With kind regards
J. W. D.

THE ANIMAL NATURE OF EOZOÖN.

BY

Sir WILLIAM DAWSON, C.M.G., LL.D., F.R.S., Etc.

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REVIEW OF THE EVIDENCE FOR THE ANIMAL NATURE OF EOZOÖN CANADENSE.

By Sir William Dawson, C.M.G., LL.D., F.R.S., Etc.

I. Historical and Stratigraphical.

THE writer of these notes had hoped to have been able long ago to let the vexed questions respecting Eozoön repose in peace in so far as he was concerned, and he is now induced to offer a short summary of the evidence in the case only with the view of correcting some misapprehensions that seem to have arisen in regard to points well established, and which, independently of any question as to the nature of Eozoön, belong to the certain data of geology. These misapprehensions lead to the confounding of the structures originally discovered by Logan with things in no way related to them, and from which they had been clearly distinguished by my own original studies, and by those of Hunt, Carpenter, and Rupert Jones. New facts relating to pre-Cambrian life have also been coming to light from time to time, and many of these are connected, either directly or indirectly, with the evidence respecting Eozoön.

As early as 1858, Sir William Logan had begun to suspect that the Stromatoporoid forms collected from the great Laurentian limestones in different parts of Canada must be of organic origin, and he ventured to mention them as possibly of this nature at the meeting of the American Association in 1859, and in his General Report on the Geology of Canada in 1863. The evidence on which he relied was their occurrence only in the limestones, their similarity in form and general structure to the Stromatoporæ, or "Layer-Corals" of the Palæozoic, and the circumstance that, while the forms and structures seemed to be identical, they were mineralized by Serpentine, Loganite, Pyroxene, and Dolomite, an indication that a similar mould had been filled by diverse minerals.

At that time the little leisure I could spare for original work was occupied with Carboniferous and Pleistocene geology, and I had no ambition to invade the great and difficult pre-Cambrian districts of Northern Canada any farther than might be necessary to my work as a teacher of geology. In the interest of that work, however, I had gone over considerable portions of the Laurentian and Huronian districts surveyed by Logan and Murray, with the aid of their maps and reports, and had satisfied myself of the great accuracy of their work, which led in my judgment to the following results:—

(1) That the upper part of the Lower Laurentian of Logan, since called the Grenville Series,[1] consisted of truly stratified metamorphic rocks, including great and extensive deposits of limestone, quartzite, iron-ore, and other rocks, evidently of aqueous origin, and that the condition and crystalline and chemical characters of these rocks were not essentially different from those of the altered Palæozoic beds with which I was familiar in Nova Scotia and New England.

(2) That the Huronian, a less disturbed, less altered, and in the main evidently a clastic series, rested unconformably on the Laurentian, and was in part composed of its materials.

(3) That the "Upper Copper-bearing series" of Lake Superior, since known as Kewenian, was newer than the Huronian, but older than the oldest fossiliferous Cambrian rocks then known in Canada.

(4) That, while the Kewenian and Huronian rocks, and those designated by Logan as Upper Laurentian, indicated by the presence of igneous masses, and, in the case of the two former, by the prevalence of coarse, clastic material, littoral conditions and much volcanic disturbance, the still older Grenville Series was of a character more indicative of long-continued quiescence, accompanied by the accumulation of great calcareous deposits, possibly of organic origin.

These conclusions were noticed in papers contributed to local societies, in published lecture-notes, and in class-teaching, and were frequently discussed with Logan and Hunt. Accordingly, when, in 1863, at the urgent request of Logan, I undertook the microscopic examination of large series of his supposed Laurentian fossils and the containing limestones, as well as of other crystalline limestones of various ages, slices of which he had caused to be made, I was not unprepared to find the curious and beautiful structures which developed themselves in his Stromatoporoid forms, and in portions of the limestone in which they were contained, but which appeared to resemble those of Foraminifera rather than those of Corals.

The results thus attained, in 1864, were not fully published until after Logan was prepared to sustain them by detailed maps and sections of the district on the Ottawa containing Eozoön, a work extending over many years of arduous and skilful labour; and until Dr. W. B. Carpenter and Prof. Rupert Jones had studied the original specimens and others prepared for themselves, along with

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[1] By Dr. Sterry Hunt.

my notes, and camera drawings prepared by the artist of the Geological Survey. Dr. Sterry Hunt had also examined chemically the serpentine and other minerals associated with the supposed fossils, and various hydrous silicates mineralizing organic remains in Silurian and other limestones, as terms of comparison. The whole was then communicated to the Geological Society of London, and appeared in the somewhat elaborate joint paper published in 1865.

