ON MICRO-GEOLOGY.

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(Read 18th December, 1862.)

The object of the present paper is to pass in review those contributions to the science of Geology which have been effected by the aid of the Microscope, and to make suggestions with regard to some points upon which further investigation by the same means is desirable.

I have no desire to exalt microscopic Geology to the dignity of a separate science; it is rather to be regarded as a subsidiary branch of physical, chemical and organic Geology, enabling us to extend and complete our studies of many terrestrial changes which, without its aid, would be incomprehensible.

In order to make himself acquainted with the nature and past history of a rock the geologist examines its lithological character and its organic remains. In each of these divisions of the subject the microscope is indispensible. I propose to begin with the Palæontological evidence furnished by the microscope; commencing by considering the assistance it has rendered in furnishing characters for the discrimination of various members of the animal and vegetable kingdoms, and afterwards passing on to notice the different formations where the knowledge thus obtained has been applied.

It will be convenient to consider animated beings under the three heads of Animals, Plants and Infusoria, including under the latter term all the organisms, whether animal, vegetable or doubtful, which are so minute as to form, of themselves, objects for microscopic examination.

Plants. The cases where the microscopic structure of a plant is preserved in its fossil state are somewhat exceptional. Usually we may expect vegetable matter lying under water to undergo decomposition and disintegration before it becomes so covered with sediment as to arrest further change of this nature. Nevertheless we have many instances where the distinctive characters of exogenous and endogenous wood can be clearly made out, occasionally by the naked eye. In the Tertiary leaf-beds the botanist finds nearly all the characters of the living plant; in lignite the woody structure is apparent to the eye; but it is when we come to examine coal that we require the microscope to accompany us even in the first steps. Doubtless there is much of this substance which underwent disintegration before it was consolidated; but in favourable specimens it is not difficult to obtain evidence of structure. In many cases we have presented to us the glandular woody tissue characteristic of the Coniferæ; and it has even been sought to ascribe such specimens to living genera, as *Pinus* and *Araucaria*, by the arrangement of the glands. We are not, however, entirely without the preserved remains of Angiosperms; and one reason why there are not more is doubtless the fact that their tissues are very rapidly destroyed by exposure to water.

In the division Cryptogams we have abundance of ferns; and the microscope not unfrequently reveals the presence of their peculiar form of vascular tissue. Equisetum stems are said to occur in the leaf beds of the Isle of Mull.

It is when portions of plants become silicified, that their structure is most beautifully preserved; in this case the vegetable matter has been removed, and replaced, atom for atom, by silex: thin polished sections then shew their most minute characters. Palms and Dicotyledons are frequently so found. On the whole, however, the fossil botanist looks to characters, other than those which are microscopical, for the discrimination of his specimens.

Animals. With few exceptions it is the hard parts of animals which are alone preserved in the fossil state. The exceptions, however, are instructive and lead us to expect further evidence of the same kind. Thus we have hair in good preservation, as in the case of the Siberian mammoth and rhinoceros, and in that of the fossil bones of Escholtz Bay, which have lost but little of their animal matter and which are dug up accompanied by hair. We have feathers of birds which have left very accurate traces in the remarkable fossil from the lithographic slate of Solenhofen, recently described by Professor Owen and by him called *Archæopteryx longicaudata.* The firm integument of Ichthyosauri is often evident, showing to what we are indebted for the wonderful state of preservation in which we find their skeletons.

The *scales* of fishes and reptiles are in many cases valuable as serving to indicate the affinities of the animal which once possessed them. The microscopic examination of "ganoid" scales shews that they are composed internally of bone and externally of enamel; and it also exhibits the presence of lacunæ, canaliculi and Haversian canals as in ordinary bone. The preservation of the vast numbers of ganoid dermal skeletons is due to the large amount of earthy matter contained in them.

When we come to *bone* the microscope again renders great assistance, although it is in most cases subsidiary to the more important investigation founded upon the outward form and size of the specimens. It may, however, be remarked that "in birds the Haversian canals are more numerous and "smaller than in the mammalia, and frequently run in a "direction at right angles to the shaft; the lacunæ are also "smaller and more numerous. In reptiles the Haversian "canals are few and very large; the lacunæ and the canali-"culi are also very large, and the latter very numerous. In "fishes the structure is more irregular; there are no con-"centric laminæ; the Haversian canals are sometimes absent, "at others very large and numerous, frequently the lacunæ "are absent, while the canaliculi are unusually long and "elegantly wavy and branched." Thus we have a means, which we may venture to consider trustworthy, of discovering the affinities of vertebrated animals, especially when we have once established the class to which they belong. We may, for instance, infer the sauroid relationship of a fish or the batrachian character of a reptile from data furnished by microscopic examination. Thus Professor Quekett examined certain bones found by Dr. Falconer in the North of India, and pronounced them to be certainly reptilian and probably chelonian; this induced Dr. Falconer to conclude that they were the toe bones of the colossal tortoise, twenty feet long *(Colossochelys atlas)* of which he had previously found the carapace in the Sewalik hills. Again, some fragments of bone which were found in a chalk pit and were referred by Professor Owen to the class of birds, on examination by the microscope indicated reptilian affinities; and it was thus shewn that they might safely be ascribed to one of the great flying lizards of the secondary rocks, the Pterodactyls.

