explain the absence of shell-secreting animals living on the bottom, on the supposition that the nature of the deposit was injurious to them; but then the idea of a current sufficiently strong to sweep them away is negatived by the extreme fineness of the sediment which is being laid down; the absence of surface shells appears to be intelligible only on the supposition that they are in some way removed.

"We conclude, therefore, that the 'red clay' is not an additional substance introduced from without, and occupying certain depressed regions on account of some law regulating its deposition, but that it is produced by the removal, by some means or other, over these areas, of the carbonate of lime, which forms probably about 98 per cent. of the material of the *Globigerina* ooze. We can trace, indeed, every successive stage in the removal of the carbonate of lime in descending the slope of the ridge or plateau where the *Globigerina* ooze is forming, to the region of the clay. We find, first, that the shells of pteropods and other surface *Mollusca* which are constantly falling on the bottom, are absent, or, if a few remain, they are brittle and yellow, and evidently decaying rapidly. These shells of *Mollusca* decompose more easily and disappear sooner than the smaller, and apparently more delicate, shells of rhizopods. The smaller *Foraminifera* now give way, and are found in lessening proportion to the larger; the coccoliths first lose their thin outer border and then disappear; and the clubs of the rhabdoliths get worn out of shape, and are last seen, under a high power, as infinitely minute cylinders scattered over the field. The larger *Foraminifera* are attacked, and instead of being vividly white and delicately sculptured, they become brown and worn, and finally they break up, each according to its fashion; the chamber-walls of *Globigerina* fall into wedge-shaped pieces, which quickly disappear, and a thick rough crust breaks away from the surface of *Orbulina*, leaving a thin inner sphere, at first beautifully transparent, but soon becoming opaque and crumbling away.

"In the meantime the proportion of the amorphous 'red clay' to the calcareous elements of all kinds increases, until the latter disappear, with the exception of a few scattered shells of the larger *Foraminifera*, which are still found even in the most characteristic samples of the 'red clay.'

"There seems to be no room left for doubt that the red clay is essentially the insoluble residue, the *ash*, as it were, of the calcareous organisms which form the *Globigerina* ooze, after the calcareous matter has been by some means removed. An ordinary mixture of calcareous *Foraminifera* with the shells of pteropods, forming a fair sample of *Globigerina* ooze from near St. Thomas, was carefully washed, and subjected by Mr. Buchanan to the action of weak acid; and he found that there remained after the carbonate of lime had been removed, about 1 per cent. of a reddish mud, consisting of silica, alumina, and the red oxide of iron. This experiment has been frequently repeated with different samples of *Globigerina* ooze, and always with the result that a small proportion of a red sediment remains, which possesses all the characters of the red clay."

* * * * *

"It seems evident from the observations here recorded, that *clay*, which we have hitherto looked upon as essentially the product of the disintegration of older rocks, may be, under certain circumstances, an organic formation like chalk; that, as a matter of fact, an area on the surface of the globe, which we have shown to be of vast extent, although we are still far from having ascertained its limits, is being covered by such a deposit at the present day.

"It is impossible to avoid associating such a formation with the fine, smooth, homogeneous clays and schists, poor in fossils, but showing worm- tubes and tracks, and bunches of doubtful branching things, such as Oldhamia, silicious sponges, and thin-shelled peculiar shrimps. Such formations, more or less metamorphosed, are very familiar, especially to the student of palaeozoic geology, and they often attain a vast thickness. One is inclined, from the great resemblance between them in composition and in the general character of the included fauna, to suspect that these may be organic formations, like the modern red clay of the Atlantic and Southern Sea, accumulations of the insoluble ashes of shelled creatures.

"The dredging in the red clay on the 13th of March was usually rich. The bag contained examples, those with calcareous shells rather stunted, of most of the characteristic deep-water groups of the Southern Sea, including *Umbellularia, Euplectella, Pterocrinus, Brisinga, Ophioglypha, Pourtalesia*, and one or two *Mollusca*. This is, however, very rarely the case. Generally the red clay is barren, or contains only a very small number of forms."

It must be admitted that it is very difficult, at present, to frame any satisfactory explanation of the mode of origin of this singular deposit of red clay.

I cannot say that the theory put forward tentatively, and with much reservation by Professor Thomson, that the calcareous matter is dissolved out by the relatively fresh water of the deep currents from the Antarctic regions, appears satisfactory to me. Nor do I see my way to the acceptance of the suggestion of Dr. Carpenter, that the red clay is the result of the decomposition of previously-formed greensand. At present there is no evidence that greensand casts are ever formed at great depths; nor has it been proved that *Glauconite* is decomposable by the agency of water and carbonic acid.

I think it probable that we shall have to wait some time for a sufficient explanation of the origin of the abyssal red clay, no less than for that of the sublittoral greensand in the intermediate zone. But the importance of the establishment of the fact that these various deposits are being formed in the ocean, at the present day, remains the same; whether its *rationale* be understood or not.

For, suppose the globe to be evenly covered with sea, to a depth say of a thousand fathoms—then, whatever might be the mineral matter composing the sea-bottom, little or no deposit would be formed upon it, the abrading and denuding action of water, at such a depth, being exceedingly slight.

Next, imagine sponges, *Radiolaria, Foraminifera*, and diatomaceous plants, such as those which now exist in the deep-sea, to be introduced: they would be distributed according to the same laws as at present, the sponges (and possibly some of the *Foraminifera*), covering the bottom, while other *Foraminifera*, with the *Radiolaria* and *Diatomacea*, would increase and multiply in the surface waters. In accordance with the existing state of things, the *Radiolaria* and Diatoms would have a universal distribution, the latter gathering most thickly in the polar regions, while the *Foraminifera* would be largely, if not exclusively, confined to the intermediate zone; and, as a consequence of this distribution, a bed of "chalk" would begin to form in the intermediate zone, while caps of silicious rock would accumulate on the circumpolar regions.

Suppose, further, that a part of the intermediate area were raised to within two or three hundred fathoms of the surface—for anything that we know to the contrary, the change of level might determine the substitution of greensand for the "chalk"; while, on the other hand, if part of the same area were depressed to three thousand fathoms, that change might determine the substitution of a different silicate of alumina and iron—namely, clay—for the "chalk" that would otherwise be formed.

If the *Challenger* hypothesis, that the red clay is the residue left by dissolved *Foraminiferous* skeletons, is correct, then all these deposits alike would be directly, or indirectly, the product of living organisms. But just as a silicious deposit may be metamorphosed into opal or quartzite, and chalk into marble, so known metamorphic agencies may metamorphose clay into schist, clay-slate, slate, gneiss, or even granite. And thus, by the agency of the lowest and simplest of organisms, our imaginary globe might be covered with strata, of all the chief kinds of rock of which the known crust of the earth is composed, of indefinite thickness and extent.

The bearing of the conclusions which are now either established, or highly probable, respecting the origin of silicious, calcareous, and clayey rocks, and their metamorphic derivatives, upon the archaeology of the earth, the elucidation of which is the ultimate object of the geologist, is of no small importance.

A hundred years ago the singular insight of Linnaeus enabled him to say that "fossils are not the children but the parents of rocks,"[9] and the whole effect of the discoveries made since his time has been to compile a larger and larger commentary upon this text. It is, at present, a perfectly tenable hypothesis that all siliceous and calcareous rocks are either directly, or indirectly, derived from material which has, at one time or other, formed part of the organized framework of living organisms. Whether the same generalization may be extended to aluminous rocks, depends upon the conclusion to be drawn from the facts respecting the red clay areas brought to light by the *Challenger*. If we accept the view taken by Wyville Thomson and his colleagues—that the red clay is the residuum left after the calcareous matter of the *Globigerinoe* ooze has been dissolved away—then clay is as much a product of life as limestone, and all known derivatives of clay may have formed part of animal bodies.

[Footnote 9: "Petrificata montium calcariorum non filii sed parentes sunt, cum omnis calx oriatur ab animalibus."—*Systema Naturae*, Ed. xii., t. iii., p. 154. It must be recollected that Linnaeus included silex, as well as limestone, under the name of "calx," and that he would probably have arranged Diatoms among animals, as part of "chaos." Ehrenberg quotes another even more pithy passage, which I have not been able to find in any edition of the *Systema* accessible to me: "Sic lapides ab animalibus, nec vice versa. Sic runes saxei non primaevi, sed temporis filiae."]

So long as the *Globigerinoe*;, actually collected at the surface, have not been demonstrated to contain the elements of clay, the *Challenger* hypothesis, as I may term it, must be accepted with reserve and provisionally, but, at present, I cannot but think that it is more probable than any other suggestion which has been made.

Accepting it provisionally, we arrive at the remarkable result that all the chief known constituents of the crust of the earth may have formed part of living bodies; that they may be the "ash" of protoplasm; that the "*rupes saxei*" are not only *"temporis,"* but "*vitae filiae*"; and, consequently, that the time during which life has been active on the globe may be indefinitely greater than the period, the commencement of which is marked by the oldest known rocks, whether fossiliferous or unfossiliferous.

And thus we are led to see where the solution of a great problem and apparent paradox of geology may lie. Satisfactory evidence now exists that some animals in the existing world have been derived by a process of gradual modification from pre-existing forms. It is undeniable, for example, that the evidence in favour of the derivation of the horse from the later tertiary *Hipparion*, and that of the *Hipparion* from *Anchitherium*, is as complete and cogent as such evidence can reasonably be expected to be; and the further investigations into the history of the tertiary mammalia are pushed, the greater is the accumulation of evidence having the same tendency. So far from palaeontology lending no support to the doctrine of evolution—as one sees constantly asserted—that doctrine, if it had no other support, would have been irresistibly forced upon us by the palaeontological discoveries of the last twenty years.

If, however, the diverse forms of life which now exist have been produced by the modification of previously-existing less divergent forms, the recent and extinct species, taken as a whole, must fall into series which must converge as we go back in time. Hence, if the period represented by the rocks is greater than, or co-extensive with, that during which life has existed, we ought, somewhere among the ancient formations, to arrive at the point to which all these series converge, or from which, in other words, they have diverged—the primitive undifferentiated protoplasmic living things, whence the two great series of plants and animals have taken their departure.

But, as a matter of fact, the amount of convergence of series, in relation to the time occupied by the deposition of geological formations, is extraordinarily small. Of all animals the higher *Vertebrata* are the most complex; and among these the carnivores and hoofed animals (*Ungulata*) are highly differentiated. Nevertheless, although the different lines of modification of the *Carnivora* and those of the *Ungulata*, respectively, approach one another, and, although each group is represented by less differentiated forms in the older tertiary rocks than at the present day, the oldest tertiary rocks do not bring us near the primitive form of either. If, in the same way, the convergence of the varied forms of reptiles is measured against the time during which their remains are preserved—which is represented by the whole of the tertiary and mesozoic formations—the amount of that convergence is far smaller than that of the lines of mammals between the present time and the beginning of the tertiary epoch. And it is a broad fact that, the lower we go in the scale of organization, the fewer signs are there of convergence towards the primitive form from whence all must have diverged, if evolution be a fact. Nevertheless, that it is a fact in some cases, is proved, and I, for one, have not the courage to suppose that the mode in which some species have taken their origin is different from that in which the rest have originated.

What, then, has become of all the marine animals which, on the hypothesis of evolution, must have existed in myriads in those seas, wherein the many thousand feet of Cambrian and Laurentian rocks now devoid, or almost devoid, of any trace of life were deposited?

Sir Charles Lyell long ago suggested that the azoic character of these ancient formations might be due to the fact that they had undergone extensive metamorphosis; and readers of the "Principles of Geology" will be familiar with the ingenious manner in which he contrasts the theory of the Gnome, who is acquainted only with the interior of the earth, with those of ordinary philosophers, who know only its exterior.

The metamorphism contemplated by the great modern champion of rational geology is, mainly, that brought about by the exposure of rocks to subterranean heat; and where no such heat could be shown to have operated, his opponents assumed that no metamorphosis could have taken place. But the formation of greensand, and still more that of the "red clay" (if the *Challenger* hypothesis be correct) affords an insight into a new kind of metamorphosis—not igneous, but aqueous—by which the primitive nature of a deposit may be masked as completely as it can be by the agency of heat. And, as Wyville Thomson suggests, in the passage I have quoted above (p. 17), it further enables us to assign a new cause for the occurrence, so puzzling hitherto, of thousands of feet of unfossiliferous fine-grained schists and slates, in the midst of formations deposited in seas which certainly abounded in life. If the great deposit of "red clay" now forming in the eastern valley of the Atlantic were metamorphosed into slate and then upheaved, it would constitute an "azoic" rock of enormous extent. And yet that rock is now forming in the midst of a sea which swarms with living beings, the great majority of which are provided with calcareous or silicious shells and skeletons; and, therefore, are such as, up to this time, we should have termed eminently preservable.