[But a preliminary account entitled "On the occurrence of Organic Remains in the Laurentian Rocks of Canada," by Sir W. E. Logan, F.R.S., F.G.S., with communications on the structure by J. W. Dawson, LL.D., F.R.S., and on the Mineralogy of the same remains by T. Sterry Hunt, F.R.S., had, however, been communicated to the British Association at Bath, Sept. 15–21, 1864, and was subsequently published in the GEOLOGICAL MAGAZINE, Vol. I, for November 1864, pp. 225–227.]

I confess that in the intervening time I have seen no good reason to induce me to doubt the essential validity of the work embodied in this paper of 1865, or to modify to any considerable extent the conclusions therein stated. On the other hand, many new and confirmatory facts have been disclosed, and after careful and, I trust, candid study of the objections raised, down to those which have recently appeared in the Dublin Transactions, I believe that they largely depend on want of knowledge of the character of the Grenville formation, and on misapprehension as to the form and structure of Eozoön and its mode of occurrence.

It is true that in those members of the Laurentian system of Logan which are below and above the Grenville Series, later observations have not only failed to detect fossils, but have shown valid reasons adverse to the probability of their occurrence, at least in the portions of those formations hitherto open to our study.[1]

The lowest Laurentian gneiss of Logan (Trembling Mountain gneiss, Ottawa gneiss, fundamental gneiss), which occupies a vast area in Northern Canada,[2] and is the only part of the system known to many geologists, consists, so far as known, wholly of foliated or massive orthoclase gneiss, with bands of hornblendic schist (amphibolite), and of hornblendo-micaceous schist. While in some places it appears to have a truly bedded structure, especially where different varieties of gneiss, amphibolite, and biotitic schist alternate, in others its foliation is obscure, or seems to have been induced by heat and pressure. Dr. F. D. Adams, who has given much study both to its characters on the large scale, and to the microscopic structure of the rocks, in his latest publication on the subject[3] characterizes it as a complicated series of rocks of unknown origin,

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[1] See GEOLOGICAL MAGAZINE, June, 1895.

[2] According to the geological map of Northern Canada prepared by Dr. G. M. Dawson for the Geological Survey, the area of Laurentian rocks exceeds two millions of square miles. Of this, so far as is known, the older or fundamental gneiss occupies by far the larger portion.

[3] American Journal of Geology, vol. i, No. 4, 1893.

but comprising a considerable amount of intrusive material. He regards it as either the remains of a primitive crust penetrated by much igneous matter, or as a series of altered rocks older than the Grenville Series, and formed under different conditions. In any case it seems to want the evidences of ordinary aqueous deposition presented by the limestones, ironstones, quartzites, and schists of the Grenville Series. Similar views were advocated in my address on the "Geological History of the Atlantic," before the British Association, in 1886.[1]

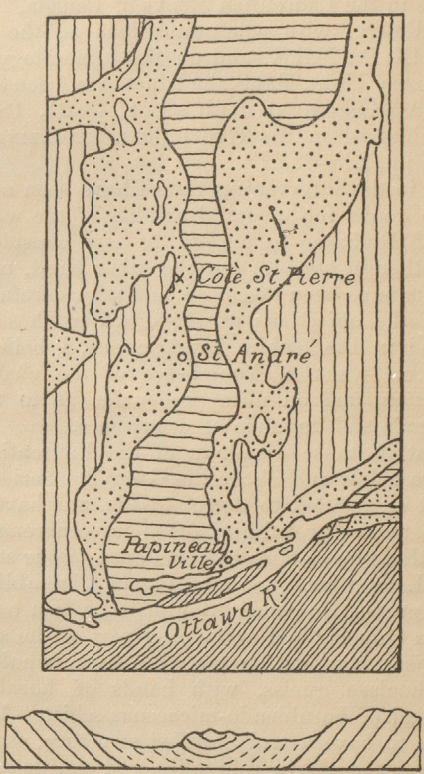

Fig. 1.—Distribution of Grenville Limestone in the district north of Papineauville, with section showing arrangement of the beds. Scale of map 7 miles to an inch. (See also Dr. Bonney's paper, Geol. Mag., July 1895, p. 295.)
Dotted area: Limestone.
Horizontal lines: Upper gneiss (fourth gneiss of Logan).
Vertical lines: Lower gneiss (third gneiss of Logan).
Diagonal lines: Overlying Cambrian and Cambro-Silurian (Ordovician).