In the *teeth* of vertebrata we have many interesting differences of structure, discernable only by the microscope. I need not remark that one of the most important Palæontological characters of teeth is the manner in which they are fixed to the jaw; but beyond this we find that in many fossil ganoid fishes a labyrinthic structure is apparent, the external layer of cement converging by numerous convoluted folds towards the central cavity of the tooth. The genus Rhizodus was originally founded upon teeth from the Devonian and Carboniferous formations which possessed this character. The teeth of the

Labyrinthodon of Warwickshire and of the Mastodonsaurus of Wirtemberg shew this structure in a most remarkable degree; and the inference was drawn that, if these animals were reptilian, they would probably turn out to be related to the class of fishes; in some members of which we find the same structure of the tooth. The conclusion was borne out by the subsequent discovery and examination of other portions of the skeleton, indicating that the Labyrinthodon or Mastodonsaurus was Batrachian in its characters. Again,—"a rock-"formation extends over many parts of Russia, whose mineral "characters might justify its being likened either to the *old* "or to the *new* red sandstone of this country, and whose posi-"tion, relatively to the other strata, is such that there is great "difficulty in obtaining evidence from the usual sources as to "its place in the series. Hence, the only hope of settling "this question, (which was one of great practical importance, "since if the formation were *new* red, coal might be expected to "underlie it, whilst if *old* red, no reasonable hope of coal could "be entertained,) lay in the determination of the organic "remains which this stratum might yield; but unfortunately "these were few and fragmentary, consisting chiefly of teeth, "which are seldom perfectly preserved. From the gigantic size "of these teeth, together with their form, it was at first inferred "that they belonged to Saurian reptiles, in which case the "sandstone must have been considered as [probably] new red; "but microscopic examination of their intimate structure "unmistakeably proved them to belong to a genus of fishes "*(Dendrodus)* which is exclusively Palæozoic, and thus "decided that the formation must be old red."—(Carpenter.) Another instance is furnished by certain teeth similar to those of the *Cestracion* or Port-Jackson shark, and referred to the genus *Acrodus*—they are found throughout the whole of the secondary rocks. From their peculiar form they are called by quarrymen "fossil leeches," and the older fossilists regarded them as petrified Vermes; but the structure, as shewn by the microscope, is closely similar to that of the teeth of Cestracion. (See Owen's *Odontography.*)

Passing to the Invertebrata we find microscopic characters of great importance in some of the divisions of the Mollusca. In many of the Cephalopoda there is an internal shell—the "cuttle-fish bone," which exhibits a very beautiful and remarkable structure. The outer shelly portion of this body consists of horny layers alternating with calcified layers, in which last may be seen a hexagonal arrangement like that present in the hinge tooth of *Mya arenaria.* The soft friable substance that occupies the hollow of this boat-shaped shell is formed of a number of delicate plates, running across it from one side to the other in parallel directions, having the appearance of millions of microscopic pillars. The shell thus becomes sufficiently light to float in water, and by its buoyancy assists in the motion of the animal. Most of the fossil cuttle fishes, however, are those which, like the Nautilus and Ammonite, possess external shell, having much the same structure that we find in bivalves. In some of the oldest fossil genera, *actinoceras, gyroceras* and *phragmoceras,* the siphuncle, or passage connecting the different chambers, is large, and contains in its centre a smaller tube, the space between the two being filled up with radiating plates, like the lamella of a coral. Another point of interest in connection with Cephalopoda is the fact that the Ammonites closed their shells by a horny or shelly operculum. In the round-backed Ammonites the operculum is shelly, and in its internal structure it resembles the cancellated tissue of bones.

The shell of the *Brachiopoda* is so characteristic that the examination of a minute fragment is sufficient to determine the class. According to Dr. Carpenter it consists of flattened prisms of considerable length arranged parallel to each other with great regularity, and obliquely to the surfaces of the shell. Besides this, in most brachiopoda the shell is traversed by canals from one surface to the other, nearly vertically, and occurring regularly, the distance and size of the perforations varying with the species.