Thus the discoveries made by the *Challenger* expedition, like all recent advances in our knowledge of the phenomena of biology, or of the changes now being effected in the structure of the surface of the earth, are in accordance with and lend strong support to, that doctrine of Uniformitarianism, which, fifty years ago, was held only by a small minority of English geologists—Lyell, Scrope, and De la Beche—but now, thanks to the long-continued labours of the first two, and mainly to those of Sir Charles Lyell, has gradually passed from the position of a heresy to that of catholic doctrine.

Applied within the limits of the time registered by the known fraction of the crust of the earth, I believe that uniformitarianism is unassailable. The evidence that, in the enormous lapse of time between the deposition of the lowest Laurentian strata and the present day, the forces which have modified the surface of the crust of the earth were different in kind, or greater in the intensity of their action, than those which are now occupied in the same work, has yet to be produced. Such evidence as we possess all tends in the contrary direction, and is in favour of the same slow and gradual changes occurring then as now.

But this conclusion in nowise conflicts with the deductions of the physicist from his no less clear and certain data. It may be certain that this globe has cooled down from a condition in which life could not have existed; it may be certain that, in so cooling, its contracting crust must have undergone sudden convulsions, which were to our earthquakes as an earthquake is to the vibration caused by the periodical eruption of a Geyser; but in that case, the earth must, like other respectable parents, have sowed her wild oats, and got through her turbulent youth, before we, her children, have any knowledge of her.

So far as the evidence afforded by the superficial crust of the earth goes, the modern geologist can, *ex animo*, repeat the saying of Hutton, "We find no vestige of a beginning—no prospect of an end." However, he will add, with Hutton, "But in thus tracing back the natural operations which have succeeded each other, and mark to us the course of time past, we come to a period in which we cannot see any further." And if he seek to peer into the darkness of this period, he will welcome the light proffered by physics and mathematics.

IV

YEAST

[1871]

It has been known, from time immemorial, that the sweet liquids which may be obtained by expressing the juices of the fruits and stems of various plants, or by steeping malted barley in hot water, or by mixing honey with water—are liable to undergo a series of very singular changes, if freely exposed to the air and left to themselves, in warm weather. However clear and pellucid the liquid may have been when first prepared, however carefully it may have been freed, by straining and filtration, from even the finest visible impurities, it will not remain clear. After a time it will become cloudy and turbid; little bubbles will be seen rising to the surface, and their abundance will increase until the liquid hisses as if it were simmering on the fire. By degrees, some of the solid particles which produce the turbidity of the liquid collect at its surface into a scum, which is blown up by the emerging air-bubbles into a thick, foamy froth. Another moiety sinks to the bottom, and accumulates as a muddy sediment, or "lees."

When this action has continued, with more or less violence, for a certain time, it gradually moderates. The evolution of bubbles slackens, and finally comes to an end; scum and lees alike settle at the bottom, and the fluid is once more clear and transparent. But it has acquired properties of which no trace existed in the original liquid. Instead of being a mere sweet fluid, mainly composed of sugar and water, the sugar has more or less completely disappeared; and it has acquired that peculiar smell and taste which we call "spirituous." Instead of being devoid of any obvious effect upon the animal economy, it has become possessed of a very wonderful influence on the nervous system; so that in small doses it exhilarates, while in larger it stupefies, and may even destroy life.

Moreover, if the original fluid is put into a still, and heated moderately, the first and last product of its distillation is simple water; while, when the altered fluid is subjected to the same process, the matter which is first condensed in the receiver is found to be a clear, volatile substance, which is lighter than water, has a pungent taste and smell, possesses the intoxicating powers of the fluid in an eminent degree, and takes fire the moment it is brought in contact with a flame. The Alchemists called this volatile liquid, which they obtained from wine, "spirits of wine," just as they called hydrochloric acid "spirits of salt," and as we, to this day, call refined turpentine "spirits of turpentine." As the "spiritus," or breath, of a man was thought to be the most refined and subtle part of him, the intelligent essence of man was also conceived as a sort of breath, or spirit; and, by analogy, the most refined essence of anything was called its "spirit." And thus it has come about that we use the same word for the soul of man and for a glass of gin.

At the present day, however, we even more commonly use another name for this peculiar liquid—namely, "alcohol," and its origin is not less singular. The Dutch physician, Van Helmont, lived in the latter part of the sixteenth and the beginning of the seventeenth century—in the transition period between alchemy and chemistry—and was rather more alchemist than chemist. Appended to his "Opera Omnia," published in 1707, there is a very needful "Clavis ad obscuriorum sensum referendum," in which the following passage occurs.—

"ALCOHOL.—Chymicis est liquor aut pulvis summé subtilisatus, vocabulo Orientalibus quoque, cum primis Habessinis, familiari, quibus *cohol* speciatim pulverem impalpabilem ex antimonio pro oculis tingendis denotat

… Hodie autem, ob analogiam, quivis pulvis tenerior ut pulvis oculorum cancri summé subtilisatus *alcohol* audit, haud aliter ac spiritus rectificatissimi *alcolisati* dicuntur."

Similarly, Robert Boyle speaks of a fine powder as "alcohol"; and, so late as the middle of the last century, the English lexicographer, Nathan Bailey, defines "alcohol" as "the pure substance of anything separated from the more gross, a very fine and impalpable powder, or a very pure, well-rectified spirit." But, by the time of the publication of Lavoisier's "Traité Elémentaire de Chimie," in 1789, the term "alcohol," "alkohol," or "alkool" (for it is spelt in all three ways), which Van Helmont had applied primarily to a fine powder, and only secondarily to spirits of wine, had lost its primary meaning altogether; and, from the end of the last century until now, it has, I believe, been used exclusively as the denotation of spirits of wine, and bodies chemically allied to that substance.

The process which gives rise to alcohol in a saccharine fluid is known tones as "fermentation"; a term based upon the apparent boiling up or "effervescence" of the fermenting liquid, and of Latin origin.

Our Teutonic cousins call the same process "gähren," "gäsen," "göschen," and "gischen"; but, oddly enough, we do not seem to have retained their verb or their substantive denoting the action itself, though we do use names identical with, or plainly derived from, theirs for the scum and lees. These are called, in Low German, "gäscht" and "gischt"; in Anglo- Saxon, "gest," "gist," and "yst," whence our "yeast." Again, in Low German and in Anglo-Saxon there is another name for yeast, having the form "barm," or "beorm"; and, in the Midland Counties, "barm" is the name by which yeast is still best known. In High German, there is a third name for yeast, "hefe," which is not represented in English, so far as I know.

All these words are said by philologers to be derived from roots expressive of the intestine motion of a fermenting substance. Thus "hefe" is derived from "heben," to raise; "barm" from "beren" or "bären," to bear up; "yeast," "yst," and "gist," have all to do with seething and foam, with "yeasty" waves, and "gusty" breezes.

The same reference to the swelling up of the fermenting substance is seen in the Gallo-Latin terms "levure" and "leaven."

It is highly creditable to the ingenuity of our ancestors that the peculiar property of fermented liquids, in virtue of which they "make glad the heart of man," seems to have been known in the remotest periods of which we have any record. All savages take to alcoholic fluids as if they were to the manner born. Our Vedic forefathers intoxicated themselves with the juice of the "soma"; Noah, by a not unnatural reaction against a superfluity of water, appears to have taken the earliest practicable opportunity of qualifying that which he was obliged to drink; and the ghosts of the ancient Egyptians were solaced by pictures of banquets in which the wine-cup passes round, graven on the walls of their tombs. A knowledge of the process of fermentation, therefore, was in all probability possessed by the prehistoric populations of the globe; and it must have become a matter of great interest even to primaeval wine-bibbers to study the methods by which fermented liquids could be surely manufactured. No doubt it was soon discovered that the most certain, as well as the most expeditious, way of making a sweet juice ferment was to add to it a little of the scum, or lees, of another fermenting juice. And it can hardly be questioned that this singular excitation of fermentation in one fluid, by a sort of infection, or inoculation, of a little ferment taken from some other fluid, together with the strange swelling, foaming, and hissing of the fermented substance, must have always attracted attention from the more thoughtful. Nevertheless, the commencement of the scientific analysis of the phenomena dates from a period not earlier than the first half of the seventeenth century.

At this time, Van Helmont made a first step, by pointing out that the peculiar hissing and bubbling of a fermented liquid is due, not to the evolution of common air (which he, as the inventor of the term "gas," calls "gas ventosum"), but to that of a peculiar kind of air such as is occasionally met with in caves, mines, and wells, and which he calls "gas sylvestre."

But a century elapsed before the nature of this "gas sylvestre," or, as it was afterwards called, "fixed air," was clearly determined, and it was found to be identical with that deadly "choke-damp" by which the lives of those who descend into old wells, or mines, or brewers' vats, are sometimes suddenly ended; and with the poisonous aëriform fluid which is produced by the combustion of charcoal, and now goes by the name of carbonic acid gas.

During the same time it gradually became evident that the presence of sugar was essential to the production of alcohol and the evolution of carbonic acid gas, which are the two great and conspicuous products of fermentation. And finally, in 1787, the Italian chemist, Fabroni, made the capital discovery that the yeast ferment, the presence of which is necessary to fermentation, is what he termed a "vegeto-animal" substance; that is, a body which gives of ammoniacal salts when it is burned, and is, in other ways, similar to the gluten of plants and the albumen and casein of animals.

These discoveries prepared the way for the illustrious Frenchman, Lavoisier, who first approached the problem of fermentation with a complete conception of the nature of the work to be done. The words in which he expresses this conception, in the treatise on elementary chemistry to which reference has already been made, mark the year 1789 as the commencement of a revolution of not less moment in the world of science than that which simultaneously burst over the political world, and soon engulfed Lavoisier himself in one of its mad eddies.

"We may lay it down as an incontestable axiom that, in all the operations of art and nature, nothing is created; an equal quantity of matter exists both before, and after the experiment: the quality and quantity of the elements remain precisely the same, and nothing takes place beyond changes and modifications in the combinations of these elements. Upon this principle the whole art of performing chemical experiments depends; we must always suppose an exact equality between the elements of the body examined and those of the products of its analysis.

"Hence, since from must of grapes we procure alcohol and carbonic acid, I have an undoubted right to suppose that must consists of carbonic acid and alcohol. From these premisses we have two modes of ascertaining what passes during vinous fermentation: either by determining the nature of, and the elements which compose, the fermentable substances; or by accurately examining the products resulting from fermentation; and it is evident that the knowledge of either of these must lead to accurate conclusions concerning the nature and composition of the other. From these considerations it became necessary accurately to determine the constituent elements of the fermentable substances; and for this purpose I did not make use of the compound juices of fruits, the rigorous analysis of which is perhaps impossible, but made choice of sugar, which is easily analysed, and the nature of which I have already explained. This substance is a true vegetable oxyd, with two bases, composed of hydrogen and carbon, brought to the state of an oxyd by means of a certain proportion of oxygen; and these three elements are combined in such a way that a very slight force is sufficient to destroy the equilibrium of their connection."

After giving the details of his analysis of sugar and of the products of fermentation, Lavoisier continues:—

"The effect of the vinous fermentation upon sugar is thus reduced to the mere separation of its elements into two portions; one part is oxygenated at the expense of the other, so as to form carbonic acid; while the other part, being disoxygenated in favour of the latter, is converted into the combustible substance called alcohol; therefore, if it were possible to re-unite alcohol and carbonic acid together, we ought to form sugar."[1]

[Footnote 1: *Elements of Chemistry*. By M. Lavoisier. Translated by Robert Kerr. Second Edition, 1793 (pp. 186-196).]