The Upper Laurentian of Logan (Labradorite, Anorthosite, or Norian Series), supposed by him to overlie the Grenville Series unconformably, is now stated by Adams to consist of eruptive

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[1] See also Museum Memoir on Eozoön, pp. 2, 3. Montreal, 1888.

matter, mainly composed of triclinic or lime felspars, and to which the name Anorthosite[1] may properly be applied. These rocks, cutting the Grenville Series, and apparently in some places interbedded with it, are not now regarded as a distinct series of beds, but as indicating local outbursts of igneous action dating about the close of the Grenville period. What aqueous rocks may have been contemporaneous with them, or may have filled the interval between the Grenville Series and the Huronian, we do not at present certainly know, though possibly some of the rocks associated with the upper part of the Laurentian, or the lower part of the Huronian in the interior, and in the eastern part of Canada, may come into this place.[2]

It is to be observed that in 1865 these facts respecting the fundamental gneiss and the Upper Laurentian of Logan, were not distinctly before our minds, though in subsequent papers I thought it best to consider the Grenville group as a distinct series under the name "Middle Laurentian." It is quite possible, however, that our referring in the first instance to the Laurentian as a whole, may have led to erroneous impressions.

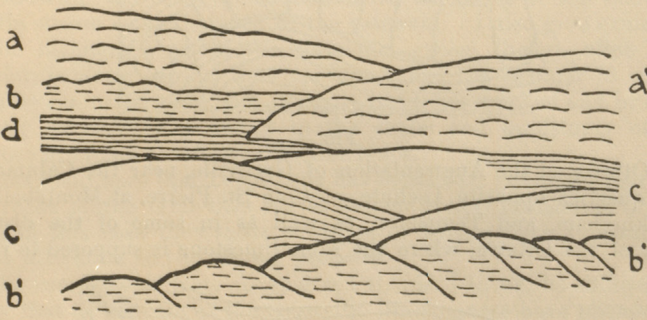

Fig. 2.—Topography at Côte St. Pierre, from the N.E. (For section see Dr. Bonney's paper, Geol. Mag., July 1895, p. 296.)

(*a*) Lower gneiss. (*a'*) The same brought forward by fold.
(*b*) Limestone (Lorne's Quarry). (*b'*) The same, exposure on La Vigne's farm.
(*c*) Limestone, mostly covered with soil.
(*d*) Pond or small lake.

For the purpose of these notes, therefore, it will be best and most accurate to confine ourselves to the Grenville Series, which has been carefully explored and mapped by the officers of the Geological Survey in the country lying north of the Ottawa River, and also in some parts of the areas between that river and the St. Lawrence. In these regions Logan recognized a thickness of 17,250 feet of deposits, of which no less than 4,750 feet consisted of limestone, principally in three great bands, though with intercalated gneissose

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[1] Proposed by Hunt.

[2] Some of these beds are regarded by Von Hise (Amer. Journ. of Geology, vol. i) as a lower member of the Huronian. They may also be identical in part with the "Kewatin" group of Lawson.

layers. The Grenville Series may thus be regarded as one of the great calcareous systems, comparable with those of the Palæozoic period, which it also rivals in its association with carbonaceous and ferruginous deposits. Though minute globular forms, probably organic, have been found in the Middle Limestone, that of Long Lake, Eozoön proper is confined, so far as known, to the Upper Limestone, known specially as the Grenville Band. This band and its accompaniments I have myself studied in the region north of the Ottawa, at the Augmentation of Grenville, near the Calumet, in the quarries opposite Lachute, at Côte St. Pierre, at Montebello, at Buckingham, and Templeton, as well as in some of the districts west of the Ottawa, where the same limestone is supposed to recur.

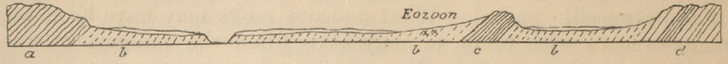

FIG. 3.—Arrangement of beds in valley of Calumet River—(*a*) Upper gneiss; (*b*) Limestone partly covered with soil; (*c*) Included bed of gneiss; (*d*) Lower gneiss.

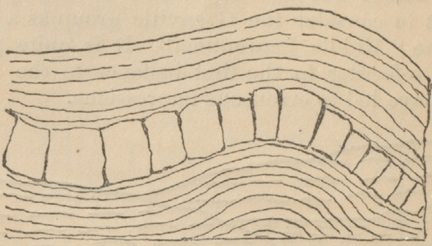

FIG. 4.

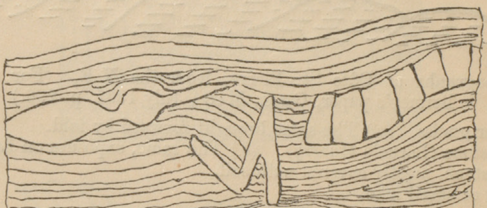

FIG. 5.

FIGS. 4 and 5.—Bent and dislocated Quartzite, in contorted schists interstratified with Grenville Limestone, near Montebello. The quartzites have been broken and displaced, while the schists have been bent and twisted. In the immediate vicinity the same beds may be seen slightly inclined and undisturbed.