It may be well to notice here, that the structure of shell in specimens from old formations, is often made out only with difficulty. Carbonate of lime, whatever be its original form, shews a strong tendency to pass into a crystalline condition by a change in molecular arrangement. Thus in fossil crinoids we often discover that although the outward form of the animal is preserved, yet it breaks up without difficulty into fragments, having the characteristic rhombohedral fracture of calcareous spar. We have a ready explanation of this phenomenon in the power which water possesses, when containing carbonic acid gas, of dissolving carbonate of lime; and of re-depositing it again in the crystalline condition, when the carbonic acid escapes from solution. Incrustations of carbonate of lime due to this cause and found in conduit pipes, shew crystalline structure in a very marked degree. We are not surprised, therefore, to find that a similar effect has been produced in old fossil shells, whether of mollusca or of other classes of animals, if composed of carbonate of lime.

The shell of Echinoderms is highly characteristic, being composed of a network of calcareous matter more or less regular, and familiar to microscopic observers. The plates are often furnished with calcareous appendages, tubercles, spines, hooks, "anchors," etc., all forming exceedingly interesting objects. Count Munster has figured the microscopic plates, apparently of a *Holothuria*, from the chalk of Warminster; and the anchor of a *Synapta* from a still older formation,—the upper oolite of Bavaria. "Microscopic "observers will doubtless meet with many such detached "plates and spines, when searching for Polycystineæ and "other Rhizopods in the oolitic and cretaceous strata." (Owen's *Palæontology.*)

The very peculiar compound eye of the Trilobite is shewn with great clearness by the microscope, which thus adds considerably to our knowledge of the life-history of these remarkable creatures.

I need say but little of the remains of corals and bryozoa; their examination of necessity includes the arrangement of their septa and other internal parts, which in many cases can only be done by the microscope.

The hard parts of sponges are the spiculæ which they contain; these, which are generally siliceous—sometimes calcareous—vary considerably in form even in the same specimen; so that they can hardly serve to distinguish genera, although they enable us to form an idea of the *class* of organism with which we are dealing. In some agates and flints we find preserved even the fibrous portion of the sponge.

Infusoria.—The organisms included under this term, though for the most part extremely minute, are in the aggregate amongst the most active and powerful agents of physical change. By their countless numbers, their rapid multiplication, and their wide distribution, they produce results which fill the mind with astonishment.

I will for a moment refer to the Desmidiaceæ. We often find in flints from the chalk formation a number of minute globular bodies, set with radiating hooked spines, resembling the organism Xanthidium. On that account these Spiniferites were referred to Desmidiaceæ, and called Xanthidia. Existing members of this group, however, are solely freshwater; and Owen remarks that the Spiniferites are certainly marine bodies, and probably the spores of sponges.

The divisions of Infusoria which are most interesting to the geologist, are the Foraminifera, the Polycystina and the Diatomaceæ.

The Foraminifera and Polycystina belong to that branch of the Animal Kingdom which is now generally called Protozoa, and to that division of it characterized by the absence of any permanent mouth. The Astomatous Protozoa are typified by the common Amœba so well-known to microscopists, which with its allies forms the group Rhizopoda, distinguished by their property of sending out portions of the body, as processes or "pseudopodia," in any direction whatever; by means of which they travel and obtain food.

The Foraminifera are minute Rhizopoda provided with calcareous shells of the most diversified and, at the same time, of the most beautiful forms. In one division the shells are perforated by minute apertures through which the pseudopodia are extended; in the rest the substance of the shell is imperforate, so that all nourishment has to be obtained through the opening or mouth of the shell or of its last chamber.

The animal has often the power of building successive chambers, much like the Nautilus and allied Cephalopods; the earlier naturalists consequently placed the Foraminifera amongst the Cephalopoda, but the examination of the body substance shewed the structure of the animal to be perfectly simple and homogeneous. The manner in which the various chambers of the shell are joined and arranged has been used for the classification of the group; but it has long been felt that the principle was not sound; and Dr. Carpenter, in his new work on Foraminifera, shews that it is not at all to be relied on, the limits of variation being far wider than was previously supposed.

The *Polycystina* are allied in character to the Foraminifera—their shells are perforated, and generally spinous. None can examine them without allowing their exquisite beauty. An important peculiarity is the fact that their shells are siliceous instead of calcareous.