Thus Lavoisier thought he had demonstrated that the carbonic acid and the alcohol which are produced by the process of fermentation, are equal in weight to the sugar which disappears; but the application of the more refined methods of modern chemistry to the investigation of the products of fermentation by Pasteur, in 1860, proved that this is not exactly true, and that there is a deficit of from 5 to 7 per cent of the sugar which is not covered by the alcohol and carbonic acid evolved. The greater part of this deficit is accounted for by the discovery of two substances, glycerine and succinic acid, of the existence of which Lavoisier was unaware, in the fermented liquid. But about 1-1/2 per cent. still remains to be made good. According to Pasteur, it has been appropriated by the yeast, but the fact that such appropriation takes place cannot be said to be actually proved.

However this may be, there can be no doubt that the constituent elements of fully 98 per cent. of the sugar which has vanished during fermentation have simply undergone rearrangement; like the soldiers of a brigade, who at the word of command divide themselves into the independent regiments to which they belong. The brigade is sugar, the regiments are carbonic acid, succinic acid, alcohol, and glycerine.

From the time of Fabroni, onwards, it has been admitted that the agent by which this surprising rearrangement of the particles of the sugar is effected is the yeast. But the first thoroughly conclusive evidence of the necessity of yeast for the fermentation of sugar was furnished by Appert, whose method of preserving perishable articles of food excited so much attention in France at the beginning of this century. Gay-Lussac, in his "Mémoire sur la Fermentation,"[2] alludes to Appert's method of preserving beer-wort unfermented for an indefinite time, by simply boiling the wort and closing the vessel in which the boiling fluid is contained, in such a way as thoroughly to exclude air; and he shows that, if a little yeast be introduced into such wort, after it has cooled, the wort at once begins to ferment, even though every precaution be taken to exclude air. And this statement has since received full confirmation from Pasteur.

[Footnote 2: *Annales de Chimie*, 1810.]

On the other hand, Schwann, Schroeder and Dutch, and Pasteur, have amply proved that air may be allowed to have free access to beer-wort, without exciting fermentation, if only efficient precautions are taken to prevent the entry of particles of yeast along with the air.

Thus, the truth that the fermentation of a simple solution of sugar in water depends upon the presence of yeast, rests upon an unassailable foundation; and the inquiry into the exact nature of the substance which possesses such a wonderful chemical influence becomes profoundly interesting.

The first step towards the solution of this problem was made two centuries ago by the patient and painstaking Dutch naturalist, Leeuwenhoek, who in the year 1680 wrote thus:—

"Saepissime examinavi fermnentum cerevisiae, semperque hoc ex globulis per materiam pellucidam fluitantibus, quarm cerevisiam esse censui, constare observavi: vidi etiam evidentissime, unumquemque hujus fermenti globulum denuo ex sex distinctis globulis constare, accurate eidem quantitate et formae, cui globulis sanguinis nostri, respondentibus.

"Verum talis mihi de horum origine et formatione conceptus formabam; globulis nempe ex quibus farina Tritici, Hordei, Avenae, Fagotritici, se constat aquae calore dissolvi et aquae commisceri; hac, vero aqua, quam cerevisiam vocare licet, refrigescente, multos ex minimis particulis in cerevisia coadunari, et hoc pacto efficere particulam sive globulum, quae sexta pars est globuli faecis, et iterum sex ex hisce globulis conjungi."[3]

[Footnote 3: Leeuwenhoek, *Arcana Naturae Detecta.* Ed. Nov., 1721.]

Thus Leeuwenhoek discovered that yeast consists of globules floating in a fluid; but he thought that they were merely the starchy particles of the grain from which the wort was made, rearranged. He discovered the fact that yeast had a definite structure, but not the meaning of the fact. A century and a half elapsed, and the investigation of yeast was recommenced almost simultaneously by Cagniard de la Tour in France, and by Schwann and Kützing in Germany. The French observer was the first to publish his results; and the subject received at his hands and at those of his colleague, the botanist Turpin, full and satisfactory investigation.

The main conclusions at which they arrived are these. The globular, or oval, corpuscles which float so thickly in the yeast as to make it muddy, though the largest are not more than one two-thousandth of an inch in diameter, and the smallest may measure less than one seven-thousandth of an inch, are living organisms. They multiply with great rapidity by giving off minute buds, which soon attain the size of their parent, and then either become detached or remain united, forming the compound globules of which Leeuwenhoek speaks, though the constancy of their arrangement in sixes existed only in the worthy Dutchman's imagination.

It was very soon made out that these yeast organisms, to which Turpin gave the name of *Torula cerevisioe*, were more nearly allied to the lower Fungi than to anything else. Indeed Turpin, and subsequently Berkeley and Hoffmann, believed that they had traced the development of the *Torula* into the well-known and very common mould—the *Penicillium glaucum*. Other observers have not succeeded in verifying these statements; and my own observations lead me to believe, that while the connection between *Torula* and the moulds is a very close one, it is of a different nature from that which has been supposed. I have never been able to trace the development of *Torula* into a true mould; but it is quite easy to prove that species of true mould, such as *Penicillium*, when sown in an appropriate nidus, such as a solution of tartrate of ammonia and yeast-ash, in water, with or without sugar, give rise to *Toruloe*, similar in all respects to *T. cerevisioe*, except that they are, on the average, smaller. Moreover, Bail has observed the development of a *Torula* larger than *T. cerevisioe*, from a *Mucor*, a mould allied to *Penicillium*.

It follows, therefore, that the *Toruloe*, or organisms of yeast, are veritable plants; and conclusive experiments have proved that the power which causes the rearrangement of the molecules of the sugar is intimately connected with the life and growth of the plant. In fact, whatever arrests the vital activity of the plant also prevents it from exciting fermentation.

Such being the facts with regard to the nature of yeast, and the changes which it effects in sugar, how are they to be accounted for? Before modern chemistry had come into existence, Stahl, stumbling, with the stride of genius, upon the conception which lies at the bottom of all modern views of the process, put forward the notion that the ferment, being in a state of internal motion, communicated that motion to the sugar, and thus caused its resolution into new substances. And Lavoisier, as we have seen, adopts substantially the same view. But Fabroni, full of the then novel conception of acids and bases and double decompositions, propounded the hypothesis that sugar is an oxide with two bases, and the ferment a carbonate with two bases; that the carbon of the ferment unites with the oxygen of the sugar, and gives rise to carbonic acid; while the sugar, uniting with the nitrogen of the ferment, produces a new substance analogous to opium. This is decomposed by distillation, and gives rise to alcohol. Next, in 1803, Thénard propounded a hypothesis which partakes somewhat of the nature of both Stahl's and Fabroni's views. "I do not believe with Lavoisier," he says, "that all the carbonic acid formed proceeds from the sugar. How, in that case, could we conceive the action of the ferment on it? I think that the first portions of the acid are due to a combination of the carbon of the ferment with the oxygen of the sugar, and that it is by carrying off a portion of oxygen from the last that the ferment causes the fermentation to commence—the equilibrium between the principles of the sugar being disturbed, they combine afresh to form carbonic acid and alcohol."

The three views here before us may be familiarly exemplified by supposing the sugar to be a card-house. According to Stahl, the ferment is somebody who knocks the table, and shakes the card-house down; according to Fabroni, the ferment takes out some cards, but puts others in their places; according to Thénard, the ferment simply takes a card out of the bottom story, the result of which is that all the others fall.

As chemistry advanced, facts came to light which put a new face upon Stahl's hypothesis, and gave it a safer foundation than it previously possessed. The general nature of these phenomena may be thus stated:—A body, A, without giving to, or taking from, another body B, any material particles, causes B to decompose into other substances, C, D, E, the sum of the weights of which is equal to the weight of B, which decomposes. Thus, bitter almonds contain two substances, amygdalin and synaptase, which can be extracted, in a separate state, from the bitter almonds. The amygdalin thus obtained, if dissolved in water, undergoes no change; but if a little synaptase be added to the solution, the amygdalin splits up into bitter almond oil, prussic acid, and a kind of sugar.

A short time after Cagniard de la Tour discovered the yeast plant, Liebig, struck with the similarity between this and other such processes and the fermentation of sugar, put forward the hypothesis that yeast contains a substance which acts upon sugar, as synaptase acts upon amygdalin. And as the synaptase is certainly neither organized nor alive, but a mere chemical substance, Liebig treated Cagniard de la Tour's discovery with no small contempt, and, from that time to the present, has steadily repudiated the notion that the decomposition of the sugar is, in any sense, the result of the vital activity of the *Torula*. But, though the notion that the *Torula* is a creature which eats sugar and excretes carbonic acid and alcohol, which is not unjustly ridiculed in the most surprising paper that ever made its appearance in a grave scientific journal,[4] may be untenable, the fact that the

Toruloe are alive, and that yeast does not excite fermentation unless it contains living *Toruloe*, stands fast. Moreover, of late years, the essential participation of living organisms in fermentation other than the alcoholic, has been clearly made out by Pasteur and other chemists.

[Footnote 4: "Das enträthselte Geheimniss der geistigen Gährung (Vorlänfige briefliche Mittheilung)" is the title of an anonymous contribution to Wöhler and Liebig's *Annalen der Pharmacie* for 1839, in which a somewhat Rabelaisian imaginary description of the organisation of the "yeast animals" and of the manner in which their functions are performed, is given with a circumstantiality worthy of the author of *Gulliver's Travels*. As a specimen of the writer's humour, his account of what happens when fermentation comes to an end may suffice. "Sobald nämlich die Thiere keinen Zucker mehr vorfinden, so fressen sie sich gegenseitig selbst auf, was durch eine eigene Manipulation geschieht; alles wird verdant bis auf die Eier, welche unverändert durch den Darmkanal hineingehen; man hat zuletzt wieder gährungsfähige Hefe, nämlich den Saamen der Thiere, der übrig bleibt."] However, it may be asked, is there any necessary opposition between the so-called "vital" and the strictly physico-chemical views of fermentation? It is quite possible that the living *Torula* may excite fermentation in sugar, because it constantly produces, as an essential part of its vital manifestations, some substance which acts upon the sugar, just as the synaptase acts upon the amygdalin. Or it may be, that, without the formation of any such special substance, the physical condition of the living tissue of the yeast plant is sufficient to effect that small disturbance of the equilibrium of the particles of the sugar, which Lavoisier thought sufficient to effect its decomposition.

Platinum in a very fine state of division—known as platinum black, or *noir de platine*—has the very singular property of causing alcohol to change into acetic acid with great rapidity. The vinegar plant, which is closely allied to the yeast plant, has a similar effect upon dilute alcohol, causing it to absorb the oxygen of the air, and become converted into vinegar; and Liebig's eminent opponent, Pasteur, who has done so much for the theory and the practice of vinegar-making, himself suggests that in this case—

"La cause du phénomène physique qui accompagne la vie de la plante réside dans un état physique propre, analogue à celui du noir de platine. Mais il est essentiel de remarquer que cet état physique de la plante est étroitement lié avec la vie de cette plante."[5]

[Footnote 5: *Etudes sur les Mycodermes*, Comptes-Rendus, liv., 1862.]

Now, if the vinegar plant gives rise to the oxidation of alcohol, on account of its merely physical constitution, it is at any rate possible that the physical constitution of the yeast plant may exert a decomposing influence on sugar.

But, without presuming to discuss a question which leads us into the very arcana of chemistry, the present state of speculation upon the *modus operandi* of the yeast plant in producing fermentation is represented, on the one hand, by the Stahlian doctrine, supported by Liebig, according to which the atoms of the sugar are shaken into new combinations either directly by the *Toruloe*, or indirectly, by some substance formed by them; and, on the other hand, by the Thénardian doctrine, supported by Pasteur, according to which the yeast plant assimilates part of the sugar, and, in so doing, disturbs the rest, and determines its resolution into the products of fermentation. Perhaps the two views are not so much opposed as they seem at first sight to be.

But the interest which attaches to the influence of the yeast plants upon the medium in which they live and grow does not arise solely from its bearing upon the theory of fermentation. So long ago as 1838, Turpin compared the *Toruloe* to the ultimate elements of the tissues of animals and plants—"Les organes élémentaires de leurs tissus, comparables aux petits végétaux des levures ordinaires, sont aussi les décompositeurs des substances qui les environnent."

Almost at the same time, and, probably, equally guided by his study of yeast, Schwann was engaged in those remarkable investigations into the form and development of the ultimate structural elements of the tissues of animals, which led him to recognise their fundamental identity with the ultimate structural elements of vegetable organisms.