Everywhere it is a large and regular bed, sometimes with even strike and dip, but at intervals thrown into violent contortions along with the enclosing beds, in the manner usually seen in disturbed strata of later age, where it is common to find portions little affected by plication alternating with strongly folded beds having the harder ones dislocated; others are merely bent or folded (Figs. 4 and 5). It presents subordinate beds of different qualities, dolomitic, serpentinous, or graphitic, and is immediately associated with thin-bedded, fine-grained gneisses, quartzite, and biotitic and hornblendic schists. In some beds it has disseminated crystals of minerals usually found in metamorphic limestones, while in others there are concretionary masses, nodules, and grains of serpentine and pyroxene. Eozoön in masses occurs only in certain layers, most frequently in those which are serpentinous, but a careful examination detects in many layers, not showing perfect examples of Eozoön, small fragments or patches having its characteristic structures, or detached chamberlets or groups of these. The occurrence of these fragments I regard as an important fact, and as showing that what may be termed "Eozoön sand" enters largely into the composition of the limestone.

In illustration of this part of my subject, I present a rough map of the district near the Petite Nation River, in rear of Papineauville, referred to by Dr. Bonney in his valuable paper in the July Number of this MAGAZINE, and in addition to the section given in his paper, one showing the order of succession in the valley of the Calumet, a little stream some distance to the eastward. I also give examples of the manner in which the associated gneiss, though often very regular, is along certain lines contorted, and the manner in which, in these contorted spots, the quartzite bands are cracked and broken, exactly as may be observed in the shales and sandstones of the Quebec group on the Lower St. Lawrence.

I may add here that Dr. Adams has found that in certain localities the rocks of the Grenville Series become almost horizontal, though even in this case they show evidence of having been subjected to much alteration and to ~~lateral~~ pressure.

The summary of facts above given should, I think, be sufficient to show that in the case of the Grenville limestone we have phenomena which cannot be explained by mere pressure acting on massive rocks, or by segregation of calcite from igneous rocks, or by vein structures, or by any contact structures arising at the junction of igneous and aqueous deposits. We have, on the contrary, to deal with a formation which indicates that in the early period to which it belongs regular sedimentation was already in full operation. The more precise vital and chemical agencies which prevailed in the ocean of the Laurentian period we must notice later.

I have merely to add here that the characters assigned above to the Grenville Series have not only been fully corroborated by the recent work of Adams and Ells in Canada,[1] but also by the surveys of Kemp and Smyth in the more disturbed and elevated district of the Adirondack Mountains in New York.[2]

We have thus paved the way for the consideration of evidence of a structural and chemical character.

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[1] American Journal of Geology, 1893, No. 4. Also Reports Geol. Surv. of Canada.

[2] Bulletin Geol. Soc. of America, March 1895.

II. PETROLOGICAL AND CHEMICAL.

Bearing in mind the statements made in the previous note, respecting the stratigraphical relations of the Grenville Series, and referring to the excellent account by my friend Dr. Bonney of his observations at Côte St. Pierre, and to some difficulties stated by him which merit attention, we may sum up the evidence so far, under the following statements :—

1. The limestones included in the Grenville Series and their associated quartzites and schists bear so strong a resemblance in mineral character to metamorphosed Palæozoic calcareous beds of organic origin and their associates, as to warrant at least the careful consideration of any forms apparently organic contained in these limestones.

2. The occurrence in these limestones of nodular silicates, of graphite, of pyrite, and of apatite, affords additional reason to suspect their organic origin.

3. The presence of large beds as well as of veins of graphite and of thick deposits of iron ore in the Grenville Series constitutes an additional analogy with Palæozoic formations holding organic remains.[1]

These facts were adduced by Dr. Sterry Hunt and Dr. J. D. Dana in evidence of the probability of life in the Laurentian period, even before the discovery of Eozoön. Certain particulars connected with them, however, now demand somewhat more detailed attention, in connection with that discovery, and with recent objections to the organic nature of Eozoön.

Dolomite or magnesian limestone is a not infrequent associate of Palæozoic fossiliferous limestones; and I have remarked in previous papers on the similarity of the mode of occurrence of silicified Stromatoporæ in the great dolomite of the Niagara formation with that of Eozoön in the Grenville Limestone, in which dolomite occurs in beds, in thin layers, and in disseminated crystals, in a manner to show that it was an original constituent of the deposit. Dolomite is also one of the most common minerals filling the cavities of Eozoön, and especially the finer tubuli. The mode of its occurrence on the small scale may be seen in the following description of a section of a portion of a bed of limestone from Côte St. Pierre, examined under a lens, after being treated with dilute acid. The specimen comprised about six inches of the thickness of the bed :—

Crystalline limestone with crystals of dolomite, constituting about one half (fragments of Eozoön in calcite portion).[2]

More finely crystalline limestone, with rounded granules of serpentine, some of them apparently moulded in cavities of Archæospherinæ, or of chamberlets of Eozoön.