Lastly, the *Diatomaceæ* are organisms which have been cast backwards and forwards between the zoologist and botanist, but which are now usually considered as belonging to the Vegetable Kingdom. They are important to the geologist as possessing a siliceous covering, which may be practically regarded as indestructible. Every microscopist is acquainted with the beautiful and varied appearance presented by their valves, and with the fact that endless controversy has taken place with respect to the precise nature of the markings on those valves.

It may be well to take a brief view of the scale upon which these various organisms are working at the present day.

Foraminifera. In the soundings of deep seas beyond the tropics, these animals are brought up in great abundance. Captain Dayman, R.N., states, that "between 15° and 45° "W. long., lies the deepest part of the ocean between Ireland "and Newfoundland, varying from about 1,500 to 2,400 "fathoms, the bottom of which is almost wholly composed of "soft mealy substance, which, for want of a better name, I "have called oaze. This substance is remarkably sticky, "having been found to adhere to the sounding rod and line "through its passage from the bottom to the surface, in some "instances from a depth of more than 2,000 fathoms." We have thus a length of more than 1,300 miles, in which only two exceptions occurred to the above description of sea bottom. When the mud is dried it resembles chalk in appearance and properties, possessing a tolerable consistency. Professor Huxley examined the sediment microscopically; and he believes 85 per cent. of the whole belong to one species of the genus Globigerina; 5 per cent. to other calcareous organisms of at most four or five species, and the remaining 10 per cent. consists partly of minute granules of quartz and partly of animal and vegetable organisms, (including diatomaceæ) provided with siliceous skeletons and envelopes.

This instance is highly instructive. We observe first that there is thus provided a means by which the carbonate of lime dissolved and brought down by rivers, and by them poured into the sea, is absorbed and again separated in the solid form by the secreting power of these innumerable minute organisms. It is true that ordinary testacea, as the shell-bearing mollusca, play the same part; but it appears to me that in the effect produced, their labour is unimportant when compared with that of the Foraminifera. The only other class of animals which can compete with these latter in the work of separating carbonate of lime from the water of the ocean, is the great class of corals, which bring about in tropical seas the same result as that obtained in extra-tropical regions by the agency of microscopic Rhizopoda. We have in the Atlantic Ocean the materials for the formation of a bed of chalk or limestone, which we may put down as having an area of at least six hundred thousand square miles, and which in the course of ages may attain to an enormous thickness.

Another reflection occurs to me. Let us suppose the bed of soft porous limestone so formed, to rise from the ocean, and become dry land. It is exposed to the action of water which, being in contact with the atmosphere, will contain carbonic acid and will thus acquire the power of dissolving carbonate of lime. The water, in percolating through the various layers of the porous limestone, will dissolve a portion of the carbonate of lime from the upper layers; and subsequently, as its carbonic acid escapes, it will re-deposit it again in the solid form in the lower layers. But, in this process, the carbonate of lime will be deposited in a crystalline condition and will naturally arrange itself round the particles it already finds, namely, the shells of the Foraminifera etc. By a continuance of this action, we shall have the lower layers of the soft calcareous formation gradually converted into a more or less compact rock, composed of small globular grains, formed by the successive deposition of layers of carbonate of lime round a microscopic shell or other fragment. In other words, we shall thus obtain an oolitic limestone of the ordinary character. By a further continuance of the same change, or by the action of other causes which it is not the place here to consider, the oolitic character may be lost, or the original substance may pass directly into the condition of a compact or crystalline limestone. We see something analogous in the change of structure to which I have referred when speaking of the shells of fossil mollusca from old formations.

It has been shewn, by Bischof, that the water of the sea contains five times the amount of carbonic acid which would be requisite to hold in solution the quantity of carbonate of lime it actually contains; or in other words, the amount of carbonate of lime in sea water must rise to five times its present amount before any would be precipitated chemically. It is possible that such a precipitation might occur locally to a small extent; but I am referring to the ocean as a whole. Hence we know of no means by which a limestone rock can be formed in the sea except the agency of organic beings; which we have seen to consist mainly of corals and rhizopoda.

The N.E. coast of Australia with its associated coral reefs has been ably described by Professor Jukes. He states that the "bottom" between the "inner reefs" of the great Australian barrier, when brought up by the dredge from a depth of fifteen or twenty fathoms, often looked very like the unconsolidated mass of some of the coarse shelly limestones to be found among the oolites of Gloucestershire. At other times the dredge came up completely filled with the small round Foraminifera called Orbitolites, and these organisms seemed in some places to make up the whole sand of the beach, either of the coral islets or of the neighbouring shores. In the deep sea around, and in all the neighbouring seas, from Torres Straits to the Straits of Malacca, whenever "bottom" was brought up by the lead, it was found to be a very fine-grained, impalpable, pale olive-green mud, which was wholly soluble in diluted hydrochloric acid. This substance, when dried, would therefore be scarcely different from chalk, though it was commonly of a greener tinge. This fine calcareous mud may be partly derived, like the oaze of the North Atlantic, from the calcareous bodies of minute animals that live either on the surface or in the depths of the seas at the bottom of which it is found; but much of it is doubtless derived from the waste of the coral reefs themselves.