The yeast plant is a mere sac, or "cell," containing a semi-fluid matter, and Schwann's microscopic analysis resolved all living organisms, in the long run, into an aggregation of such sacs or cells, variously modified; and tended to show, that all, whatever their ultimate complication, begin their existence in the condition of such simple cells.

In his famous "Mikroskopische Untersuchungen" Schwann speaks of *Torula* as a "cell"; and, in a remarkable note to the passage in which he refers to the yeast plant, Schwann says:—

"I have been unable to avoid mentioning fermentation, because it is the most fully and exactly known operation of cells, and represents, in the simplest fashion, the process which is repeated by every cell of the living body."

In other words, Schwann conceives that every cell of the living body exerts an influence on the matter which surrounds and permeates it, analogous to that which a *Torula* exerts on the saccharine solution by which it is bathed. A wonderfully suggestive thought, opening up views of the nature of the chemical processes of the living body, which have hardly yet received all the development of which they are capable.

Kant defined the special peculiarity of the living body to be that the parts exist for the sake of the whole and the whole for the sake of the parts. But when Turpin and Schwann resolved the living body into an aggregation of quasi-independent cells, each, like a *Torula*, leading its own life and having its own laws of growth and development, the aggregation being dominated and kept working towards a definite end only by a certain harmony among these units, or by the superaddition of a controlling apparatus, such as a nervous system, this conception ceased to be tenable. The cell lives for its own sake, as well as for the sake of the whole organism; and the cells which float in the blood, live at its expense, and profoundly modify it, are almost as much independent organisms as the *Toruloe* which float in beer-wort.

Schwann burdened his enunciation of the "cell theory" with two false suppositions; the one, that the structures he called "nucleus"[6] and "cell-wall" are essential to a cell; the other, that cells are usually formed independently of other cells; but, in 1839, it was a vast and clear gain to arrive at the conception, that the vital functions of all the higher animals and plants are the resultant of the forces inherent in the innumerable minute cells of which they are composed, and that each of them is, itself, an equivalent of one of the lowest and simplest of independent living beings—the *Torula*.

[Footnote 6: Later investigations have thrown an entirely new light upon the structure and the functional importance of the nucleus; and have proved that Schwann did not over-estimate its importance. 1894.]

From purely morphological investigations, Turpin and Schwann, as we have seen, arrived at the notion of the fundamental unity of structure of living beings. And, before long, the researches of chemists gradually led up to the conception of the fundamental unity of their composition.

So far back as 1803, Thénard pointed out, in most distinct terms, the important fact that yeast contains a nitrogenous "animal" substance; and that such a substance is contained in all ferments. Before him, Fabroni and Fourcroy speak of the "vegeto-animal" matter of yeast. In 1844 Mulder endeavoured to demonstrate that a peculiar substance, which he called "protein," was essentially characteristic of living matter.

In 1846, Payen writes:—

"Enfin, une loi sans exception me semble apparaître dans les faits nombreux que j'ai observés et conduire à envisager sous un nouveau jour la vie végétale; si je ne m'abuse, tout ce que dans les tissus végétaux la vue directe où amplifiée nous permet de discerner sous la forme de cellules et de vaisseaux, ne représente autre chose que les enveloppes protectrices, les réservoirs et les conduits, à l'aide desquels les corps animés qui les secrètent et les façonnent, se logent, puisent et charrient leurs aliments, déposent et isolent les matières excrétées."

And again:—

"Afin de compléter aujourd'hui l'énoncé du fait général, je rappellerai que les corps, doué des fonctions accomplies dans les tissus des plantes, sont formés des éléments qui constituent, en proportion peu variable, les organismes animaux; qu'ainsi l'on est conduit à reconnaître une immense unité de composition élémentaire dans tous les corps vivants de la nature."[7]

[Footnote 7: Mém. sur les Développements des Végétaux, &c.—*Mém. Présentées*. ix. 1846.]

In the year (1846) in which these remarkable passages were published, the eminent German botanist, Von Mohl invented the word "protoplasm," as a name for one portion of those nitrogenous contents of the cells of living plants, the close chemical resemblance of which to the essential constituents of living animals is so strongly indicated by Payen. And through the twenty-five years that have passed, since the matter of life was first called protoplasm, a host of investigators, among whom Cohn, Max Schulze, and Kühne must be named as leaders, have accumulated evidence, morphological, physiological, and chemical, in favour of that "immense unité de composition élémentaire dans tous les corps vivants de la nature," into which Payen had, so early, a clear insight.

As far back as 1850, Cohn wrote, apparently without any knowledge of what Payen had said before him:—

"The protoplasm of the botanist, and the contractile substance and sarcode of the zoologist, must be, if not identical, yet in a high degree analogous substances. Hence, from this point of view, the difference between animals and plants consists in this; that, in the latter, the contractile substance, as a primordial utricle, is enclosed within an inert cellulose membrane, which permits it only to exhibit an internal motion, expressed by the phenomena of rotation and circulation, while, in the former, it is not so enclosed. The protoplasm in the form of the primordial utricle is, as it were, the animal element in the plant, but which is imprisoned, and only becomes free in the animal; or, to strip off the metaphor which obscures simple thought, the energy of organic vitality which is manifested in movement is especially exhibited by a nitrogenous contractile substance, which in plants is limited and fettered by an inert membrane, in animals not so."[8]

[Footnote 8: Cohn, "Ueber Protococcus pluvialis," in the *Nova Acta* for 1850.]

In 1868, thinking that an untechnical statement of the views current among the leaders of biological science might be interesting to the general public, I gave a lecture embodying them in Edinburgh. Those who have not made the mistake of attempting to approach biology, either by the high *à priori* road of mere philosophical speculation, or by the mere low *à posteriori* lane offered by the tube of a microscope, but have taken the trouble to become acquainted with well-ascertained facts and with their history, will not need to be told that in what I had to say "as regards protoplasm" in my lecture "On the Physical Basis of Life" (Vol. I. of these Essays, p. 130), there was nothing new; and, as I hope, nothing that the present state of knowledge does not justify us in believing to be true. Under these circumstances, my surprise may be imagined, when I found, that the mere statement of facts and of views, long familiar to me as part of the common scientific property of Continental workers, raised a sort of storm in this country, not only by exciting the wrath of unscientific persons whose pet prejudices they seemed to touch, but by giving rise to quite superfluous explosions on the part of some who should have been better informed.

Dr. Stirling, for example, made my essay the subject of a special critical lecture,[9] which I have read with much interest, though, I confess, the meaning of much of it remains as dark to me as does the "Secret of Hegel" after Dr. Stirling's elaborate revelation of it. Dr. Stirling's method of dealing with the subject is peculiar. "Protoplasm" is a question of history, so far as it is a name; of fact, so far as it is a thing. Dr. Stirling, has not taken the trouble to refer to the original authorities for his history, which is consequently a travesty; and still less has he concerned himself with looking at the facts, but contents himself with taking them also at second-hand. A most amusing example of this fashion of dealing with scientific statements is furnished by Dr. Stirling's remarks upon my account of the protoplasm of the nettle hair. That account was drawn up from careful and often- repeated observation of the facts. Dr. Stirling thinks he is offering a valid criticism, when he says that my valued friend Professor Stricker gives a somewhat different statement about protoplasm. But why in the world did not this distinguished Hegelian look at a nettle hair for himself, before venturing to speak about the matter at all? Why trouble himself about what either Stricker or I say, when any tyro can see the facts for himself, if he is provided with those not rare articles, a nettle and a microscope? But I suppose this would have been "*Aufklärung*"—a recurrence to the base common-sense philosophy of the eighteenth century, which liked to see before it believed, and to understand before it criticised Dr. Stirling winds up his paper with the following paragraph:—

[Footnote 9: Subsequently published under the title of "As regards Protoplasm."]

"In short, the whole position of Mr. Huxley, (1) that all organisms consist alike of the same life-matter, (2) which life-matter is, for its part, due only to chemistry, must be pronounced untenable—nor less untenable (3) the materialism he would found on it."

The paragraph contains three distinct assertions concerning my views, and just the same number of utter misrepresentations of them. That which I have numbered (1) turns on the ambiguity of the word "same," for a discussion of which I would refer Dr. Stirling to a great hero of "*Aufklärung*" Archbishop Whately; statement number (2) is, in my judgment, absurd, and certainly I have never said anything resembling it; while, as to number (3), one great object of my essay was to show that what is called "materialism" has no sound philosophical basis!

As we have seen, the study of yeast has led investigators face to face with problems of immense interest in pure chemistry, and in animal and vegetable morphology. Its physiology is not less rich in subjects for inquiry. Take, for example, the singular fact that yeast will increase indefinitely when grown in the dark, in water containing only tartrate of ammonia a small percentage of mineral salts and sugar. Out of these materials the *Toruloe* will manufacture nitrogenous protoplasm, cellulose, and fatty matters, in any quantity, although they are wholly deprived of those rays of the sun, the influence of which is essential to the growth of ordinary plants. There has been a great deal of speculation lately, as to how the living organisms buried beneath two or three thousand fathoms of water, and therefore in all probability almost deprived of light, live. If any of them possess the same powers as yeast (and the same capacity for living without light is exhibited by some other fungi) there would seem to be no difficulty about the matter.

Of the pathological bearings of the study of yeast, and other such organisms, I have spoken elsewhere. It is certain that, in some animals, devastating epidemics are caused by fungi of low order—similar to those of which *Torula* is a sort of offshoot. It is certain that such diseases are propagated by contagion and infection, in just the same way as ordinary contagious and infectious diseases are propagated. Of course, it does not follow from this, that all contagious and infectious diseases are caused by organisms of as definite and independent a character as the *Torula*; but, I think, it does follow that it is prudent and wise to satisfy one's self in each particular case, that the "germ theory" cannot and will not explain the facts, before having recourse to hypotheses which have no equal support from analogy.

V

ON THE FORMATION OF COAL

[1870]

The lumps of coal in a coal-scuttle very often have a roughly cubical form. If one of them be picked out and examined with a little care, it will be found that its six sides are not exactly alike. Two opposite sides are comparatively smooth and shining, while the other four are much rougher, and are marked by lines which run parallel with the smooth sides. The coal readily splits along these lines, and the split surfaces thus formed are parallel with the smooth faces. In other words, there is a sort of rough and incomplete stratification in the lump of coal, as if it were a book, the leaves of which had stuck together very closely.

Sometimes the faces along which the coal splits are not smooth, but exhibit a thin layer of dull, charred-looking substance, which is known as "mineral charcoal."

Occasionally one of the faces of a lump of coal will present impressions, which are obviously those of the stem, or leaves, of a plant; but though hard mineral masses of pyrites, and even fine mud, may occur here and there, neither sand nor pebbles are met with.

When the coal burns, the chief ultimate products of its combustion are carbonic acid, water, and ammoniacal products, which escape up the chimney; and a greater or less amount of residual earthy salts, which take the form of ash. These products are, to a great extent, such as would result from the burning of so much wood.

These properties of coal may be made out without any very refined appliances, but the microscope reveals something more. Black and opaque as ordinary coal is, slices of it become transparent if they are cemented in Canada balsam, and rubbed down very thin, in the ordinary way of making thin sections of non-transparent bodies. But as the thin slices, made in this way, are very apt to crack and break into fragments, it is better to employ marine glue as the cementing material. By the use of this substance, slices of considerable size and of extreme thinness and transparency may be obtained.[1]

[Footnote 1: My assistant in the Museum of Practical Geology, Mr. Newton, invented this excellent method of obtaining thin slices of coal.]

Now let us suppose two such slices to be prepared from our lump of coal— one parallel with the bedding, the other perpendicular to it; and let us call the one the horizontal, and the other the vertical, section. The horizontal section will present more or less rounded yellow patches and streaks, scattered irregularly through the dark brown, or blackish, ground substance; while the vertical section will exhibit mere elongated bars and granules of the same yellow materials, disposed in lines which correspond, roughly, with the general direction of the bedding of the coal.

