ART. XXXVI.—*On the History of Eozoön Canadense.*

WITH A PLATE.

IN volume xxxvii of this Journal, at p. 272, will be found a note to one of the Editors from Sir W. E. Logan, dated Feb. 17, 1864, announcing the discovery in the Laurentian limestones of Canada of organic remains, which, after a careful microscopic examination had been pronounced by Dr. Dawson, to belong to a gigantic Rhizopod. On page 431 of the same volume is a further note by Dr. T. Sterry Hunt, dated April 2, 1864, in which he states that in these organic remains the calcareous skeleton remains unchanged, while the sarcode is replaced by certain silicates, pyroxene, serpentine, and a mineral allied to chlorite in composition; the minute tubuli of the fossil being injected by these silicates in a manner analogous to that presented by the tertiary and modern Rhizopods, which are filled with glauconite.

These were the first announcements of this remarkable discovery, which has since been zealously followed up. Specimens of this fossil, which Dr. Dawson has named *Eozoön Canadense*, have been submitted to Dr. W. B. Carpenter of London, who is well known to be the great authority on Rhizopods, and the result of his examinations has been to confirm completely the determinations of Dr. Dawson, and to add to the description by the latter some further structural details, which the more perfect specimens examined by Dr. Carpenter enabled him to detect.

The results of the various investigations of the Eozoön are found in four papers published in the Journal of the Geological Society of London, for February, 1865. The first of these by Sir W. E. Logan describes the general geological relations of the Laurentian rocks, and is accompanied by two sections which we reproduce below.

He also relates the history of the first discovery of the fossil, specimens of which were exhibited by him to the American Association, at Springfield in August, 1859—and were then regarded by him and by Prof. James Hall as organic, although the microscope had as yet failed to detect the beautiful structure since found in such perfection in the specimens from other localities.

Sir William Logan moreover recalls the fact that Dr. Hunt had already from the presence of iron-ore beds, graphite, and metallic sulphurets, argued for the existence of life during the formation of the Laurentian rocks. See on this point a paper read in Jan. 1859 before the Geol. Society of London, and published in the Journal of that society, of which a review will be found in this Journal, [2], xxx, 134. This view is further developed in Dr. Hunt's paper on American Geology in this Journal, [2], xxxi, 396, where he concludes on chemical grounds to "the existence of an abundant vegetation during the Laurentian period."

The second paper is by Dr. Dawson, and gives his zoological description of Eozoön and its affnities, with a lithographed plate. The third is an extended note by Dr. Carpenter, in which he fully confirms the sagacious determination of Dr. Dawson as to the rhizopod characters and foraminiferal affinities of Eozoön, and is illustrated with a wood-cut and ten lithographed plates. In the fourth place we have a paper on the mineralogy of Eozoön by Dr. T. Sterry Hunt.

These four papers are reprinted in the Canadian Naturalist for April, 1865, with a single lithographed plate containing selections from the three just mentioned, and with the addition of a nature-printed section of Eozoön, both of which we place before our readers, together with extracts of the papers.

The Eozoön has also been carefully studied by Prof. T. Rupert Jones, who in the Popular Science Review for April, 1865, has given an excellent paper on the geological and zoological relations of the new fossil, together with a colored plate. In addition to this the Intellectual Observer for May, 1865, contains an essay of twenty-four pages on the same subject by Dr. Carpenter, with two excellent plates. As a further contribution to the literature of Eozoön we may mention that the pages of the London Reader for June, contain a correspondence between Dr. Carpenter and Messrs. King & Rowney, of Galway, who venture to question the opinion of Messrs. Dawson, Carpenter and Rupert Jones as to the organic nature of Eozoön. This correspondence is chiefly interesting as giving from Dr. Carpenter the authorized announcement by Milne-Edwards, that he, after a careful study, fully concurs in the views of the latter named observers as to the structure and affinities of Eozoön.

We now proceed to notice Sir William Logan's description of the Laurentian rocks, the general facts in whose history are briefly given in a paper by Dr. T. Sterry Hunt in this Journal, [2], xxxvi, 222.

"The oldest known rocks of North America are those which compose the Laurentide Mountains in Canada and the Adirondacks in the state of New York. By the investigations of the Geological Survey of Canada, they have been shown to be a great series of strata, which, though profoundly altered, consist chiefly of quartzose, aluminous, and calcareous rocks, like the sedimentary deposits of less ancient times. This great mass of crystalline rocks is divided into two groups, and it appears that the Upper Laurentian or Labrador series rests unconformably upon the Lower Laurentian series. The united thickness of the two groups in Canada cannot be less than 30,000 feet, and probably much exceeds it. The Laurentian of the west of Scotland, also according to Sir Roderick Murchison, attains a great thickness." In that region the Labrador series had not until recently been certainly recognized, although from the descriptions of Mcculloch, and from an examination of the specimens collected by him, and now in the Museum of the Geological Society in London, Dr. Hunt in 1863, had expressed the opinion that the rocks of Skye belong to this series. (See as above, page 226.) Prof. Haughton of Dublin has since visited the islands of Iona and Skye, and confirmed the observations of Dr. Hunt. (Geol. Magazine, Feb. 1865, page 73.)

The labradorite and hypersthene rocks from that island are identical with those of the Labrador series in Canada and New York, and unlike those of any formation at any other known horizon. This resemblance did not escape the notice of Emmons, who, in his description of the Adirondack Mountains, referred these rocks to the hypersthene-rock of McCulloch, although these observers, on the opposite sides of the Atlantic, looked upon them as unstratified.