Polycistina. Shells of this class are found in deep sea soundings associated with the shells of foraminifera, as in the mud of the Gulf of the Erebus and Terror, and in the mud of the North Atlantic. Soundings of the gulf stream near Key Tiscayne, Florida, varying in depth from 147 fathoms to 205 fathoms give a light greenish-grey mud composed of Foraminifers, Diatoms, Polycystins and Geolites, in a profusion only surpassed by the fossil polycystinous strata of Barbadoes. The Foraminifers compose the largest part of these muds.

Diatomaceæ. These organisms, generally far more minute than the smallest testaceous Rhizopoda, produce by their numbers the most surprising results. They appear to be universally distributed whenever there happens to be a collection of water in which they may live and multiply. According to Ehrenberg, there are formed annually in the mud deposited in the harbour of Wismar, in the Baltic, 17,946 cubic feet of siliceous organisms. Although it takes a hundred millions of these to weigh a grain, Ehrenberg collected a pound weight of them in an hour. According to the same authority the water of the Mississippi at Memphis, carries down in every second

147 cubic feet of solid matter, in which are contained from 2 to 3 cubic feet of infusoria. The Nile carries down every second 130·9 cubic feet of mud, containing from 6 to 13 cubic feet of infusoria. And the Ganges with 557 cubic feet of mud per second, conveys from 69 to 139 cubic feet of infusoria, the latter number forming 25 per cent. of the whole sediment. The greater portion of the infusoria will doubtless consist of diatomaceæ.

Dr. Lorenz in describing the Gulf of Quarnero at the N.E. end of the Adriatic, says, "the vegetable organisms of "the Quarnero are distributed among one super-littoral and "four marine zones, having their maxima at the respective "depths of ½, 8, 20 and 45 fathoms. The higher these "zones the more they number new forms and bear a charac- "teristic type. The Diatomaceæ analogous in this respect to "the animal organisms, follow a different rule of distribution, "their new forms becoming more numerous with increasing "depth. The habitats of nearly 600 species of *Algæ*, (among "which are about 300 Diatomaceæ), have been ascertained."

In warm latitudes and seasons the water of peat bogs and stagnant water of all kinds swarm with infusoria, and the siliceous shells of those which are so covered, (chiefly the Diatomaceæ), have been found beneath peat bogs forming strata of many feet in thickness and co-extensive with the turbary, forming a siliceous marl of a pure whiteness. The "bergmehl" or mountain meal of Sweden is a fine powdery substance deposited upon the shores of the lake near Urania. It is used by the poorer inhabitants, when mixed with flour, as an article of food. It consists in great part of siliceous shells of infusoria with a little organic matter.

I remarked that we have in foraminifera potent agents for removing carbonate of lime from water and depositing it in the solid form. In the same manner we may view Polycystina, Diatomaceæ and Sponges as agents whereby silica is separated from water containing it in solution. The changes to which a deposit so formed would be naturally subject subsequently, are not very clearly understood; but we have all we require to account for the formation of a siliceous rock or of a siliceous portion of another rock, when not strictly of inorganic origin. We almost invariably find beds of limestone to contain siliceous fragments or concretions, more or less irregular in form and disposition. Thus we have the menilite of the Paris tertiary limestones, the flints of the chalk formation and the chert of the carboniferous limestone. In some, probably in all, of these cases organic agency has been involved, though to what extent it would often be difficult to say.

I proceed to notice the various formations in the descending order with reference to the microscopic organisms they contain.

Bischof mentions a diatomaceous clay amongst the deposits lying under the town of Amsterdam, at a depth of 138 feet. It is 8 feet in thickness and contains the siliceous shells of innumerable organisms amounting to $\frac{1}{3}$ or $\frac{1}{2}$ its entire mass. It also contains the remains of plants.

The town of Richmond, Virginia, is built on barren siliceous strata of marine origin and tertiary age. The strata are twenty feet in thickness, composed chiefly of infusorial flint-shells, including the well-known and beautiful microscopic objects Actinocyclus and Coscinodiscus.