This is the microscopic structure of an ordinary piece of coal. But if a great series of coals, from different localities and seams, or even from different parts of the same seam, be examined, this structure will be found to vary in two directions. In the anthracitic, or stone-coals, which burn like coke, the yellow matter diminishes, and the ground substance becomes more predominant, blacker, and more opaque, until it becomes impossible to grind a section thin enough to be translucent; while, on the other hand, in such as the "Better-Bed" coal of the neighbourhood of Bradford, which burns with much flame, the coal is of a far lighter, colour and transparent sections are very easily obtained. In the browner parts of this coal, sharp eyes will readily detect multitudes of curious little coin-shaped bodies, of a yellowish brown colour, embedded in the dark brown ground substance. On the average, these little brown bodies may have a diameter of about one-twentieth of an inch. They lie with their flat surfaces nearly parallel with the two smooth faces of the block in which they are contained; and, on one side of each, there may be discerned a figure, consisting of three straight linear marks, which radiate from the centre of the disk, but do not quite reach its circumference. In the horizontal section these disks are often converted into more or less complete rings; while in the vertical sections they appear like thick hoops, the sides of which have been pressed together. The disks are, therefore, flattened bags; and favourable sections show that the three-rayed marking is the expression of three clefts, which penetrate one wall of the bag.

The sides of the bags are sometimes closely approximated; but, when the bags are less flattened, their cavities are, usually, filled with numerous, irregularly rounded, hollow bodies, having the same kind of wall as the large ones, but not more than one seven-hundredth of an inch in diameter.

In favourable specimens, again, almost the whole ground substance appears to be made up of similar bodies— more or less carbonized or blackened— and, in these, there can be no doubt that, with the exception of patches of mineral charcoal, here and there, the whole mass of the coal is made up of an accumulation of the larger and of the smaller sacs.

But, in one and the same slice, every transition can be observed from this structure to that which has been described as characteristic of ordinary coal. The latter appears to rise out of the former, by the breaking-up and increasing carbonization of the larger and the smaller sacs. And, in the anthracitic coals, this process appears to have gone to such a length, as to destroy the original structure altogether, and to replace it by a completely carbonized substance.

Thus coal may be said, speaking broadly, to be composed of two constituents: firstly, mineral charcoal; and, secondly, coal proper. The nature of the mineral charcoal has long since been determined. Its structure shows it to consist of the remains of the stems and leaves of plants, reduced a little more than their carbon. Again, some of the coal is made up of the crushed and flattened bark, or outer coat, of the stems of plants, the inner wood of which has completely decayed away. But what I may term the "saccular matter" of the coal, which, either in its primary or in its degraded form constitutes by far the greater part of all the bituminous coals I have examined, is certainly not mineral charcoal; nor is its structure that of any stem or leaf. Hence its real nature is at first by no means apparent, and has been the subject of much discussion.

The first person who threw any light upon the problem, as far as I have been able to discover, was the well-known geologist, Professor Morris. It is now thirty-four years since he carefully described and figured the coin-shaped bodies, or larger sacs, as I have called them, in a note appended to the famous paper "On the Coalbrookdale Coal-Field," published at that time, by the present President of the Geological Society, Mr. Prestwich. With much sagacity, Professor Morris divined the real nature of these bodies, and boldly affirmed them to be the spore-cases of a plant allied to the living club-mosses.

But discovery sometimes makes a long halt; and it is only a few years since Mr. Carruthers determined the plant (or rather one of the plants) which produces these spore-cases, by finding the discoidal sacs still adherent to the leaves of the fossilized cone which produced them. He gave the name of *Flemingites gracilis* to the plant of which the cones form a part. The branches and stem of this plant are not yet certainly known, but there is no sort of doubt that it was closely allied to the *Lepidodendron*, the remains of which abound in the coal formation. The *Lepidodendra* were shrubs and trees which put one more in mind of an *Araucaria* than of any other familiar plant; and the ends of the fruiting branches were terminated by cones, or catkins, somewhat like the bodies so named in a fir, or a willow. These conical fruits, however, did not produce seeds; but the leaves of which they were composed bore upon their surfaces sacs full of spores or sporangia, such as those one sees on the under surface of a bracken leaf. Now, it is these sporangia of the Lepidodendroid plant *Flemingites* which were identified by Mr. Carruthers with the free sporangia described by Professor Morris, which are the same as the large sacs of which I have spoken. And, more than this, there is no doubt that the small sacs are the spores, which were originally contained in the sporangia.

The living club-mosses are, for the most part, insignificant and creeping herbs, which, superficially, very closely resemble true mosses, and none of them reach more than two or three feet in height. But, in their essential structure, they very closely resemble the earliest Lepidodendroid trees of the coal: their stems and leaves are similar; so are their cones; and no less like are the sporangia and spores; while even in their size, the spores of the *Lepidodendron* and those of the existing *Lycopodium*, or club-moss, very closely approach one another.

Thus, the singular conclusion is forced upon us, that the greater and the smaller sacs of the "Better-Bed" and other coals, in which the primitive structure is well preserved, are simply the sporangia and spores of certain plants, many of which were closely allied to the existing club- mosses. And if, as I believe, it can be demonstrated that ordinary coal is nothing but "saccular" coal which has undergone a certain amount of that alteration which, if continued, would convert it into anthracite; then, the conclusion is obvious, that the great mass of the coal we burn is the result of the accumulation of the spores and spore-cases of plants, other parts of which have furnished the carbonized stems and the mineral charcoal, or have left their impressions on the surfaces of the layer.

Of the multitudinous speculations which, at various times, have been entertained respecting the origin and mode of formation of coal, several appear to be negatived, and put out of court, by the structural facts the significance of which I have endeavoured to explain. These facts, for example, do not permit us to suppose that coal is an accumulation of peaty matter, as some have held.

Again, the late Professor Quekett was one of the first observers who gave a correct description of what I have termed the "saccular" structure of coal; and, rightly perceiving that this structure was something quite different from that of any known plant, he imagined that it proceeded from some extinct vegetable organism which was peculiarly abundant amongst the coal-forming plants. But this explanation is at once shown to be untenable when the smaller and the larger sacs are proved to be spores or sporangia.

Some, once more, have imagined that coal was of submarine origin; and though the notion is amply and easily refuted by other considerations, it may be worth while to remark, that it is impossible to comprehend how a mass of light and resinous spores should have reached the bottom of the sea, or should have stopped in that position if they had got there.

At the same time, it is proper to remark that I do not presume to suggest that all coal must needs have the same structure; or that there may not be coals in which the proportions of wood and spores, or spore-cases, are very different from those which I have examined. All I repeat is, that none of the coals which have come under my notice have enabled me to observe such a difference. But, according to Principal Dawson, who has so sedulously examined the fossil remains of plants in North America, it is otherwise with the vast accumulations of coal in that country.

"The true coal," says Dr. Dawson, "consists principally of the flattened bark of Sigillarioid and other trees, intermixed with leaves of Ferns and *Cordaites*, and other herbaceous *débris*, and with fragments of decayed wood, constituting 'mineral charcoal,' all these materials having manifestly alike grown and accumulated where we find them."[2]

[Footnote 2: *Acadian Geology*, 2nd edition, p. 135.]

When I had the pleasure of seeing Principal Dawson in London last summer, I showed him my sections of coal, and begged him to re-examine some of the American coals on his return to Canada, with an eye to the presence of spores and sporangia, such as I was able to show him in our English and Scotch coals. He has been good enough to do so; and in a letter dated September 26th, 1870, he informs me that—

"Indications of spore-cases are rare, except in certain coarse shaly coals and portions of coals, and in the roofs of the seams. The most marked case I have yet met with is the shaly coal referred to as containing *Sporangites* in my paper on the conditions of accumulation of coal ("Journal of the Geological Society," vol. xxii. pp. 115, 139, and 165). The purer coals certainly consist principally of cubical tissues with some true woody matter, and the spore-cases, &c., are chiefly in the coarse and shaly layers. This is my old doctrine in my two papers in the "Journal of the Geological Society," and I see nothing to modify it. Your observations, however, make it probable that the frequent *clear spots* in the cannels are spore-cases."

Dr. Dawson's results are the more remarkable, as the numerous specimens of British coal, from various localities, which I have examined, tell one tale as to the predominance of the spore and sporangium element in their composition; and as it is exactly in the finest and purest coals, such as the "Better-Bed" coal of Lowmoor, that the spores and sporangia obviously constitute almost the entire mass of the deposit.

Coal, such as that which has been described, is always found in sheets, or "seams," varying from a fraction of an inch to many feet in thickness, enclosed in the substance of the earth at very various depths, between beds of rock of different kinds. As a rule, every seam of coal rests upon a thicker, or thinner, bed of clay, which is known as "under-clay." These alternations of beds of coal, clay, and rock may be repeated many times, and are known as the "coal-measures"; and in some regions, as in South Wales and in Nova Scotia, the coal-measures attain a thickness of twelve or fourteen thousand feet, and enclose eighty or a hundred seams of coal, each with its under-clay, and separated from those above and below by beds of sandstone and shale.

The position of the beds which constitute the coal-measures is infinitely diverse. Sometimes they are tilted up vertically, sometimes they are horizontal, sometimes curved into great basins; sometimes they come to the surface, sometimes they are covered up by thousands of feet of rock. But, whatever their present position, there is abundant and conclusive evidence that every under-clay was once a surface soil. Not only do carbonized root-fibres frequently abound in these under-clays; but the stools of trees, the trunks of which are broken off and confounded with the bed of coal, have been repeatedly found passing into radiating roots, still embedded in the under-clay. On many parts of the coast of England, what are commonly known as "submarine forests" are to be seen at low water. They consist, for the most part, of short stools of oak, beech, and fir-trees, still fixed by their long roots in the bed of blue clay in which they originally grew. If one of these submarine forest beds should be gradually depressed and covered up by new deposits, it would present just the same characters as an under-clay of the coal, if the *Sigillaria* and *Lepidodendron* of the ancient world were substituted for the oak, or the beech, of our own times.

In a tropical forest, at the present day, the trunks of fallen trees, and the stools of such trees as may have been broken by the violence of storms, remain entire for but a short time. Contrary to what might be expected, the dense wood of the tree decays, and suffers from the ravages of insects, more swiftly than the bark. And the traveller, setting his foot on a prostrate trunk, finds that it is a mere shell, which breaks under his weight, and lands his foot amidst the insects, or the reptiles, which have sought food or refuge within.

The trees of the coal forests present parallel conditions. When the fallen trunks which have entered into the composition of the bed of coal are identifiable, they are mere double shells of bark, flattened together in consequence of the destruction of the woody core; and Sir Charles Lyell and Principal Dawson discovered, in the hollow stools of coal trees of Nova Scotia, the remains of snails, millipedes, and salamander-like creatures, embedded in a deposit of a different character from that which surrounded the exterior of the trees. Thus, in endeavouring to comprehend the formation of a seam of coal, we must try to picture to ourselves a thick forest, formed for the most part of trees like gigantic club- mosses, mares'-tails, and tree-ferns, with here and there some that had more resemblance to our existing yews and fir-trees. We must suppose that, as the seasons rolled by, the plants grew and developed their spores and seeds; that they shed these in enormous quantities, which accumulated on the ground beneath; and that, every now and then, they added a dead frond or leaf; or, at longer intervals, a rotten branch, or a dead trunk, to the mass.

A certain proportion of the spores and seeds no doubt fulfilled their obvious function, and, carried by the wind to unoccupied regions, extended the limits of the forest; many might be washed away by rain into streams, and be lost; but a large portion must have remained, to accumulate like beech-mast, or acorns, beneath the trees of a modern forest.

But, in this case it may be asked, why does not our English coal consist of stems and leaves to a much greater extent than it does? What is the reason of the predominance of the spores and spore-cases in it?

A ready answer to this question is afforded by the study of a living full-grown club-moss. Shake it upon a piece of paper, and it emits a cloud of fine dust, which falls over the paper, and is the well-known Lycopodium powder. Now this powder used to be, and I believe still is, employed for two objects which seem, at first sight, to have no particular connection with one another. It is, or was, employed in making lightning, and in making pills. The coats of the spores contain so much resinous matter, that a pinch of Lycopodium powder, thrown through the flame of a candle, burns with an instantaneous flash, which has long done duty for lightning on the stage. And the same character makes it a capital coating for pills; for the resinous powder prevents the drug from being wetted by the saliva, and thus bars the nauseous flavour from the sensitive papilla; of the tongue.