Sir William then proceeds to notice the ancient gneiss which in Bavaria and Bohemia underlies the primordial zone, with a great intervening mass of clay slates. This old gneiss, which is estimated by Gümbel and Crejci to have a thickness of 90,000 feet, may, as Sir William suggests, include both the Upper and Lower Laurentian, and perhaps the Huronian, which is believed to be more recent than the Labrador series, although the two groups have never yet been found in contact. He then proceeds to remark:

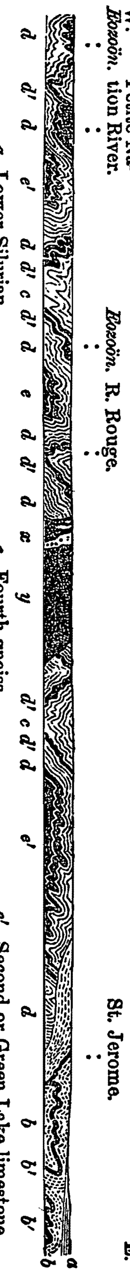
"The united thickness of these three great series may possibly far surpass that of all the succeeding rocks from the base of the Palæozoic series to the present time. We are thus carried back to a period so far remote, that the appearance of the so-called Primordial fauna may by some be considered a comparatively modern event. We however find that even during the Laurentian period, the same chemical and mechanical processes which have ever since been at work disintegrating and reconstructing the earth's crust were in operation as now. In the conglomerates of the Huronian series there are enclosed boulders derived from the Laurentian, which seem to show that the parent rock was altered to its present crystalline condition before the deposit of the newer formation; while interstratified with the Laurentian limestones there are beds of conglomerate, the pebbles of which are themselves rolled fragments of an older laminated sand-rock, and the formation of these beds leads us still further into the past."

"In both the Upper and Lower Laurentian series there are several zones of limestone, each of sufficient volume to constitute an independent formation. Of these calcareous masses it has been ascertained that three, at least, belong to the Lower Laurentian. But as we do not as yet know with certainty either the base or the summit of this series, these three may be conformably followed by many more. Although the Lower and Upper Laurentian rocks spread over more than 200,000 square miles in Canada, only about 1500 square miles have yet been fully and connectedly examined in any one district; and it is still impossible to say whether the numerous exposures of Laurentian limestone met with in other parts of the province are equivalent to any of the three zones, or whether they overlie or underlie them all."

In this connection are given the two following sections, which serve to show the structure of the Lower Laurentian rocks, and their relation to the overlying Labrador and Lower Silurian series.

The Eozoön Canadense occurs at Grenville, and in the Petite Nation seigniory at the two points indicated in the first section, and in both places in the third or uppermost band of the Lower Laurentian limestone. The same fossil has also been obtained to the south of the Ottawa, in Burgess, and farther west at the Grand Calumet on the Ottawa, in both instances in a limestone band whose pre-

Fig. 1.—*Section from Petite Nation Seigniory to St. Jerome* (66 miles).

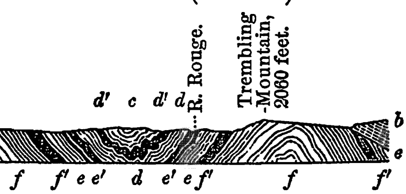


a. Lower Silurian.
b. Upper Laurentian.
b'. Upper Laurentian limestone.
c. Fourth gneiss.
d'. Third or Grenville limestone.
d. Third gneiss.
e'. Second or Green Lake limestone.
x. Porphyry; intrusive.
y. Granite; do.

cise place in the series has not been determined, nor is it known whether the fossil extends to the two lower conformable limestone bands, or to the calcareous zones in the unconformable Upper Laurentian series.

"The Grenville zone of limestone is in some places about 1500 feet thick, and it appears to be divided for considerable distances into two or three parts by very thick bands of gneiss. One of these bands occupies a position toward the lower part of the limestone, and may have a volume of between 100 and 200 feet. It is at the base of this limestone formation that the fossil occurs. This part of the zone is largely composed of great and small irregular masses of white crystalline pyroxene, some of them twenty yards in length by four or five wide. They appear to be confusedly placed one above another, with many ragged interstices, and smoothly-worn, rounded, large and small pits and sub-cylindrical cavities, some of them pretty deep. The pyroxene, though it appears compact, presents a multitude of small spaces filled with carbonate of lime, and many of these show minute structure similar to that of the fossil. These masses of pyroxene may characterize a thickness of about 200 feet, and the interspaces among them are filled with a mixture of serpentine and carbonate of lime. In general a sheet of pure dark green serpentine invests each mass of pyroxene; the thickness of the serpentine, varying from the sixteenth of an inch to several inches, rarely exceeding half a foot. This is followed in different spots by parallel waving, irregularly alternating plates of carbonate of lime and serpentine, which become gradually finer as they recede from the pyroxene, and occasionally occupy a total thickness of five or six inches. These portions constitute the unbroken fossil, which may sometimes spread over an area of about a square foot, or perhaps more. Other parts, immediately on the outside of the sheet of serpentine, are occupied with about the same thickness of what appear to be the ruins of the fossil, broken up into a more or less granular mixture of calcspar and serpentine, the former still showing minute structure; and on the outside of the whole a similar mixture appears to have been swept by currents and eddies into rudely parallel and curving layers; the mixture becoming gradually more calcareous as it recedes from the pyroxene. Sometimes beds of

Fig. 2.—*Section across Trembling Mountain* (21 miles).