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[1] See papers by the author on the Graphite and Phosphates of the Laurentian Rocks, Quart. Journ. Geol. Soc. London, 1869 and 1876.

[2] Distinguished by their fine granular texture and canal-systems.

Limestone with dolomite as above, but including a thin layer of limestone with granules of serpentine.
Limestone and dolomite, with a few grains of serpentine and fragments of Eozoön.
Crystalline dolomite with a few fragments of Eozoön, as limestone, with canals in dolomite.
Limestone with fragments of Eozoön, granules of serpentine, and groups of chamberlets filled with serpentine.

We have thus a bed of limestone in which dolomitic and serpentinous layers appear to alternate, and occasional fragments of Eozoön occur in both, while the smaller forms resembling fossils are, so far as can be observed, limited to the serpentinous layers.

At Arnprior on the Ottawa a portion of the Grenville Limestone presents dark graphitic layers parallel to the bedding, and giving it a banded grey and white appearance which has led to its use as a marble. An analysis by Dr. Harrington shows that the graphitic layers contain 8·32 per cent. of magnesia, the lighter layers only 2·57 per cent., in the state of grains or crystals of dolomite. Associated with the marble there are also beds of brown-weathering dolomite, affording 42·10 of magnesia. The graphite in this marble, under the microscope appears as fibrils and groups of minute clots, and sometimes coats the surfaces of crystals or fragments of calcite, the appearances being not unlike those seen in carbonaceous and bituminous limestones of later date.

In both the above cases the magnesium carbonate is evidently an original ingredient of the bed, and cannot have been introduced by any metamorphic action. It must be explicable by the causes which produce dolomite in more recent limestones.

Dana has thrown light on these by his observations on the occurrence of dolomite in the elevated coral island of Matea in Polynesia,[1] under circumstances which show that it was formed in the lagoon of an ancient coral atoll, while he finds that coral and coral sands of the same elevated reef contain very little magnesia. He concludes that the introduction of magnesia into the consolidating under-water coral sand or mud has apparently taken place—"(1) In sea-water at the ordinary temperature; and (2) without the agency of any other mineral water except that of the ocean"; but the sand and mud were those of a lagoon in which the saline matter was in process of concentration by evaporation under the solar heat. Klement has more recently taken up this fact in the way of experiment, and finds that, while in the case of ordinary calcite this action is slow and imperfect, with the aragonite which constitutes the calcareous framework of certain corals, and at temperatures of 60° or over, it is very rapid and complete, producing a mixture of calcium and magnesium carbonates, from which a pure dolomite more or less mixed with calcite may subsequently result.[2]

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[1] "Corals and Coral Islands," p. 356, etc.

[2] Bulletin Geol. Soc. Belgium, vol. ix (1895, p. 3). Also notice in GEOL. MAG., July 1895, p. 329.

I regard these observations as of the utmost importance in reference to the relations of dolomite with fossiliferous limestones, and especially with those of the Grenville Series. The waters of the Laurentian ocean must have been much richer in salts of magnesium than those of the present seas, and the temperature was probably higher, so that chemical changes now proceeding in limited lagoons might have occurred over much larger areas. If at that time there were, as in later periods, calcareous organisms composed of aragonite, these may have been destroyed by conversion into dolomite, while others more resisting were preserved, just as a modern *Polytrema* or *Balanus* might remain, when a coral to which it might be attached would be dolomitized. This would account for the persistence of Eozoön and its fragments, when other organisms may have perished, and also for the frequent filling of the canals and tubuli with the magnesian carbonate.

The question now arises as to the mineralization of Eozoön with serpentine, and more rarely, especially in the case of its larger and lower chambers, with pyroxene. Connected with this is the alternation, as above described, of serpentinous and dolomitic layers in the limestone, as if in successive times the conditions were alternately favourable to the deposition of magnesium in the form of carbonate and in that of silicate.