But this resinous matter, which lies in the walls of the spores and sporangia, is a substance not easily altered by air and water, and hence tends to preserve these bodies, just as the bituminized cerecloth preserves an Egyptian mummy; while, on the other hand, the merely woody stem and leaves tend to rot, as fast as the wood of the mummy's coffin has rotted. Thus the mixed heap of spores, leaves, and stems in the coal- forest would be persistently searched by the long-continued action of air and rain; the leaves and stems would gradually be reduced to little but their carbon, or, in other words, to the condition of mineral charcoal in which we find them; while the spores and sporangia remained as a comparatively unaltered and compact residuum.

There is, indeed, tolerably clear evidence that the coal must, under some circumstances, have been converted into a substance hard enough to be rolled into pebbles, while it yet lay at the surface of the earth; for in some seams of coal, the courses of rivulets, which must have been living water, while the stratum in which their remains are found was still at the surface, have been observed to contain rolled pebbles of the very coal through which the stream has cut its way.

The structural facts are such as to leave no alternative but to adopt the view of the origin of such coal as I have described, which has just been stated; but, happily, the process is not without analogy at the present day. I possess a specimen of what is called "white coal" from Australia. It is an inflammable material, burning with a bright flame and having much the consistence and appearance of oat-cake, which, I am informed covers a considerable area. It consists, almost entirely, of a compacted mass of spores and spore-cases. But the fine particles of blown sand which are scattered through it, show that it must have accumulated, subaërially, upon the surface of a soil covered by a forest of cryptogamous plants, probably tree-ferns.

As regards this important point of the subaërial region of coal, I am glad to find myself in entire accordance with Principal Dawson, who bases his conclusions upon other, but no less forcible, considerations. In a passage, which is the continuation of that already cited, he writes:—

"(3) The microscopical structure and chemical composition of the beds of cannel coal and earthy bitumen, and of the more highly bituminous and carbonaceous shale, show them to have been of the nature of the fine vegetable mud which accumulates in the ponds and shallow lakes of modern swamps. When such tine vegetable sediment is mixed, as is often the case, with clay, it becomes similar to the bituminous limestone and calcareo- bituminous shales of the coal-measures. (4) A few of the under-clays, which support beds of coal, are of the nature of the vegetable mud above referred to; but the greater part are argillo-arenaceous in composition, with little vegetable matter, and bleached by the drainage from them of water containing the products of vegetable decay. They are, in short, loamy or clay soils, and must have been sufficiently above water to admit of drainage. The absence of sulphurets, and the occurrence of carbonate of iron in connection with them, prove that, when they existed as soils, rain-water, and not sea-water, percolated them. (5) The coal and the fossil forests present many evidences of subaërial conditions. Most of the erect and prostrate trees had become hollow shells of bark before they were finally embedded, and their wood had broken into cubical pieces of mineral charcoal. Land-snails and galley-worms (*Xylobius*) crept into them, and they became dens, or traps, for reptiles. Large quantities of mineral charcoal occur on the surface of all the large beds of coal. None of these appearances could have been produced by subaqueous action. (6) Though the roots of the *Sigillaria* bear more resemblance to the rhizomes of certain aquatic plants; yet, structurally, they are absolutely identical with the roots of Cycads, which the stems also resemble. Further, the *Sigillarioe* grew on the same soils which supported Conifers, *Lepidodendra*, *Cordaites*, and Ferns-plants which could not have grown in water. Again, with the exception perhaps of some *Pinnularioe*, and *Asterophyllites*, there is a remarkable absence from the coal measures of any form of properly aquatic vegetation. (7) The occurrence of marine, or brackish-water animals, in the roofs of coal- beds, or even in the coal itself, affords no evidence of subaqueous accumulation, since the same thing occurs in the case of modern submarine forests. For these and other reasons, some of which are more fully stated in the papers already referred to, while I admit that the areas of coal accumulation were frequently submerged, I must maintain that the true coal is a subaërial accumulation by vegetable growth on soils, wet and swampy it is true, but not submerged."

I am almost disposed to doubt whether it is necessary to make the concession of "wet and swampy"; otherwise, there is nothing that I know of to be said against this excellent conspectus of the reasons for believing in the subaërial origin of coal.

But the coal accumulated upon the area covered by one of the great forests of the carboniferous epoch would in course of time, have been wasted away by the small, but constant, wear and tear of rain and streams had the land which supported it remained at the same level, or been gradually raised to a greater elevation. And, no doubt, as much coal as now exists has been destroyed, after its formation, in this way. What are now known as coal districts owe their importance to the fact that they were areas of slow depression, during a greater or less portion of the carboniferous epoch; and that, in virtue of this circumstance, Mother Earth was enabled to cover up her vegetable treasures, and preserve them from destruction.

Wherever a coal-field now exists, there must formerly have been free access for a great river, or for a shallow sea, bearing sediment in the shape of sand and mud. When the coal-forest area became slowly depressed, the waters must have spread over it, and have deposited their burden upon the surface of the bed of coal, in the form of layers, which are now converted into shale, or sandstone. Then followed a period of rest, in which the superincumbent shallow waters became completely filled up, and finally replaced, by fine mud, which settled down into a new under-clay, and furnished the soil for a fresh forest growth. This flourished, and heaped up its spores and wood into coal, until the stage of slow depression recommenced. And, in some localities, as I have mentioned, the process was repeated until the first of the alternating beds had sunk to near three miles below its original level at the surface of the earth.

In reflecting on the statement, thus briefly made, of the main facts connected with the origin of the coal formed during the carboniferous epoch, two or three considerations suggest themselves.

In the first place, the great phantom of geological time rises before the student of this, as of all other, fragments of the history of our earth— springing irrepressibly out of the facts, like the Djin from the jar which the fishermen so incautiously opened; and like the Djin again, being vaporous, shifting, and indefinable, but unmistakably gigantic. However modest the bases of one's calculation may be, the minimum of time assignable to the coal period remains something stupendous.

Principal Dawson is the last person likely to be guilty of exaggeration in this matter, and it will be well to consider what he has to say about it:—

"The rate of accumulation of coal was very slow. The climate of the period, in the northern temperate zone, was of such a character that the true conifers show rings of growth, not larger, nor much less distinct, than those of many of their modern congeners. The *Sigillarioe* and *Calamites* were not, as often supposed, composed wholly, or even principally, of lax and soft tissues, or necessarily short-lived. The former had, it is true, a very thick inner bark; but their dense woody axis, their thick and nearly imperishable outer bark, and their scanty and rigid foliage, would indicate no very rapid growth or decay. In the case of the *Sigillarioe*, the variations in the leaf-scars in different parts of the trunk, the intercalation of new ridges at the surface representing that of new woody wedges in the axis, the transverse marks left by the stages of upward growth, all indicate that several years must have been required for the growth of stems of moderate size. The enormous roots of these trees, and the condition of the coal-swamps, must have exempted them from the danger of being overthrown by violence. They probably fell in successive generations from natural decay; and making every allowance for other materials, we may safely assert that every foot of thickness of pure bituminous coal implies the quiet growth and fall of at least fifty generations of *Sigillarioe*, and therefore an undisturbed condition of forest growth enduring through many centuries. Further, there is evidence that an immense amount of loose parenchymatous tissue, and even of wood, perished by decay, and we do not know to what extent even the most durable tissues may have disappeared in this way; so that, in many coal-seams, we may have only a very small part of the vegetable matter produced."

Undoubtedly the force of these reflections is not diminished when the bituminous coal, as in Britain, consists of accumulated spores and spore- cases, rather than of stems. But, suppose we adopt Principal Dawson's assumption, that one foot of coal represents fifty generations of coal plants; and, further, make the moderate supposition that each generation of coal plants took ten years to come to maturity—then, each foot- thickness of coal represents five hundred years. The superimposed beds of coal in one coal-field may amount to a thickness of fifty or sixty feet, and therefore the coal alone, in that field, represents 500 x 50 = 25,000 years. But the actual coal is but an insignificant portion of the total deposit, which, as has been seen, may amount to between two and three miles of vertical thickness. Suppose it be 12,000 feet—which is 240 times the thickness of the actual coal —is there any reason why we should believe it may not have taken 240 times as long to form? I know of none. But, in this case, the time which the coal-field represents would be 25,000 x 240 = 6,000,000 years. As affording a definite chronology, of course such calculations as these are of no value; but they have much use in fixing one's attention upon a possible minimum. A man may be puzzled if he is asked how long Rome took a-building; but he is proverbially safe if he affirms it not to have been built in a day; and our geological calculations are all, at present, pretty much on that footing.

A second consideration which the study of the coal brings prominently before the mind of any one who is familiar with palaeontology is, that the coal Flora, viewed in relation to the enormous period of time which it lasted, and to the still vaster period which has elapsed since it flourished, underwent little change while it endured, and in its peculiar characters, differs strangely little from that which at present exist.

The same species of plants are to be met with throughout the whole thickness of a coal-field, and the youngest are not sensibly different from the oldest. But more than this. Notwithstanding that the carboniferous period is separated from us by more than the whole time represented by the secondary and tertiary formations, the great types of vegetation were as distinct then as now. The structure of the modern club-moss furnishes a complete explanation of the fossil remains of the *Lepidodendra*, and the fronds of some of the ancient ferns are hard to distinguish from existing ones. At the same time, it must be remembered, that there is nowhere in the world, at present, any *forest* which bears more than a rough analogy with a coal-forest. The types may remain, but the details of their form, their relative proportions, their associates, are all altered. And the tree-fern forest of Tasmania, or New Zealand, gives one only a faint and remote image of the vegetation of the ancient world.

Once more, an invariably-recurring lesson of geological history, at whatever point its study is taken up: the lesson of the almost infinite slowness of the modification of living forms. The lines of the pedigrees of living things break off almost before they begin to converge.

Finally, yet another curious consideration. Let us suppose that one of the stupid, salamander-like Labyrinthodonts, which pottered, with much belly and little leg, like Falstaff in his old age, among the coal-forests, could have had thinking power enough in his small brain to reflect upon the showers of spores which kept on falling through years and centuries, while perhaps not one in ten million fulfilled its apparent purpose, and reproduced the organism which gave it birth: surely he might have been excused for moralizing upon the thoughtless and wanton extravagance which Nature displayed in her operations.

But we have the advantage over our shovel-headed predecessor—or possibly ancestor—and can perceive that a certain vein of thrift runs through this apparent prodigality. Nature is never in a hurry, and seems to have had always before her eyes the adage, "Keep a thing long enough, and you will find a use for it." She has kept her beds of coal many millions of years without being able to find much use for them; she has sent them down beneath the sea, and the sea-beasts could make nothing of them; she has raised them up into dry land, and laid the black veins bare, and still, for ages and ages, there was no living thing on the face of the earth that could see any sort of value in them; and it was only the other day, so to speak, that she turned a new creature out of her workshop, who by degrees acquired sufficient wits to make a fire, and then to discover that the black rock would burn.

I suppose that nineteen hundred years ago, when Julius Caesar was good enough to deal with Britain as we have dealt with New Zealand, the primaeval Briton, blue with cold and woad, may have known that the strange black stone, of which he found lumps here and there in his wanderings, would burn, and so help to warm his body and cook his food. Saxon, Dane, and Norman swarmed into the land. The English people grew into a powerful nation, and Nature still waited for a full return of the capital she had invested in the ancient club-mosses. The eighteenth century arrived, and with it James Watt. The brain of that man was the spore out of which was developed the modern steam-engine, and all the prodigious trees and branches of modern industry which have grown out of this. But coal is as much an essential condition of this growth and development as carbonic acid is for that of a club-moss. Wanting coal, we could not have smelted the iron needed to make our engines, nor have worked our engines when we had got them. But take away the engines, and the great towns of Yorkshire and Lancashire vanish like a dream. Manufactures give place to agriculture and pasture, and not ten men can live where now ten thousand are amply supported.

Thus, all this abundant wealth of money and of vivid life is Nature's interest upon her investment in club-mosses, and the like, so long ago. But what becomes of the coal which is burnt in yielding this interest? Heat comes out of it, light comes out of it; and if we could gather together all that goes up the chimney, and all that remains in the grate of a thoroughly-burnt coal-fire, we should find ourselves in possession of a quantity of carbonic acid, water, ammonia, and mineral matters, exactly equal in weight to the coal. But these are the very matters with which Nature supplied the club-mosses which made the coal She is paid back principal and interest at the same time; and she straightway invests the carbonic acid, the water, and the ammonia in new forms of life, feeding with them the plants that now live. Thrifty Nature! Surely no prodigal, but most notable of housekeepers!