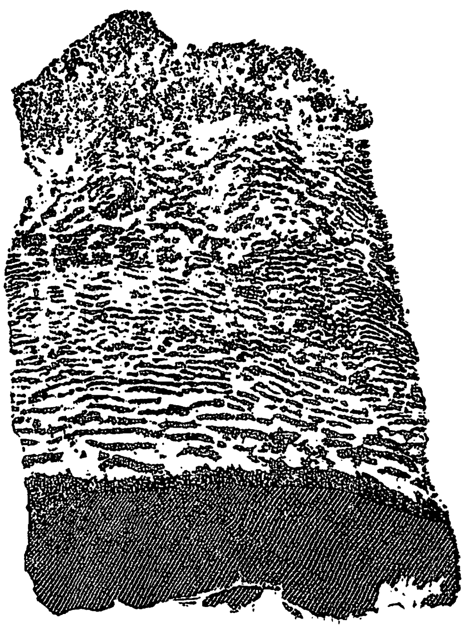


b. Upper Laurentian.
c. Fourth gneiss.
d′. Third limestone.
d. Third gneiss.
e′. Second limestone.
e. Second gneiss.
f′. First limestone.
f. First gneiss.

limestone of several feet in thickness, with the green serpentine more or less aggregated into layers, and studded with isolated lumps of pyroxene, are irregularly interstratified in the mass of rock; and less frequently there are met with lenticular patches of sandstone or granular quartzite, of a foot in thickness and several yards in diameter, holding in abundance small disseminated leaves of graphite."

"The general character of the mass produces the impression that it is a great Foraminiferal reef, in which the pyroxenic masses represent a more ancient portion, which having died, and having become much broken up, and worn into cavities and deep recesses, afforded a seat for a new growth of *Foraminifera*, represented by the calcareo-serpentinous part. This in its turn became broken up, leaving in some places uninjured portions of the general form. The main differenee between this Foraminiferal reef and more recent coral-reefs seems to be that, while with the latter are usually associated marine shells and other organic remains, in the more ancient ones the only remains yet found are those of the animal which built the reef."

The structure and appearance of the unbroken fossil will be understood from the following nature-printed section, the preparation of which is thus described by Dr. Hunt.



3. Nature-printed section of a specimen of *Eozoön Canadense* from Petite Nation Seigniory.

" The replacing mineral in this specimen being serpentine, the calcareous septa were dissolved from the polished surface by the action of an acid, and the fine material replacing the tubuli having been removed by the aid of a brush, a wax mould of the etched surface furnished the electrotype cast from which the above figure is printed. The lights thus represent the calcareous skeleton, and the shaded portion a thick mass of serpentine, which is distinguishable from a contiguous thin stratum of the same mineral, that seems to form the base of the Eozoön. The gradual passage from the wide chambers and thick septa to the narrower and thinner ones, and finally to the irregularly aggregated mode of growth, designated by Dr. Carpenter as *acervuline*, is well seen. The white patches in the upper portion of the figure do not arise from any imperfection in the electrotype, but represent the irregular growth of this part of the calcareous skeleton."

Slices of the fossils having been prepared for microscopic examination, and submitted to Dr. Dawson, were at once recognized by him as presenting the characters of Foraminiferal shells. After a careful examination of a large number of specimens he named and described the fossil as follows.

"EOZOÖN CANADENSE; *gen. et. spec. nov.*

General form.—Massive, in large sessile patches or irregular cylinders, growing at the surface by the addition of successive laminæ.

Internal structure.—Chambers large, flattened, irregular, with numerous rounded extensions, and separated by walls of variable thickness, which are penetrated by septal orifices irregularly disposed. Thicker parts of the walls with bundles of fine branching tubuli."

The grounds on which he inferred its foraminiferal character are thus stated by Dr. Dawson:

"1. The serpentine and pyroxene which fill the cavities of the calcareous matter have no appearance of concretionary structure. On the contrary, their aspect is that of matter introduced by infiltration, or as sediment, and filling spaces previously existing. In other words, the calcareous matter has not been moulded on the forms of the serpentine and augite, but these have filled spaces or chambers in a hard calcareous mass. This conclusion is further confirmed by the fact, to be refered to in the sequel, that the serpentine includes multitudes of minute foreign bodies, while the calcareous matter is uniform and homogeneous. It is also to be observed that small veins of carbonate of lime occasionally traverse the specimens, and in their entire absence of structures other than crystalline, present a striking contrast to the supposed fossils."

"2. Though the calcareous laminæ have in places a crystalline cleavage, their forms and structures have no relation to this. Their cells and canals are rounded, and have smooth walls, which are occasionally lined with films apparently of carbonaceous matter. Above all, the minute tubuli are different from anything likely to occur in merely crystalline calcspar. While in such rocks little importance might be attached to external forms simulating the appearances of corals, sponges, or other organisms, these delicate internal structures have a much higher claim to attention. Nor is there any improbability in the preservation of such minute parts in rocks so highly crystalline, since it is a circumstance of frequent occurrence in the microscopic examination of fossils that the finest structures are visible in specimens in which the general form and the arrangement of parts have been entirely obliterated. It is also to be observed that the structure of the calcareous laminæ is the same, whether the intervening spaces are filled with serpentine or with pyroxene."

"3. The structures above described are not merely definite and uniform, but they are of a kind proper to animal organisms, and more especially to one particular type of animal life, as likely as any other to occur under such circumstances; I refer to that of the Rhizopods of the order *Foraminifera.* The most important point of difference is in the great size and compact habit of growth of the specimens in question; but there seems no good reason to maintain that *Foraminifera* must necessarily be of small size, more especially since forms of considerable magnitude referred to this type are known in the Lower Silurian. Prof. Hall has described specimens of *Receptaculites* twelve inches in diameter; and the fossils from the Potsdam formation of Labrador, referred by Mr. Billings to the genus *Archæocyathus,* are examples of *Protozoa* with calcareous skeletons scarcely inferior in their massive style of growth to the forms now under consideration."