In 1836, portions of the stone called "tripoli" or "polir-" schiefer" (polishing-slate) were microscopically examined by Ehrenberg, who discovered it to be wholly composed of the siliceous shells of infusoria and chiefly of an extinct species of Gallionella. At Bilin, in Bohemia, there is a single stratum of polierschiefer, not less than fourteen feet thick, forming the upper layer of a hill, in every cubic inch of which there are forty-one thousand millions of this one species. This mineral likewise contains shells of Navicula, Bacillaria, Actinocyclus and other siliceous organisms. The lower part of the stratum consists of the shells compacted together without any visible cement; in the upper masses the shells are cemented together and filled by amorphous siliceous matter possibly formed out of dissolved shells. At Egea, in Bohemia, there is a stratum of two miles in length and averaging twenty-eight feet in thickness, of which the uppermost ten feet are composed wholly of the siliceous shells of infusoria, including the beautiful Campylodiscus.

In the middle Eocene period we have limestones of vast extent almost entirely made up of Nummulites which, though not microscopic objects, have a structure which can only be investigated by the microscope, which shews them to belong to the Foraminifera. The nummulite limestones are found in Southern Europe, in Northern Africa, in India and China. They also occur in Jamaica and over vast areas of North America. They were evidently sedentary organisms; and, in the large thin species, one side is moulded to the inequalities of the sea-bed on which it grew. The summits of some of the Alps, such as the Dent du Midi and Diableretz, are formed of these beds; and the same rock forms the stone of which the Egyptian pyramids are built.

The mud of the Levant has been found to contain twenty-six species of Diatoms and eight species of Foraminifera, along with sponge spiculæ and fragments of Echinoderms and molluscs. The *Calcaire Grossier* of the Paris basin strongly resembles Levant mud in character. It contains countless numbers of Foraminifers; it forms a good building stone; and it has therefore been remarked that we may say the capital of France is almost entirely constructed of these minute shells.

The tertiary marls of Barbadoes have furnished an almost innumerable variety of shells of Polycystina. Their exquisite forms excite our admiration in the highest degree. Mr.

Stoddart says he has procured Polycystins from this earth at the rate of more than ten millions per avoirdupois pound.

The *Chalk* formation is remarkable for its flint nodules containing the remains of sponges, chiefly their spiculæ, along with other siliceous bodies, as the valves of Diatoms. The chalk itself is composed of the shells of Foraminifera, of other minute calcareous organisms and of bodies called crystalloids that probably are of inorganic origin.

The green sands of the Cretaceous formation and, indeed, of all formations from the Tertiary to the Silurian period contain casts of the minute shells of Foraminifera and Mollusca. Many of the cretaceous Foraminifers contain a brown colouring matter, which remains after the shell has been dissolved with weak acid and which has been regarded as the remains of the organic substance which once filled the shell.

In the Oolitic period we find that, in limestones having the character from which the formation derives its name, the globular calcareous grains of which the rock is composed are generally formed of a number of concentric layers of carbonate of lime incrusting foraminiferous shells. Near Bristol are two beds of this period composed of shell debris, Entomostraca, coral and Echinoderms. In many places the shell partings are covered with Cytheridæ and Estheridæ. The slabs of Oolite at Bath, Minchinhampton and Dundry afford perfect specimens of minute forms.

The Carboniferous limestone formation has in places furnished remarkable results. Thus, in Russia there is limestone of this period varying in thickness from 15 inches to 5 feet, almost entirely composed of foraminiferous shells of the genus Fusulina. Amongst the beds at Clifton belonging to the same formation Mr. Stoddart discovered one twelve feet thick, every pound by weight of which contains more than two millions of perfect Microzoa, Cytheridæ, Gasteropods and very beautiful cylindriform Polyzoa, the latter being so perfectly preserved as to show the cells and thin apertures.

The Silurian rocks are not without Foraminifera, which we thus see to have run through all the formations with which we are well acquainted. In hard limestones and marbles they can be detected in polished sections, and in thin slices laid on glass.

Dr. M. C. White has examined various specimens of the hornstone nodules found in the Devonian and Silurian rocks of New York, and has discovered abundant organisms referable to the Desmidiaceæ, besides a few Diatomaceæ, numerous spicula of sponges and also fragments of the teeth of Gasteropods. Among the Desmids there is a large variety of forms of Xanthidia supposed to be the Sporangia of Desmids [to these the same remarks will apply as to the Xanthidia of flints], besides an occasional duplicated Desmid, (?) also lines of cells, some of which appear to be sparingly branched.

Below the Silurian system microscopic examination does not appear to have been extended.