VI

ON THE BORDER TERRITORY BETWEEN THE ANIMAL AND THE VEGETABLE KINGDOMS

[1876]

In the whole history of science there is nothing more remarkable than the rapidity of the growth of biological knowledge within the last half- century, and the extent of the modification which has thereby been effected in some of the fundamental conceptions of the naturalist.

In the second edition of the "Règne Animal," published in 1828, Cuvier devotes a special section to the "Division of Organised Beings into Animals and Vegetables," in which the question is treated with that comprehensiveness of knowledge and clear critical judgment which characterise his writings, and justify us in regarding them as representative expressions of the most extensive, if not the profoundest, knowledge of his time. He tells us that living beings have been subdivided from the earliest times into *animated beings*, which possess sense and motion, and *inanimated beings*, which are devoid of these functions and simply vegetate.

Although the roots of plants direct themselves towards moisture, and their leaves towards air and light,—although the parts of some plants exhibit oscillating movements without any perceptible cause, and the leaves of others retract when touched,—yet none of these movements justify the ascription to plants of perception or of will. From the mobility of animals, Cuvier, with his characteristic partiality for teleological reasoning, deduces the necessity of the existence in them of an alimentary cavity, or reservoir of food, whence their nutrition may be drawn by the vessels, which are a sort of internal roots; and, in the presence of this alimentary cavity, he naturally sees the primary and the most important distinction between animals and plants.

Following out his teleological argument, Cuvier remarks that the organisation of this cavity and its appurtenances must needs vary according to the nature of the aliment, and the operations which it has to undergo, before it can be converted into substances fitted for absorption; while the atmosphere and the earth supply plants with juices ready prepared, and which can be absorbed immediately. As the animal body required to be independent of heat and of the atmosphere, there were no means by which the motion of its fluids could be produced by internal causes. Hence arose the second great distinctive character of animals, or the circulatory system, which is less important than the digestive, since it was unnecessary, and therefore is absent, in the more simple animals.

Animals further needed muscles for locomotion and nerves for sensibility. Hence, says Cuvier, it was necessary that the chemical composition of the animal body should be more complicated than that of the plant; and it is so, inasmuch as an additional substance, nitrogen, enters into it as an essential element; while, in plants, nitrogen is only accidentally joined with he three other fundamental constituents of organic beings—carbon, hydrogen, and oxygen. Indeed, he afterwards affirms that nitrogen is peculiar to animals; and herein he places the third distinction between the animal and the plant. The soil and the atmosphere supply plants with water, composed of hydrogen and oxygen; air, consisting of nitrogen and oxygen; and carbonic acid, containing carbon and oxygen. They retain the hydrogen and the carbon, exhale the superfluous oxygen, and absorb little or no nitrogen. The essential character of vegetable life is the exhalation of oxygen, which is effected through the agency of light. Animals, on the contrary, derive their nourishment either directly or indirectly from plants. They get rid of the superfluous hydrogen and carbon, and accumulate nitrogen. The relations of plants and animals to the atmosphere are therefore inverse. The plant withdraws water and carbonic acid from the atmosphere, the animal contributes both to it. Respiration—that is, the absorption of oxygen and the exhalation of carbonic acid—is the specially animal function of animals, and constitutes their fourth distinctive character.

Thus wrote Cuvier in 1828. But, in the fourth and fifth decades of this century, the greatest and most rapid revolution which biological science has ever undergone was effected by the application of the modern microscope to the investigation of organic structure; by the introduction of exact and easily manageable methods of conducting the chemical analysis of organic compounds; and finally, by the employment of instruments of precision for the measurement of the physical forces which are at work in the living economy.

That the semi-fluid contents (which we now term protoplasm) of the cells of certain plants, such as the *Charoe* are in constant and regular motion, was made out by Bonaventura Corti a century ago; but the fact, important as it was, fell into oblivion, and had to be rediscovered by Treviranus in 1807. Robert Brown noted the more complex motions of the protoplasm in the cells of *Tradescantia* in 1831; and now such movements of the living substance of plants are well known to be some of the most widely-prevalent phenomena of vegetable life.

Agardh, and other of the botanists of Cuvier's generation, who occupied themselves with the lower plants, had observed that, under particular circumstances, the contents of the cells of certain water-weeds were set free, and moved about with considerable velocity, and with all the appearances of spontaneity, as locomotive bodies, which, from their similarity to animals of simple organisation, were called "zoospores." Even as late as 1845, however, a botanist of Schleiden's eminence dealt very sceptically with these statements; and his scepticism was the more justified, since Ehrenberg, in his elaborate and comprehensive work on the *Infusoria*, had declared the greater number of what are now recognised as locomotive plants to be animals.

At the present day, innumerable plants and free plant cells are known to pass the whole or part of their lives in an actively locomotive condition, in no wise distinguishable from that of one of the simpler animals; and, while in this condition, their movements are, to all appearance, as spontaneous—as much the product of volition—as those of such animals.

Hence the teleological argument for Cuvier's first diagnostic character— the presence in animals of an alimentary cavity, or internal pocket, in which they can carry about their nutriment—has broken down, so far, at least, as his mode of stating it goes. And, with the advance of microscopic anatomy, the universality of the fact itself among animals has ceased to be predicable. Many animals of even complex structure, which live parasitically within others, are wholly devoid of an alimentary cavity. Their food is provided for them, not only ready cooked, but ready digested, and the alimentary canal, become superfluous, has disappeared. Again, the males of most Rotifers have no digestive apparatus; as a German naturalist has remarked, they devote themselves entirely to the "Minnedienst," and are to be reckoned among the few realisations of the Byronic ideal of a lover. Finally, amidst the lowest forms of animal life, the speck of gelatinous protoplasm, which constitutes the whole body, has no permanent digestive cavity or mouth, but takes in its food anywhere; and digests, so to speak, all over its body. But although Cuvier's leading diagnosis of the animal from the plant will not stand a strict test, it remains one of the most constant of the distinctive characters of animals. And, if we substitute for the possession of an alimentary cavity, the power of taking solid nutriment into the body and there digesting it, the definition so changed will cover all animals except certain parasites, and the few and exceptional cases of non-parasitic animals which do not feed at all. On the other hand, the definition thus amended will exclude all ordinary vegetable organisms.

Cuvier himself practically gives up his second distinctive mark when he admits that it is wanting in the simpler animals.

The third distinction is based on a completely erroneous conception of the chemical differences and resemblances between the constituents of animal and vegetable organisms, for which Cuvier is not responsible, as it was current among contemporary chemists. It is now established that nitrogen is as essential a constituent of vegetable as of animal living matter; and that the latter is, chemically speaking, just as complicated as the former. Starchy substances, cellulose and sugar, once supposed to be exclusively confined to plants, are now known to be regular and normal products of animals. Amylaceous and saccharine substances are largely manufactured, even by the highest animals; cellulose is widespread as a constituent of the skeletons of the lower animals; and it is probable that amyloid substances are universally present in the animal organism, though not in the precise form of starch.

Moreover, although it remains true that there is an inverse relation between the green plant in sunshine and the animal, in so far as, under these circumstances, the green plant decomposes carbonic acid and exhales oxygen, while the animal absorbs oxygen and exhales carbonic acid; yet, the exact researches of the modern chemical investigators of the physiological processes of plants have clearly demonstrated the fallacy of attempting to draw any general distinction between animals and vegetables on this ground. In fact, the difference vanishes with the sunshine, even in the case of the green plant; which, in the dark, absorbs oxygen and gives out carbonic acid like any animal.[1] On the other hand, those plants, such as the fungi, which contain no chlorophyll and are not green, are always, so far as respiration is concerned, in the exact position of animals. They absorb oxygen and give out carbonic acid.

[Footnote 1: There is every reason to believe that living plants, like living animals, always respire, and, in respiring, absorb oxygen and give off carbonic acid; but, that in green plants exposed to daylight or to the electric light, the quantity of oxygen evolved in consequence of the decomposition of carbonic acid by a special apparatus which green plants possess exceeds that absorbed in the concurrent respiratory process.]

Thus, by the progress of knowledge, Cuvier's fourth distinction between the animal and the plant has been as completely invalidated as the third and second; and even the first can be retained only in a modified form and subject to exceptions.

But has the advance of biology simply tended to break down old distinctions, without establishing new ones?

With a qualification, to be considered presently, the answer to this question is undoubtedly in the affirmative. The famous researches of Schwann and Schleiden in 1837 and the following years, founded the modern science of histology, or that branch of anatomy which deals with the ultimate visible structure of organisms, as revealed by the microscope; and, from that day to this, the rapid improvement of methods of investigation, and the energy of a host of accurate observers, have given greater and greater breadth and firmness to Schwann's great generalisation, that a fundamental unity of structure obtains in animals and plants; and that, however diverse may be the fabrics, or *tissues*, of which their bodies are composed, all these varied structures result from the metamorphosis of morphological units (termed *cells*, in a more general sense than that in which the word "cells" was at first employed), which are not only similar in animals and in plants respectively, but present a close resemblance, when those of animals and those of plants are compared together.

The contractility which is the fundamental condition of locomotion, has not only been discovered to exist far more widely among plants than was formerly imagined; but, in plants, the act of contraction has been found to be accompanied, as Dr. Burdon Sanderson's interesting investigations have shown, by a disturbance of the electrical state of the contractile substance, comparable to that which was found by Du Bois Reymond to be a concomitant of the activity of ordinary muscle in animals.

Again, I know of no test by which the reaction of the leaves of the Sundew and of other plants to stimuli, so fully and carefully studied by Mr. Darwin, can be distinguished from those acts of contraction following upon stimuli, which are called "reflex" in animals.

On each lobe of the bilobed leaf of Venus's fly-trap (*Dionoea muscipula*) are three delicate filaments which stand out at right angle from the surface of the leaf. Touch one of them with the end of a fine human hair and the lobes of the leaf instantly close together[2] in virtue of an act of contraction of part of their substance, just as the body of a snail contracts into its shell when one of its "horns" is irritated.

[Footnote 2: Darwin, *Insectivorous Plants*, p. 289.]

The reflex action of the snail is the result of the presence of a nervous system in the animal. A molecular change takes place in the nerve of the tentacle, is propagated to the muscles by which the body is retracted, and causing them to contract, the act of retraction is brought about. Of course the similarity of the acts does not necessarily involve the conclusion that the mechanism by which they are effected is the same; but it suggests a suspicion of their identity which needs careful testing.

The results of recent inquiries into the structure of the nervous system of animals converge towards the conclusion that the nerve fibres, which we have hitherto regarded as ultimate elements of nervous tissue, are not such, but are simply the visible aggregations of vastly more attenuated filaments, the diameter of which dwindles down to the limits of our present microscopic vision, greatly as these have been extended by modern improvements of the microscope; and that a nerve is, in its essence, nothing but a linear tract of specially modified protoplasm between two points of an organism—one of which is able to affect the other by means of the communication so established. Hence, it is conceivable that even the simplest living being may possess a nervous system. And the question whether plants are provided with a nervous system or not, thus acquires a new aspect, and presents the histologist and physiologist with a problem of extreme difficulty, which must be attacked from a new point of view and by the aid of methods which have yet to be invented.

Thus it must be admitted that plants may be contractile and locomotive; that, while locomotive, their movements may have as much appearance of spontaneity as those of the lowest animals; and that many exhibit actions, comparable to those which are brought about by the agency of a nervous system in animals. And it must be allowed to be possible that further research may reveal the existence of something comparable to a nervous system in plants. So that I know not where we can hope to find any absolute distinction between animals and plants, unless we return to their mode of nutrition, and inquire whether certain differences of a more occult character than those imagined to exist by Cuvier, and which certainly hold good for the vast majority of animals and plants, are of universal application.

A bean may be supplied with water in which salts of ammonia and certain other mineral salts are dissolved in due proportion; with atmospheric air containing its ordinary minute dose of carbonic acid; and with nothing else but sunlight and heat. Under these circumstances, unnatural as they are, with proper management, the bean will thrust forth its radicle and its plumule; the former will grow down into roots, the latter grow up into the stem and leaves of a vigorous bean-plant; and this plant will, in due time, flower and produce its crop of beans, just as if it were grown in the garden or in the field.