"These reasons are, I think, sufficient to justify me in regarding these remarkable structures as truly organic, and in searching for their nearest allies among the *Foraminifera.*"

"Supposing then that the spaces between the calcareous laminæ, as well as the canals and tubuli traversing their substance, were once filled with the sarcode-body of a Rhizopod, comparisons with modern forms at once suggest themselves."

"From the polished specimens in the Museum of the Canadian Geological Survey, it appears certain that these bodies were sessile by a broad base, and grew by the addition of successive layers of chambers, separated by calcareous laminæ, but communicating with each other by canals or septal orifices sparsely and irregularly distributed. Small specimens have thus much the aspect of the modern genera *Carpenteria* and *Polytrema.* Like the first of these genera, there would also seem to have been a tendency to leave in the midst of the structure a large central canal, or deep funnel-shaped or cylindrical opening, for communication with the sea-water. Where the laminæ coalesce, and the structure becomes more vesicular, it assumes the 'acervuline' character seen in such modern forms as *Nubecularia.*"

"Still the magnitude of these fossils is enormous when compared with the species of the genera above named; and from the specimens in the larger slabs from Grenville, in the Museum of the Canadian Survey, it would seem that these organisms grew in groups, which ultimately coalesced, and formed large masses penetrated by deep irregular canals; and that they continued to grow at the surface, while the lower parts became dead, and were filled up with infiltrated matter or sediment. In short, we have to imagine an organism having the habit of growth of *Carpenteria*, but attaining to an enormous size, and by the aggregation of individuals assuming the aspect of a coral reef."

"The complicated systems of tubuli in the the Laurentian fossil indicate however a more complex structure than that of any of the forms mentioned above. I have carefully compared these with the similar structures in the 'supplementary skeleton' (or the shell-substance that carries the vascular system) of *Calcarina* and other forms, and can detect no difference except in the somewhat coarser texture of the tubuli in the Laurentian specimens. It accords well with the great dimensions of these, that they should thus thicken their walls with an extensive deposit of tubulated calcareous matter; and from the frequency of the bundles of tubuli, as well as from the thickness of the partitions, I have no doubt that all the successive walls, as they were formed, were thickened in this manner, just as in so many of the higher genera of more modern *Foraminifera*."

Dr. Dawson further ascertained that certain parts of the fossil present that irregular mode of growth which Dr. Carpenter has designated as acervuline, and moreover that considerable masses of Laurentian limestones are made up of fragments of the fossils. He further points out the presence in these limestones of other fragments, which are probably organic, and which may indicate the existence of other animal remains. Films of carbonaceous matter in some of these limestones also exhibit under the microscope forms which indicate that they may be the remains of plants. He further adds, that "although the abundance and wide distribution of *Eozoön*, and the important part it seems to have acted in the accumulation of limestone, indicate that it was one of the most prevalent forms of animal existence in the seas of the Laurentian period, the non-existence of other organic beings is not implied. On the contrary, independently of the indications afforded by the limestones themselves, it is evident that in order to the existence and growth of these large Rhizopods, the waters must have swarmed with more minute animal or vegetable organisms on which they could subsist. On the other hand, though this is a less certain inference, the dense calcareous skeleton of *Eozoön* may indicate that it also was liable to the attacks of animal enemies. It is also possible that the growth of *Eozoön*, or the deposition of the serpentine and pyroxene in which its remains have been preserved, or both, may have been connected with certain oceanic depths and conditions, and that we have as yet revealed to us the life of only certain stations in the Laurentian seas."

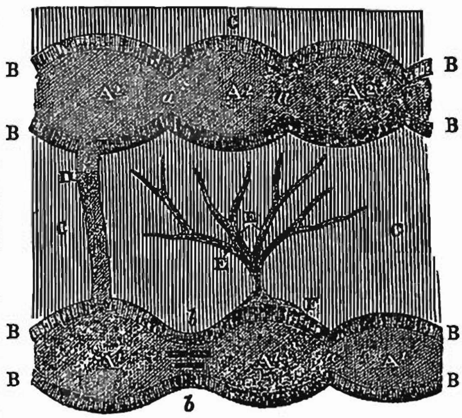
Subsequent to the above examination and description by Dr. Dawson, specimens of the new fossil from Grenville, and also more perfect ones from a similar and newly discovered locality in the Petite Nation Seigniory were taken to London by Sir William Logan and submitted to Dr. Carpenter, who fully confirmed the above results, and made out some additional structure. More especially he observed in specimens from the new locality, the preservation of the fine tubulation of the original cell-wall, which had not before been clearly made out. The additional points are thus stated by Dr. Carpenter:

"Although Dr. Dawson has noticed that some parts of the sections which he examined present the fine tubulation characteristic of the shells of the Nummuline Foraminifera, he does not seem to have recognized the fact, which the sections placed in my hands have enabled me most satisfactorily to determine,—that the proper walls of the chambers everywhere present the fine tubulation of the Nummuline shell (plate, figs. 3, 6); a point of the highest importance in the determination of the affinities of *Eozoön*. This tubulation, although not seen with the clearness with which it is to be discerned in recent examples of the Nummuline type, is here far better displayed than it is in the majority of fossil Nummulites, in which the tubuli have been filled up by the infiltration of calcareous matter, rendering the shell-substance nearly homogeneous. In *Eozoön* these tubuli have been filled up by the infiltration of a mineral different from that of which the shell is composed, and therefore not coalescing with it; and the tubular structure is consequently much more satisfactorily distinguishable. In decalcified specimens, the free margins of the casts of the chambers are often seen to be bordered with a delicate white glistening fringe; and when this fringe is examined with a sufficient magnifying power, it is seen to be made up of a multitude of extremely delicate *aciculi*, standing side by side like the fibres of asbestos. These, it is obvious, are the internal casts of the fine tubuli which perforated the proper wall of the chambers, passing directly from its inner to its outer surface; and their presence in this situation affords the most satisfactory confirmation of the evidence of that tubulation afforded by thin sections of the shell-wall."