With regard to the range in geological time through which various organisms extended, it has been remarked that the lower we descend in the scale of organization the less is the liability to change or extinction which we find to exist. Species of *Bacillaria* still exist which were in being at the period of the deposition of the chalk. Existing species of Diatomaceæ have been detected as low down as the Oolite. Ehrenberg has discovered more than twenty species of siliceous-shelled Infusoria fossil in the chalk and chalk marls, which are indentical in species with some now living in the bed of the Baltic.

In Foraminifera most of the fossil genera and even some of the species pass through many formations; indeed, if correctly observed, the existing forms are the oldest known living organisms. *Dentalina communis, Orbitolites complanatus, Rosalina italica* and *Rotalina globulosa,* all living species, are said to be found in the chalk; *Rotalina umbilicata* ranges to the gault; and *Webbina rugosa* is common to the upper lias, the chalk and the present sea. There is, however, a source of error in this case which requires to be noticed. Fossil shells of Foraminifera are set free by the disintegration of sea cliffs and mixed with recent shells on every beach.

I proceed to notice in the next place, the evidence which the microscope has contributed in the study of the *lithological* character of rocks. In this branch of the subject I have little to report—it is as yet a field almost entirely unworked. I will briefly refer to Mr. Sorby's observations on the microscopic structure of crystals, in which he shews that it is possible to arrive at some knowledge of the temperature and depth at which the crystalline particles of granite and other igneous rocks were formed. Crystals formed from warm fluid solutions are often full of cavities which contain some of the fluid in which they were formed; but crystals formed in substances rendered fluid by fusion, contain cavities in which is some of the fused matter now become solid stone together with vacuiities, the relative size of which enables us to calculate the amount of heat requisite to melt and expand the contained stone or glass so as to fill up the whole cavity. Mr. Sorby applies his principles to the examination of many igneous rocks, lavas, traps and granites, and proves from them the igneous origin of all, with the remarkable result that the fluidity of the more superficial lavas and traps was more purely igneous than that of the deeper seated traps and granites. The blocks ejected from Vesuvius during eruption contain water, while the lavas do not; and the crystals of the Cornish elvans and the Cornish and Scotch granites contain both fluid and stone cavities, proving the presence of water and perhaps also of gas, as well as the existence of great heat. He says that in some coarse granites it is impossible to draw a line between them and veins, in which crystals of felspar, only upon the threshold of this description of scientific enquiry—and the steps which have been hitherto taken have indicated that the area still to be explored is that of a vast continent, upon the shores of which we have but just set our feet. I may be permitted to point out, therefore, in the next place, a few of the points which require furthur examination by the employment of the means upon which I have been dilating.

And first, we are in want of a systematic description of fossil microzoa. It is true that the organisms found in isolated deposits, such as those of Barbadoes, Virginia and other places, have been examined and described; but this by no means completes our knowledge either of the organisms themselves or of the classes to which they belong, or of the rocks in which they occur. The information which has thus been gained, and which will be gained in the same manner, requires systematizing and arranging. Dr. Carpenter's "Introduction to the study of the Foraminifera" is an example of what may be done by a patient study of one particular class of organisms; but even here our knowledge cannot be considered as at all complete so long as we are so little acquainted with the microscopic contents of the palæozoic and older secondary formations. We require, then, a scientific classification of microscopic organisms; whether, as in the case of the Diatoms and the Foraminifers, they belong to classes of which most of the members are minute; or whether, as with certain Gasteropods, they are microscopic genera of classes which in the main consist of individuals of larger size.

One of the phenomena most interesting to the student of nature is the succession of life in time—the gradual but constant change in the species of living beings peopling the earth through the countless ages of which the researches of geology have furnished evidence; and one of the problems which have caused most discussion, and which require the most profound reflection and patient investigation, is that which endeavours to account for this change. Hitherto the question has been studied almost exclusively with reference to organisms not microscopic. But just as the study of recent microzoa has thrown light upon the phenomena of life in the higher animals, which could not otherwise have been obtained; so it may well be surmised that the examination of the fossil microzoa of successive geological ages will lend very considerable assistance in the elucidation of this most interesting and, at present, most unsettled problem.

It is obvious that, before studying the succession of microscopic life in time, it is required to have a trustworthy list of organisms found in the various strata. The compilation of such a catalogue will again necessitate the complete examination of each formation, and especially of those in which no such examination has as yet been made. The ground yet to be explored is immense. So far, the limestones have yielded the most promising results; but, with few exceptions, it is only the limestones of comparatively recent formations that have been examined microscopically. We may hope for results interesting in the highest degree from such an examination of limestones of Silurian age—as previously mentioned, they have already furnished organisms. Or, to go still farther back in the world's history, the oldest rocks that have hitherto furnished fossils are those of the Cambrian age. So far, these fossils are very scanty. But in formations still older, the Laurentian of America, there are bands of limestone; and it has already been shown as highly probable that all limestones have been formed by organic agency, often by microscopic beings.