We learn from the "Challenger" Reports that under certain circumstances the presence of organic matter in oceanic deposits causes an alkaline condition, tending to the solution of silica and the formation of silicates. We also learn that siliceous matter in a state of fine division (*e.g.* volcanic dust) may afford material for the production of hydrous silicates, either directly or indirectly through the agency of organisms forming siliceous skeletons. The "Challenger" Reports also show that the silicates known under the name of glauconite, and thus deposited, contain several bases to some extent interchangeable. Of these the principal are aluminium, potash, and iron, though magnesia is also present. Some older silicates injecting fossils in the Palæozoic rocks are less complicated, and contain more magnesia; and, as Hunt has shown, there is nothing anomalous in the supposition that in the Laurentian period silicate of magnesium and iron may have acted in this capacity.[1]

It is true that serpentine is now usually regarded as a product of the hydration of olivine and pyroxene; still, even on this supposition, it might be formed from the hydration of fine volcanic dust falling into the sea. Hunt also has shown that the serpentine of the Grenville Limestone differs chemically from those supposed to be of direct igneous origin in its comparative freedom from iron oxide, in its larger proportion of water, and in its lower specific gravity, besides being a more pure silicate of magnesium. That it can be deposited by water is shown by the chrysotile filling veins, and by my own observations, published long ago, on the serpentine

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[1] See Analyses of Glauconites, etc., by Dr. Hunt in "Dawn of Life," p. 126. One tertiary example is silicate of iron and magnesia. See also Hoskins on Glauconite, GEOL. MAG., July 1895.

replacing and filling cavities of Cambro-Silurian fossils at Melbourne in Canada, and filling the cells of Silurian corals at Lake Chebogamong.[1]

The occurrence of pyroxene in the limestone, and filling some of the chambers of Eozoön, may also be easily explained. Dr. Bonney well remarks that it does not resemble any igneous rock known to him, and it is quite certain from its mode of occurrence that it cannot be directly igneous. Somewhat thick and continuous beds of a coarser pyroxenite occur in some parts of the Grenville Series, *e.g.* at Templeton, and I have described them as probably volcanic ash-beds, while the large pyroxene crystals found in the veins of apatite traversing these beds are probably of thermo-aqueous origin. But the limited and irregular masses and concretions of white pyroxene occurring in the limestones are of different texture and colour, and more purely silicates of lime and magnesia. They may have resulted from local showers of volcanic ashes drifted by currents into hollows of the Eozoön reefs, and sufficiently fine to fill the larger chambers of dead specimens, and when consolidated to form a basis for the growth of new individuals. This is, I think, the only supposition on which they can be explained, and it would also explain the difficulty suggested by Dr. Bonney as to the association of the pyroxene with Eozoön.

There seems, however, to be no good evidence that any portion of the pyroxene has been changed into serpentine; and it is evident that if such a change had occurred after the consolidation of the rock, serious chemical and mechanical difficulties would be involved, whereas if volcanic débris, whether of the nature of olivine or pyroxene, became hydrated while the rock was incoherent and in process of formation, this would tend greatly to promote the infiltration with hydrous silicates of any fossils present in the mass.

Assuming the serpentine and pyroxene to have been deposited as above suggested, the remaining objections stated by Dr. Bonney would at once disappear. Specimens of Eozoön or other fossils might be infiltrated or filled with these silicates, and while the latter were superabundant they might form separate concretions or grains which might in some cases envelop the fossils or be attached to them in irregular forms, just as one finds in the case of the flints in chalk or the chert in some other limestones.[2]

It is scarcely necessary to say that no objection to the organic origin of the Eozoön can be founded on the fact that many of the specimens are fractured, crushed, bent, or faulted, by the movement of the containing rock, or on the circumstance that well-preserved specimens should be rare, and found chiefly in beds containing

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[1] Quart. Journ. Geol. Soc. 1864, p. 69, also 1879, p. 48 *et seq.*, Memoir on Eozoön in Peter Redpath Museum, 1888, p. 48 *et seq.*

[2] It is a curious coincidence that Dr. Johnston-Lavis has described in the July Number of this Journal, the aqueous deposition at ordinary temperature of crystals of pyroxene and hornblende, in cavities and crevices of bones included in an ash-bed of recent date, and in presence of calcite, apatite, and fluoride of calcium, as in the Grenville Series. This is a modern instance analogous to that suggested above.

silicates capable of injecting their cavities. On the other hand, the circumstance that fragments of Eozoön are abundant in the limestone is one of the best possible proofs that we are dealing with a calcareous organism. It would be interesting to describe and figure a number of specimens in our collections illustrating these points; but to do so would require an extensive illustrated memoir, for which neither space nor means are at present available.

I observe, in conclusion of this part of the subject, that in any highly crystalline limestone we can hope to find well-preserved fossils only when their cavities and pores have been filled with some enduring siliceous mineral; but, on the other hand, that porous fossils, once so infiltrated, become imperishable. It still remains to consider shortly new facts bearing on the structure of Eozoön and its possible biological affinities.