"The successive layers, each having its own proper wall, are often superposed one upon another without the intervention of any supplemental or intermediate skeleton such as presents itself in all the more massive forms of the Nummuline series; but a deposit of this form of shell-substance, readily distinguishable by its homogeneousness from the finely tubular shell immediately investing the segments of the sarcode-body, is the source of the great thickening which the calcareous zones often present in vertical sections of *Eozoön.* The presence of this intermediate skeleton has been correctly indicated by Dr. Dawson; but he does not seem to have clearly differentiated it from the proper wall of the chambers. All the tubuli which he has described belong to that canal-system which, as I have shown, is limited in its distribution to the intermediate skeleton, and is expressly destined to supply a channel for its nutrition and augmentation. Of this canal-system, which presents most remarkable varieties in dimensions and distribution, we learn more from the casts presented by decalcified specimens, than from sections, which only exhibit such parts of it as their plane may happen to traverse."

"It does not appear to me that the 'canal-system' takes its origin directly from the cavity of the chambers. On the contrary, I believe that, as in *Calcarina* (which Dr. Dawson has correctly referred to as presenting the nearest parallel to it among recent *Foraminifera*), they originate in lacunar spaces on the outside of the proper walls of the chambers, into which the tubuli of those walls open externally; and that the extensions of the sarcode-body which occupied them were formed by the coalescence of the pseudopodia issuing from those tubuli."

We have here a diagram by Dr. Carpenter which he has given in his paper in the Quarterly Geological Journal; and from his subsequent memoir in the Intellectual Observer extract the following remarks: It will be understood that not only the chamber, but the canals and minute tubuli in the fossil are injected with serpentine, which, when the calcareous skeleton is removed by an acid, remains, and Dr. Carpenter especially notices "the marvellous completeness with which the minutest extensions of the sarcode-body of the animal are represented in decalcified specimens by these serpentine models; even



4. *Diagram illustrating the structure of Eozoön.*

A^1, A^1, A^1. Three chambers of one layer, communicating with each other directly at *a*, and by three passages through a shelly partition at *b*.

A^2, A^2, A^2. Three chambers of a more superficial layer.

B, B, B. Proper wall of the chambers, composed of finely tubular shell-substance.

C, C, C. Intermediate or supplemental skeleton, traversed by D, a stolon of communication between two chambers of different layers, and by E, E, a canal-system originating in the lacunar space F.

the most delicate pseudopodial threads, consisting of the softest and most transitory form of living substance which were put forth through pores in the shell-wall less than one ten-thousandth of an inch in diameter, being thus perpetuated to all time." "The proper walls of the chambers are everywhere formed of a pellucid vitreous shell-substance minutely perforated with tubuli, so as exactly to correspond with those of *Nummulites*, *Operculina*, etc." The serpentine casts of these tubuli are frequently detached by the disengagement of the gas while the skeleton is being removed by an acid, but they often remain behind, standing side by side like the filaments which form the pile of velvet, their lower ends resting on the subjacent segment, while their upper extremities present a uniform surface. These casts of tubuli are distinguished from the adjacent serpentine, which is pale-green by their whiteness, yet the two are found by Dr. Hunt to be identical in composition, and thus, as he, and Dr. Carpenter after him, remarks, their whiteness is due to their fine division; many groups and bunches of this white substance being found by Dr. Carpenter to be aggregations of the elementary forms of sarcodic prolongation, which he has described in detail.

With regard to the intermediate or supplemental skeleton, which resembles closely that existing in *Calcarina* as described by Dr. Carpenter in his admirable Introduction to the Study of the Foraminifera, it is an exogenous deposit on the outer surface of the proper walls of the chamber, where it seems to be produced by the sarcodic layer which is formed by the coalescence of the pseudopodia after they have issued from the tubuli, and is traversed by a more or less minutely distributed canal-system, occupied during life by prolongations of that sarcodic layer. In those portions of the fossil where the chambers, instead of being regularly arranged in floors, are piled up in the *acervuline* manner, there is little or no trace of this intermediate skeleton, but in these irregularly aggregated chambers the structure of their proper walls is still well seen, both in transparent sections and in decalcified specimens.

In the solid masses of limestone which are made up of fragments of Eozoön, Dr. Carpenter could find no trace of the intermediate skeleton, though these specimens afford the most perfect examples of the Nummuline tubulation. He hence concludes that "the breaking up of the surface of the original Eozoön must have taken place before the proper walls of its highest tiers of chambers had been strengthened by exogenous deposit."

Space will not permit us to follow Dr. Carpenter in his comparison of Eozoön with other Foraminifera. He remarks, however, the resemblance in its mode of growth with the discoidal modern *Cycloclypeus* from the coast of Borneo, which attains a diameter of more than two inches and is made up of many thousand segments, while in Globigerina the continuous increase of the individual body by segments soon ceases and new individuals are formed by the separation of the segments.

Reverting to Dr. Dawson's remark as to the important part played by the Eozoön in the Laurentian seas, Dr. Carpenter observes the significance of the fact that this lowest type of animal life known to the physiologist (the Rhizopod) should have attained such a great development and apparently culminated in the very earliest known period in the history of the life of our globe.