The weight of the nitrogenous protein compounds, of the oily, starchy, saccharine and woody substances contained in the full-grown plant and its seeds, will be vastly greater than the weight of the same substances contained in the bean from which it sprang. But nothing has been supplied to the bean save water, carbonic acid, ammonia, potash, lime, iron, and the like, in combination with phosphoric, sulphuric, and other acids. Neither protein, nor fat, nor starch, nor sugar, nor any substance in the slightest degree resembling them, has formed part of the food of the bean. But the weights of the carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur, and other elementary bodies contained in the bean- plant, and in the seeds which it produces, are exactly equivalent to the weights of the same elements which have disappeared from the materials supplied to the bean during its growth. Whence it follows that the bean has taken in only the raw materials of its fabric, and has manufactured them into bean-stuffs.

The bean has been able to perform this great chemical feat by the help of its green colouring matter, or chlorophyll; for it is only the green parts of the plant which, under the influence of sunlight, have the marvellous power of decomposing carbonic acid, setting free the oxygen and laying hold of the carbon which it contains. In fact, the bean obtains two of the absolutely indispensable elements of its substance from two distinct sources; the watery solution, in which its roots are plunged, contains nitrogen but no carbon; the air, to which the leaves are exposed, contains carbon, but its nitrogen is in the state of a free gas, in which condition the bean can make no use of it;[3] and the chlorophyll[4] is the apparatus by which the carbon is extracted from the atmospheric carbonic acid—the leaves being the chief laboratories in which this operation is effected.

[Footnote 3: I purposely assume that the air with which the bean is supplied in the case stated contains no ammoniacal salts.]

[Footnote 4: The recent researches of Pringsheim have raised a host of questions as to the exact share taken by chlorophyll in the chemical operations which are effected by the green parts of plants. It may be that the chlorophyll is only a constant concomitant of the actual deoxidising apparatus.]

The great majority of conspicuous plants are, as everybody knows, green; and this arises from the abundance of their chlorophyll. The few which contain no chlorophyll and are colourless, are unable to extract the carbon which they require from atmospheric carbonic acid, and lead a parasitic existence upon other plants; but it by no means follows, often as the statement has been repeated, that the manufacturing power of plants depends on their chlorophyll, and its interaction with the rays of the sun. On the contrary, it is easily demonstrated, as Pasteur first proved, that the lowest fungi, devoid of chlorophyll, or of any substitute for it, as they are, nevertheless possess the characteristic manufacturing powers of plants in a very high degree. Only it is necessary that they should be supplied with a different kind of raw material; as they cannot extract carbon from carbonic acid, they must be furnished with something else that contains carbon. Tartaric acid is such a substance; and if a single spore of the commonest and most troublesome of moulds—*Penicillium*—be sown in a saucerful of water, in which tartrate of ammonia, with a small percentage of phosphates and sulphates is contained, and kept warm, whether in the dark or exposed to light, it will, in a short time, give rise to a thick crust of mould, which contains many million times the weight of the original spore, in protein compounds and cellulose. Thus we have a very wide basis of fact for the generalisation that plants are essentially characterised by their manufacturing capacity—by their power of working up mere mineral matters into complex organic compounds.

Contrariwise, there is a no less wide foundation for the generalisation that animals, as Cuvier puts it, depend directly or indirectly upon plants for the materials of their bodies; that is, either they are herbivorous, or they eat other animals which are herbivorous.

But for what constituents of their bodies are animals thus dependent upon plants? Certainly not for their horny matter; nor for chondrin, the proximate chemical element of cartilage; nor for gelatine; nor for syntonin, the constituent of muscle; nor for their nervous or biliary substances; nor for their amyloid matters; nor, necessarily, for their fats.

It can be experimentally demonstrated that animals can make these for themselves. But that which they cannot make, but must, in all known cases, obtain directly or indirectly from plants, is the peculiar nitrogenous matter, protein. Thus the plant is the ideal *prolétaire* of the living world, the worker who produces; the animal, the ideal aristocrat, who mostly occupies himself in consuming, after the manner of that noble representative of the line of Zähdarm, whose epitaph is written in "Sartor Resartus."

Here is our last hope of finding a sharp line of demarcation between plants and animals; for, as I have already hinted, there is a border territory between the two kingdoms, a sort of no-man's-land, the inhabitants of which certainly cannot be discriminated and brought to their proper allegiance in any other way.

Some months ago, Professor Tyndall asked me to examine a drop of infusion of hay, placed under an excellent and powerful microscope, and to tell him what I thought some organisms visible in it were. I looked and observed, in the first place, multitudes of *Bacteria* moving about with their ordinary intermittent spasmodic wriggles. As to the vegetable nature of these there is now no doubt. Not only does the close resemblance of the *Bacteria* to unquestionable plants, such as the *Oscillatorioe* and the lower forms of *Fungi*, justify this conclusion, but the manufacturing test settles the question at once. It is only needful to add a minute drop of fluid containing *Bacteria*, to water in which tartrate, phosphate, and sulphate of ammonia are dissolved; and, in a very short space of time, the clear fluid becomes milky by reason of their prodigious multiplication, which, of course, implies the manufacture of living Bacterium-stuff out of these merely saline matters.

But other active organisms, very much larger than the *Bacteria*, attaining in fact the comparatively gigantic dimensions of 1/3000 of an inch or more, incessantly crossed the field of view. Each of these had a body shaped like a pear, the small end being slightly incurved and produced into a long curved filament, or *cilium*, of extreme tenuity. Behind this, from the concave side of the incurvation, proceeded another long cilium, so delicate as to be discernible only by the use of the highest powers and careful management of the light. In the centre of the pear-shaped body a clear round space could occasionally be discerned, but not always; and careful watching showed that this clear vacuity appeared gradually, and then shut up and disappeared suddenly, at regular intervals. Such a structure is of common occurrence among the lowest plants and animals, and is known as a *contractile vacuole*.

The little creature thus described sometimes propelled itself with great activity, with a curious rolling motion, by the lashing of the front cilium, while the second cilium trailed behind; sometimes it anchored itself by the hinder cilium and was spun round by the working of the other, its motions resembling those of an anchor buoy in a heavy sea. Sometimes, when two were in full career towards one another, each would appear dexterously to get out of the other's way; sometimes a crowd would assemble and jostle one another, with as much semblance of individual effort as a spectator on the Grands Mulets might observe with a telescope among the specks representing men in the valley of Chamounix.

The spectacle, though always surprising, was not new to me. So my reply to the question put to me was, that these organisms were what biologists call *Monads*, and though they might be animals, it was also possible that they might, like the *Bacteria*, be plants. My friend received my verdict with an expression which showed a sad want of respect for authority. He would as soon believe that a sheep was a plant. Naturally piqued by this want of faith, I have thought a good deal over the matter; and, as I still rest in the lame conclusion I originally expressed, and must even now confess that I cannot certainly say whether this creature is an animal or a plant, I think it may be well to state the grounds of my hesitation at length. But, in the first place, in order that I may conveniently distinguish this "Monad" from the multitude of other things which go by the same designation, I must give it a name of its own. I think (though, for reasons which need not be stated at present, I am not quite sure) that it is identical with the species *Monas lens* as defined by the eminent French microscopist Dujardin, though his magnifying power was probably insufficient to enable him to see that it is curiously like a much larger form of monad which he has named *Heteromita*. I shall, therefore, call it not *Monas*, but *Heteromita lens*.

I have been unable to devote to my *Heteromita* the prolonged study needful to work out its whole history, which would involve weeks, or it may be months, of unremitting attention. But I the less regret this circumstance, as some remarkable observations recently published by Messrs. Dallinger and Drysdale[5] on certain Monads, relate, in part, to a form so similar to my *Heteromita lens*, that the history of the one may be used to illustrate that of the other. These most patient and painstaking observers, who employed the highest attainable powers of the microscope and, relieving one another, kept watch day and night over the same individual monads, have been enabled to trace out the whole history of their *Heteromita*; which they found in infusions of the heads of fishes of the Cod tribe.

[Footnote 5: "Researches in the Life-history of a Cercomonad: a Lesson in Biogenesis"; and "Further Researches in the Life-history of the Monads," —*Monthly Microscopical Journal*, 1873.]

Of the four monads described and figured by these investigators, one, as I have said, very closely resembles *Heteromita lens* in every particular, except that it has a separately distinguishable central particle or "nucleus," which is not certainly to be made out in *Heteromita lens*; and that nothing is said by Messrs. Dallinger and Drysdale of the existence of a contractile vacuole in this monad, though they describe it in another.

Their *Heteromita*, however, multiplied rapidly by fission. Sometimes a transverse constriction appeared; the hinder half developed a new cilium, and the hinder cilium gradually split from its base to its free end, until it was divided into two; a process which, considering the fact that this fine filament cannot be much more than 1/100000 of an inch in diameter, is wonderful enough. The constriction of the body extended inwards until the two portions were united by a narrow isthmus; finally, they separated and each swam away by itself, a complete *Heteromita*, provided with its two cilia. Sometimes the constriction took a longitudinal direction, with the same ultimate result. In each case the process occupied not more than six or seven minutes. At this rate, a single *Heteromita* would give rise to a thousand like itself in the course of an hour, to about a million in two hours, and to a number greater than the generally assumed number of human beings now living in the world in three hours; or, if we give each *Heteromita* an hour's enjoyment of individual existence, the same result will be obtained in about a day. The apparent suddenness of the appearance of multitudes of such organisms as these in any nutritive fluid to which one obtains access is thus easily explained.

During these processes of multiplication by fission, the *Heteromita* remains active; but sometimes another mode of fission occurs. The body becomes rounded and quiescent, or nearly so; and, while in this resting state, divides into two portions, each of which is rapidly converted into an active *Heteromita*.

A still more remarkable phenomenon is that kind of multiplication which is preceded by the union of two monads, by a process which is termed *conjugation*. Two active *Heteromitoe* become applied to one another, and then slowly and gradually coalesce into one body. The two nuclei run into one; and the mass resulting from the conjugation of the two *Heteromitoe*, thus fused together, has a triangular form. The two pairs of cilia are to be seen, for some time, at two of the angles, which answer to the small ends of the conjoined monads; but they ultimately vanish, and the twin organism, in which all visible traces of organisation have disappeared, falls into a state of rest. Sudden wave- like movements of its substance next occur; and, in a short time, the apices of the triangular mass burst, and give exit to a dense yellowish, glairy fluid, filled with minute granules. This process, which, it will be observed, involves the actual confluence and mixture of the substance of two distinct organisms, is effected in the space of about two hours.

The authors whom I quote say that they "cannot express" the excessive minuteness of the granules in question, and they estimate their diameter at less than 1/200000 of an inch. Under the highest powers of the microscope, at present applicable, such specks are hardly discernible. Nevertheless, particles of this size are massive when compared to physical molecules; whence there is no reason to doubt that each, small as it is, may have a molecular structure sufficiently complex to give rise to the phenomena of life. And, as a matter of fact, by patient watching of the place at which these infinitesimal living particles were discharged, our observers assured themselves of their growth and development into new monads. In about four hours from their being set free, they had attained a sixth of the length of the parent, with the characteristic cilia, though at first they were quite motionless; and, in four hours more, they had attained the dimensions and exhibited all the activity of the adult. These inconceivably minute particles are therefore the germs of the *Heteromita*; and from the dimensions of these germs it is easily shown that the body formed by conjugation may, at a low estimate, have given exit to thirty thousand of them; a result of a matrimonial process whereby the contracting parties, without a metaphor, "become one flesh," enough to make a Malthusian despair of the future of the Universe.

I am not aware that the investigators from whom I have borrowed this history have endeavoured to ascertain whether their monads take solid nutriment or not; so that though they help us very much to fill up the blanks in the history of my *Heteromita*, their observations throw no light on the problem we are trying to solve—Is it an animal or is it a plant?

Undoubtedly it is possible to bring forward very strong arguments in favour of regarding *Heteromita* as a plant.

For example, there is a Fungus, an obscure and almost microscopic mould, termed *Peronospora infestans*. Like many other Fungi, the *Peronosporoe* are parasitic upon other plants; and this particular *Peronospora* happens to have attained much notoriety and political importance, in a way not without a parallel in the career of notorious politicians, namely, by reason of the frightful mischief it has done to mankind. For it is this *Fungus* which is the cause of the potato disease; and, therefore, *Peronospora infestans* (doubtless of exclusively Saxon origin, though not a