III. STRUCTURAL AND BIOLOGICAL.

In recent years I have been disposed to attach more importance than formerly to the general form and macroscopical characters of Eozoön. The earlier examples studied were, for the most part, imbedded in the limestone in such a manner as to give little definite information as to external form; and at a later date, when Sir William Logan employed one of his assistants, Mr. Lowe, to quarry large specimens at Grenville and Côte St. Pierre, the attempt was made to secure the most massive blocks possible, in order to provide large slabs for showing museum specimens. More recently, when collections have been made from the eroded and crumbling surfaces of the limestone in its wider exposures, it was found that specimens of moderate size had been weathered out, and could, either naturally or by treatment with acid, be entirely separated from the matrix. Such specimens sometimes showed, either on the surfaces or on the sides of cavities and tubes penetrating the mass, a confluence of the laminæ, constituting a porous cortex or limiting structure. Specimens of this kind were figured in 1888,[1] and I was enabled to add to the characters of the species that the original and proper form was "broadly turbinate with a depression or cavity above, and occasionally with oscula or pits penetrating the mass." The great flattened masses thus seemed to represent confluent or overgrown individuals, often contorted by the folding of the enclosing beds.

There are also in well-preserved specimens certain constant properties of the old calcite and serpentine ~~lagoons~~ layers. The former are continuous, and connected at intervals, so that if the siliceous filling of the chambers could be removed, *the calcareous portion* would form a continuous skeleton, while the serpentine filling the chambers, when the calcareous plates are dissolved out by an acid, forms a continuous cast of the animal matter filling the chambers. This cast of the sarcodous material, when thus separated, is very uniformly and beautifully mammillated on the surfaces of the laminæ, and this

[1] GEOLOGICAL MAGAZINE, and Museum Memoir.

tuberculation gradually passes upward into smaller chambers, having amœboid outlines, and finally into rounded chamberlets. It is also a very constant point of structure that the lower laminæ of calcite are thicker than those above, and have the canal-systems larger and coarser. There is thus in the more perfect specimens a definite plan of macroscopical structure.

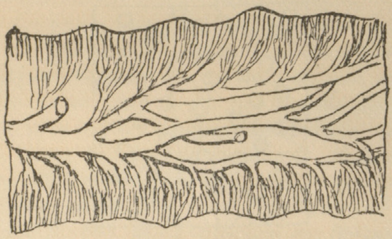

Fig. 6.—Diagram of typical mode of arrangement of canals and tubuli in a lamina of *Eozoön Canadense.* (Magnified.)

The normal mode of mineralization at Côte St. Pierre and Grenville is that the laminæ of the test remain as calcite, while the chambers and larger canals are filled with serpentine of a light green or olive colour, and the finer tubuli are injected with dolomite. It may also be observed that the serpentine in the larger cavities often shows a banded structure, as if it had been deposited in successive coats, and the canals are sometimes lined with a tubular film of serpentine, with a core or axis of dolomite, which also extends into the finer tubuli of the surfaces of the laminæ. This, on the theory of animal origin, is the most perfect state of preservation, and it equals anything I have seen in calcareous organisms of later periods. This state of perfection is, however, naturally of infrequent occurrence. The finer tubuli are rarely perfect or fully infiltrated. Even the coarser canals are not infrequently imperfect, while the laminæ themselves are sometimes crumpled, crushed, faulted, or penetrated with veins of chrysotile or of calcite. In some instances the calcareous laminæ are replaced by dolomite, in which case the canal-systems are always imperfect or obsolete. The laminæ of the test itself are also in some cases replaced by serpentine in a flocculent form. At the opposite extreme are specimens or portions of specimens in which the chambers are obliterated by pressure, or occupied only with calcite. In such cases the general structure is entirely lost to view, and scarcely appears in weathering. It can be detected only by microscopic examination of slices, in parts where the granular structure or the tubulation of the calcite layers has been preserved. All palæontologists who have studied silicified fossils in the older rocks are familiar with such appearances.

It has been alleged by Möbius and others that the canal-systems and tubes present no organic regularity. This difficulty, however, arises solely from imperfect specimens or inattention to the necessary results of slicing any system of ramifying canals. In Eozoön the canals form ramifying groups in the middle planes of the laminæ, and proceed at first almost horizontally, dividing into smaller branches, which ultimately give off brushes of minute tubuli running nearly at right angles to the surfaces of the lamina, and forming the extremely fine tubulation which Dr. Carpenter regarded as the proper wall. In my earlier description I did not distinguish this from the canal-system, with which its tubuli are inwardly continuous; Dr. Carpenter, however, understood this arrangement, and has represented it in his figures[1] (see also Fig. 6). It is evident that in a structure like this a transverse or oblique section will show truncated portions of the larger tubes apparently intermixed with others much finer and not continuous with them, except very rarely. Good specimens and many slices and decalcified portions are necessary to understand the arrangement. This consideration alone I think entirely invalidates the criticisms of Möbius, and renders his large and costly figures of little value, though his memoir is, as I have elsewhere shown, liable to other and fatal objections.[2]

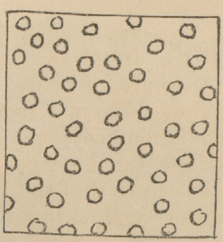

Fig. 7.—Cross section of minute tubuli, about 5 microms. in diameter. (Magnified.)