The serpentine marbles of Tyree and of Skye, whose probable Laurentian age had been pointed out by Dr. Hunt in the paper already cited, offer, according to Dr. Carpenter, "a structure clearly identical with that of the Canadian Eozoön." A like structure has been discovered by Mr. Sandford in the serpentine marble of Connemara, known as *Irish green* marble. "I have," says Dr. Carpenter, "examined decalcified specimens of several portions of this rock, and have not the smallest hesitation in identifying them with the acervuline portion of the *Eozoön Canadense*, although I have met with nothing corresponding to the lamellated structure of other portions of the Eozoön. Moreover in place of the continuous asbestiform layer covering the segments, long straight bundles of filaments radiate from them." The age of the Connemara rock is by no means certain. Sir Roderick Murchison was at first disposed to regard it as Laurentian, but has since expressed the opinion that it is of Silurian age.

In this connection we call the attention of American geologists and microscopists to the crystalline limestones of the Highlands of New York, which are doubtless of Laurentian age,[1] and also to the figure and description, given by Dr. Emmons on page 60 of his Geology of the 2nd district of New York, of a banded arrangement in rounded or oval masses of serpentine and carbonate of lime, much resembling in external form the Eozoön of Canada. The specimen figured by him is from Warrensburg, Warren County, New York.

The mode in which the Eozoön has been preserved by the injection of serpentine has already been noticed, but is further described in Dr. Hunt's paper, from which we make the following extracts:

"The details of structure have been preserved by the introduction of certain mineral silicates, which have not only filled up the chambers, cells, and canals left vacant by the disappearance of the animal matter, but have in very many cases been injected into the tubuli, filling even their smallest ramifications. These silicates have thus taken the place of the original sarcode,

[1] See this Journal, [2], xxxix, 97.

while the calcareous septa remain. It will then be understood that when the replacement of the Eozoön by silicates is spoken of, this is to be understood of the soft parts only; since the calcareous skeleton is preserved in most cases without any alteration. The vacant spaces left by the decay of the sarcode may be supposed to have been filled by a process of infiltration, in which the silicates were deposited from solution in water, like the silica which fills up the pores of wood in the process of silicification. The replacing silicates, so far as yet observed, are a white pyroxene, a pale-green serpentine, and a dark-green alumino-magnesian mineral, which is allied in composition to chlorite and to pyrosclerite, and which I have referred to loganite. The calcareous septa in the last case are found to be dolomitic, but in the other instances are nearly pure carbonate of lime. The relations of the carbonate and the silicates are well seen in thin sections under the microscope, especially by polarized light. The calcite, dolomite, and pyroxene exhibit their crystalline structure to the unaided eye; and the serpentine and loganite are also seen to be crystalline when examined with the microscope. When portions of the fossil are submitted to the action of an acid, the carbonate of lime is dissolved, and a coherent mass of serpentine is obtained, which is a perfect cast of the soft parts of the Eozoön. The form of the sarcode which filled the chambers and cells is beautifully shown, as well as the connecting canals and the groups of tubuli; these latter are seen in great perfection upon surfaces from which the carbonate of lime has been partially dissolved. Their preservation is generally most complete when the replacing mineral is serpentine, although very perfect specimens are sometimes found in pyroxene. The crystallization of the latter mineral appears, however, in most cases to have disturbed the calcareous septa."

"Serpentine and pyroxene are generally associated in these specimens, as if their deposition had marked different stages of a continuous process. At the Calumet, one specimen of the fossil exhibits the whole of the sarcode replaced by serpentine; while, in another one from the same locality, a layer of pale green translucent serpentine occurs in immediate contact with the white pyroxene. The calcareous septa in this specimen are very thin, and are transverse to the plane of contact of the two minerals; yet they are seen to traverse both the pyroxene and the serpentine without any interruption or change. Some sections exhibit these two minerals filling adjacent cells, or even portions of the same cell, a clear line of division being visible between them. In the specimens from Grenville, on the other hand, it would seem as if the development of the Eozoön (considerable masses of which were replaced by pyroxene) had been interrupted, and that a second growth of the amimal, which was replaced by serpentine, had taken place upon the older masses, filling up their interstices."

The paper of Dr. Hunt contains numerous analyses of the various minerals noticed above. We extract his account of the loganite, which replaces the Eozoön from Burgess. The calcareous septa in these specimens are represented by a "somewhat ferriferous dolomite, the analysis of which was made upon portions mechanically separated from the enclosed silicate; it yielded carbonate of magnesia 40·7, carbonate of lime, with a little peroxyd of iron, 59·0=99·7. The septa of the specimen from this locality are in some parts more than 3·0 millimeters in thickness, and exhibit the chambers, cells and septal orifices; but no tubuli are seen. The replacing material has the hardness of serpentine, for which it was at first mistaken. Its color is blackish-green, but olive-green in thin sections, when it is seen by transmitted light to be crystalline in texture. Its fracture is granular, and its lustre feebly shining. It is decomposed by heated sulphuric acid, and was thus analyzed, yielding the result I. The centesimal composition of the soluble portion is given under II.

	I.	II.	III.
Silica	33·75	35·14	36·50
Alumina	9·74	10·15	10·80
Magnesia	30·24	31·47	28·20
Protoxyd of iron	8·19	8·60	9·54
Water	14·08	14·64	14·62
Insoluble sand	2·50	....	....
	98·51	100·00	99·66

"The silicate which here takes the place of the pyroxene and serpentine observed in the other specimens of Eozoön is one of frequent occurrence in the Laurentian limestones, and appears to constitute a distinct species, which I long since described under the name of loganite, and which occurs at the Calumet in dark brown prismatic crystals. I have since observed a similar mineral in two other localities besides the one here noticed. The result III, which is placed by the side of the analysis of the Burgess fossil, was obtained with a greenish-grey sparry prismatic variety from North Elmsley, having a hardness of 3·0, and a specific gravity of 2·539. These hydrous alumino-magnesian silicates, which I have included under the name of loganite,[1] are related to chlorite and to pyrosclerite in composition; but these last are distinguished from it by their eminently foliated micaceous structure."