But other beds besides those which are calcareous will doubtless yield evidence of life on examination. Many shales, from their carbonaceous character and plant remains, have evidently been deposited near to land possibly under conditions not far removed from marshy or boggy—conditions highly favourable to the growth of microscopic organisms. The same remark holds with even greater force of beds formed mainly of carbonaceous material, as lignite, coal and cannel. In connexion with beds of peat we often find deposits of infusorial remains; it is in my opinion extremely probable that similar remains will be found along with coal and other varieties of fossilized vegetable matter.

In the examination of *rock materials* the ground has scarcely been broken. Yet the precise manner in which sediment has been collected, deposited and consolidated, the various sources from which it has been derived, the materials which have been subsequently added and the changes to which it has been subject since its deposition, changes which may be purely physical, or chemical, or organic, or a combination of these, cannot well be discovered or understood without constant reference to the microscope. On this and the preceding subjects Mr. T. Rupert Jones makes the following remarks:—"The careful microscopical examination of a "good series of successive deposits cannot but be useful both "to the geologist and palæontologist. The conditions of "deposit will be elucidated by the proportions of fine and "coarse materials in the beds, especially if these be traced "along a considerable tract by the examination of many "samples of the deposit through its variations from clay "to sand (or vice versâ), or in its changes from an argil-"laceous or arenaceous to a calcareous condition. * * * "Except by careful separation in water and patient sorting and "picking, the minute shells and other fosils cannot be obtained "in anything like a fair average; and year by year the Fora-"minifera, Entomostraca, Bryozoa and the small fry of the "mollusca are becoming more valuable as leading characters "of strata, as our knowledge of these microzoa in the recent

" and fossil state advances. Such researches as these made " on any series of deposits, whether British or foreign, must " be of use, either for the improvement and correction of " observations already made and published, or for the ground- " work of future descriptions of strata and their fossils."

Special attention might be paid with advantage to certain beds of exceptional origin. Thus the materials composing the tertiary " drift " are within the reach of every one. It would be interesting to know whether or not it maintained the same general microscopic character over the whole of the immense area which it covers. In the same way the breccia of the Permian formation may give some indication which will throw light upon its supposed glacial origin.

The origin of flint in chalk and of corresponding silicious masses in other rocks is not by any means cleared up. Many of the supposed organisms found in agate and attributed to sponges are by some microscopists considered doubtful. (See the *Micrographic Dictionary.*) Much more is wanted in our knowledge of these singular masses of silica.

The substance Cannel, so different from coal in structure, so similar to it in composition, has received but little attention. Nothing is known regarding its formation ; and little, probably, will be discovered, until it is carefully examined by the help of the microscope. The vegetable origin of the diamond was partly inferred from the structure of its undisturbed ash, which under the microscope presented a regularly arranged network of silicious fibres. I would suggest that this instance furnishes an indication of a method which may give valuable information when applied to the examination of the varieties of fossil fuel.

In the case of igneous rocks I must content myself with observing that the experiments of Mr. Sorby and of M. des Cloizeaux are highly interesting, from the important results which we see them to have obtained at the outset of their journey into this hitherto untrodden country. And those of the latter observer are also useful as indicating another mode in which may be made available that powerful aid to the microscopist, polarized light.

Lastly, the structure of mineral veins and the nature of the deposits contained in them will, probably, on microscopical examination, enable geologists to make a nearer approach than they have hitherto done to a definite and trustworthy idea of their mode of formation and the laws governing them and their contents. If so, the practical advantages of such an investigation will be very great.

Such is a very brief and imperfect sketch of what man has done and of what man may expect to do with the help of the microscope in furthering the study of the science of geology. It will have been seen what a small proportion the knowledge hitherto obtained by this means bears to that which we may yet hope to gain; and we have incentives to such a pursuit in the numberless points of interest which have already shewn themselves, in the vast area still unworked and in the certainty that we shall, by such investigations, be enabled to throw light upon some of the grandest truths which it is the privilege of man to discover. In following out the object which every true student of science bears constantly in view we have the unalloyed satisfaction of assisting in the great work which has engaged so many master minds; and we shall feel that we are members of one great family whose distinction it is to combat error and, with a perseverance unaffected by personal considerations and an energy borne up by the consciousness of a pure intention and a holy ambition, to labour on in the great cause of TRUTH.