"When examined under the microscope, the loganite which replaces the Eozoön of Burgess, shows traces of cleavage-lines,

[1] For a description of this and similar silicates, see Geology of Canada, p. 491.

which indicate a crystalline structure. The grains of insoluble matter found in the analysis, chiefly of quartz sand, are distinctly seen as foreign bodies imbedded in the mass, which is moreover marked by lines apparently due to cracks formed by a shrinking of the silicate, and subsequently filled by a further infiltration of the same material. This arrangement resembles on a minute scale that of septaria. Similar appearances are also observed in the serpentine which replaces the Eozoön of Grenville, and also in a massive serpentine from Burgess, resembling this, and enclosing fragments of the fossil. In both of these specimens also grains of mechanical impurities are detected by the microscope; they are, however, rarer than in the loganite of Burgess."

"From the above facts it may be concluded that the various silicates which now constitute pyroxene, serpentine, and loganite were directly deposited in waters in the midst of which the Eozoön was still growing, or had only recently perished; and that these silicates penetrated, enclosed, and preserved the calcareous structure precisely as carbonate of lime might have done. The association of the silicates with the Eozoön is only accidental; and large quantities of them, deposited at the same time, include no organic remains. Thus, for example, there are found associated with the Eozoön limestones of Grenville, massive layers and concretions of pure serpentine; and a serpentine from Burgess has already been mentioned as containing only small broken fragments of the fossil. In like manner large masses of white pyroxene, often surrounded by serpentine, both of which are destitute of traces of organic structure, are found in the limestone at the Calumet. In some cases, however, the crystallization of the pyroxene has given rise to considerable cleavage-planes, and has thus obliterated the organic structure from masses which, judging from portions visible here and there, appear to have been at one time penetrated by the calcareous plates of Eozoön. Small irregular veins of crystalline calcite, and of serpentine, are found to traverse such pyroxene masses in the Eozoön-limestone of Grenville."

Veins of fibrous serpentine (chrysotile) in like manner intersect the serpentine of this region, and are sometimes found cutting across the masses of Eozoön. It is stated in a note to this portion of the paper that, "Recent examinations have shown that some of these masses encrusted with Eozoön replaced by serpentine, consist of crystalline pyrallolite (rensselaerite); which seems, like the other silicates, to have replaced the organic matter of the Rhizopod."

"These observations bring the formation of siliceous minerals face to face with life, and show that their generation was not incompatible with the contemporaneous existence and the preservation of organic forms. They confirm, moreover, the view which I some years since put forward, that these silicated minerals have been formed, not by subsequent metamorphism in deeply buried sediments, but by reactions going on at the earth's surface.[2] In support of this view, I have elsewhere referred to the deposition of silicates of lime, magnesia, and iron from natural waters, to the great beds of sepiolite in the unaltered tertiary strata of Europe; to the contemporaneous formation of neolite (an alumina-magnesian silicate related to loganite and chlorite in composition); and to glauconite, which occurs not only in secondary, tertiary, and recent deposits, but also, as I have shown, in Lower Silurian strata.[3] This hydrous silicate of protoxyd of iron and potash, which sometimes includes a considerable proportion of alumina in its composition, has been observed by Ehrenberg, Mantell, and Bailey associated with organic forms in a manner which seems identical with that in which pyroxene, serpentine, and loganite occur with the Eozoön in the Laurentian limestones. According to the first of these observers, the grains of green-sand or glauconite from the tertiary limestone of Alabama are casts of the interior of Polythalamia; the glauconite having filled them by 'a species of natural injection, which is often so perfect that not only the large and coarse cells, but also the very finest canals of the cell-walls, and all their connecting tubes, are thus petrified and separately exhibited.' Bailey confirmed these observations, and extended them. He found in various cretaceous and tertiary limestones of the United States, casts, in glauconite, not only of *Foraminifera*, but of spines of *Echinus*, and of the cavities of corals. Besides, there were numerous red, green, and white casts of minute anastomosing tubuli, which, according to Bailey, resemble the casts of the holes made by burrowing sponges (*Cliona*) and worms. These forms are seen after the dissolving of the carbonate of lime by a dilute acid. He found moreover, similar casts of *Foraminifera*, of minute mollusks, and of branching tubuli, in mud obtained from soundings in the Gulf-stream, and concluded that the deposition of glauconite is still going on in the depths of the sea.[4] Pourtales has followed up these investigations on the recent formation of glauconite in the Gulf-stream waters. He has observed its deposition also in the cavities of *Millepores*, and in the canals in the shells of *Balanus*. According to him, the glauconite grains formed in *Foraminifera* lose after a time their calcareous envelopes, and finally become 'conglomerated into small black pebbles,' sections of which still

[2] This Journal, [2], xxix, 281; xxxii, 286. Geology of Canada, p. 577.
[3] This Journal, [2], xxxiii, 277. Geology of Canada, p. 487.
[4] This Journal, [2], xii, 280.

show under a microscope the characteristic spiral arrangement of the cells.[5]

"It appears probable from these observations that glauconite is formed by chemical reactions in the ooze at the bottom of the sea, where dissolved silica comes in contact with iron-oxyd rendered soluble by organic matter; the resulting silicate deposits itself in cavities of shells and other vacant spaces. A process analogous to this in its results, has filled the chambers and canals of the Laurentian *Foraminifera* with other silicates; from the comparative rarity of mechanical impurities in these silicates, however, it would appear that they were deposited in clear water. Alumina and oxyd of iron enter into the composition of loganite as well as of glauconite; but in the other replacing minerals, pyroxene and serpentine, we have only silicates of lime and magnesia, which were probably formed by the direct action of alkaline silicates, either dissolved in surface-waters, or in those of submarine springs, upon the calcareous and magnesian salts of the sea water."

In the second part of Dr. Hunt's paper on Natural Waters, published in this Journal for July, there will be found in § 41 some observations bearing on the formation of the silicates of lime and magnesia. The chemical and mineralogical relations of the Eozoön, or rather of its replacing silicates, are by no means the least important points in the history of this remarkable fossil.

Explanation of the Plate illustrating the Structure and Affinities of Eozoön Canadense.

Of the figures here given, 1, 3, 6 *a*, 6 *b*, and 7, are selected from two plates given by Dr. Carpenter to illustrate his paper; while 2, 4, and 5, are from the plates accompanying Dr. Dawson's description, and are from drawings by Mr. Horace H. Smith, the artist of the Canadian Geological Survey.

The figures, with the exception of 7, are from transparent sections of specimens in which the original shell was well preserved, and its minutest cavities infiltrated with serpentine. Figure 7 is from a specimen from which the calcareous skeleton was removed by an acid, and represents the internal casts of the tubes, as seen by reflected light.

Fig. 1. Vertical section of regularly stratified portion of *Eozoön* showing the ordinarily continuous connection of the chambers of each stratum; magnified 10 diameters.

2. Horizontal section of *Eozoön* from Grenville, magnified 25 diameters; *a*, systems of tubuli; *b*, secondary chamber.

3. Portions of two chambers of different layers, showing at *a*, *a*, the proper wells of their chambers; at *b*, *b*, the intermediate

[5] Report of United States Coast Survey, 1858, p. 248.

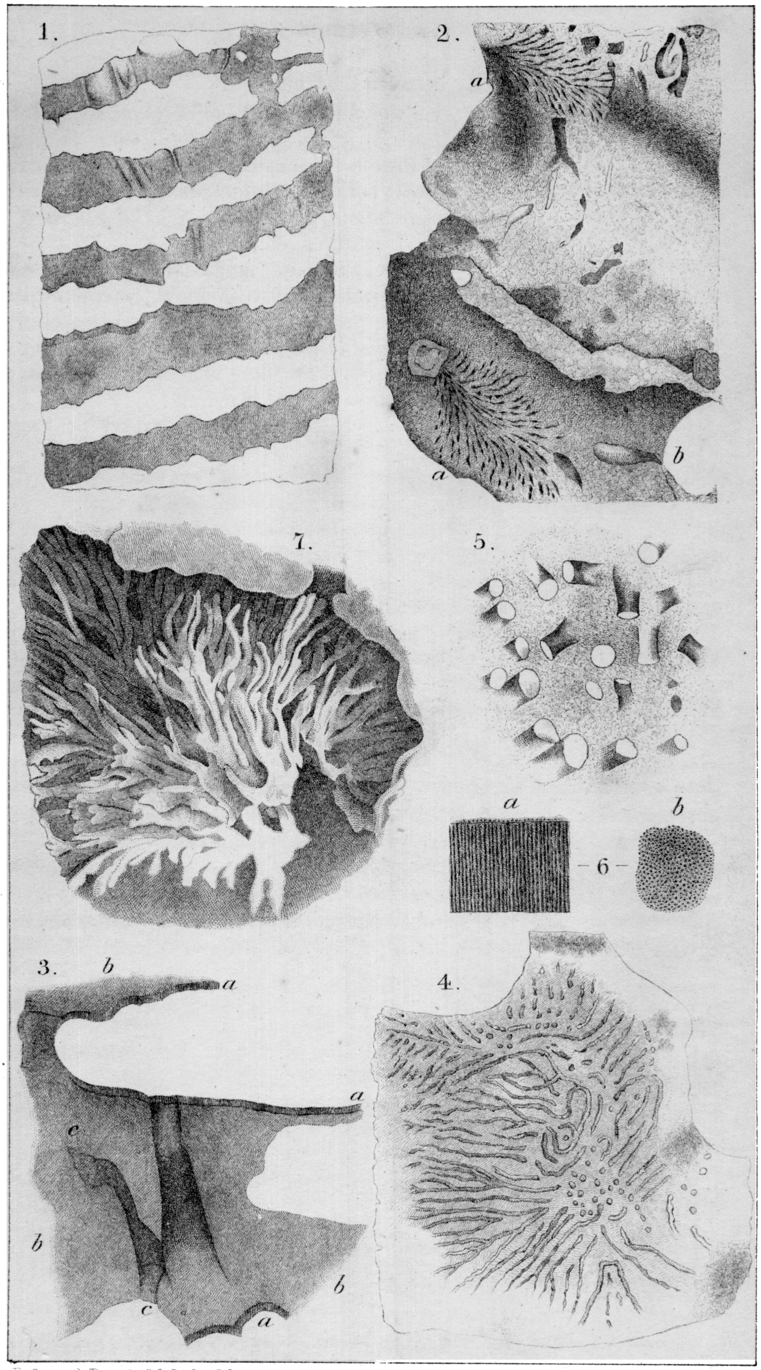
skeleton; and at *c, c*, a stoloniferous passage; magnified 25 diameters.

Fig. 4. One of the systems of tubuli cut transversely; magnified 100 diameters.

5. Part of a system of tubuli cut transversely; magnified 200 diameters.

6. Portions of the proper wall of the chambers, showing its Nummuline tubulation, as seen at *a* in longitudinal, and at *b* in transverse section; magnified 100 diameters.

7. Cast of the interior of canal-system; an entire group magnified 10 diameters.



Roberts & Reinhold, Litho. Montreal.

EOZOON CANADENSE, Dawson.