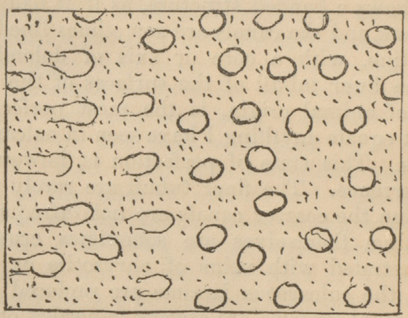

Fig. 8.—Cross section of similar tubuli, more highly magnified, and showing granular character of the test. (From camera tracings.)

It has been pretended that the veins of chrysotile, when parallel to the laminæ, cannot be distinguished from the minute tubuli terminating on the surfaces of the laminæ. I feel confident,

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[1] Ann. and Mag. Nat. Hist., ser. 4, xiii, p. 456, figs. 3, 4.

[2] Museum Memoir, pp. 50 *et seq.*

however, that no microscopist who has seen both, under proper conditions of preservation and study, could confound them. The fibres of chrysotile are closely appressed parallel prisms, with the optical properties of serpentine. The best preserved specimens of the "proper wall" contain no serpentine, but are composed of calcite with extremely minute parallel cylinders of dolomite about five to ten microms. in diameter, and separated by spaces greater than their own diameter (see my comparative figure, "Dawn of Life," p. 106; also Figs. 5, 6). In the rare cases where the cylinders are filled with serpentine they are, of course, still more distinct and beautiful. At the same time I do not doubt that observers who have not seen the true tubulation may have been misled by chrysotile veins when these fringe the laminæ. Möbius, for instance, figures the true and false structure as if they were the same.

Protest should here be made against that mode of treating ancient fossils which regards the most obscure or defaced specimens as typical, and those better preserved as mere accidents of mineral structure. In Tertiary Nummulites injected with glauconite, it is rare to find the tubuli perfectly filled, except in tufts here and there, yet no one doubts that these patches represent a continuous structure.

I have remarked on previous occasions that the calcite constituting the laminæ of Eozoön often has a minutely granular appearance, different from that of the surrounding limestone. This is, I presume, the "dusty" appearance referred to by Dr. Bonney. Under a high power it resolves itself into extremely minute dots or flocculi, somewhat uniformly diffused. Whether these dots are particles of carbon, iron, apatite, or siliceous matter, or the remains of a porous structure, I do not know; but similar appearances occur in the calcareous fossils contained in altered limestones of later date. Wherever they occur in crystalline limestones supposed to be organic, the microscopist should examine these with care. I have sometimes by this appearance detected fragments of Eozoön which afterward revealed their canals.

I have not space here to notice late observations on Archæospherinæ and other objects supposed to be organic found in pre-Cambrian rocks in Canada and in Europe. They afford, however, to some extent, corroborative evidence in favour of Eozoön.

Supposing a probability to be established of the animal nature of Eozoön, we should naturally expect to detect links of connection between it and fossils known to us in the succeeding geological formations. We have, however, here to make allowance for the probability that an organism so very ancient may differ materially from any of its successors, and may probably be a synthetic or generalized type, or present embryonic characters. Analogy might also justify the supposition that it might be represented in later times by smaller as well as more specialized forms. In this connection also, the probable warmth and shallowness of the Laurentian ocean, and its abundance in calcium carbonate and in carbonaceous matter, probably organized, should be taken into account. It should also be noted that the formations next in ascending order are of a character little likely to preserve organic marine forms of the "benthos" or ground-living group. We might thus expect a gap in our record between the fauna of the Grenville Series and that of the next fossiliferous formations.

Logan naturally compared his earlier specimens with the Stromatoporæ so abundant in the Ordovician and Silurian Limestones; and in this he was justified, for, whatever may be the ultimate judgment of naturalists as to these problematical fossils, and whether they are referred to Protozoa or to Hydrozoa, or, as seems more likely, are divided between the two, they resemble Eozoön in general structure and mode of accumulation of calcareous matter, and occupied a similar place in nature. My own conclusion, on discussing the microscopic structures of the specimens of Eozoön, was that they were probably those of Protozoa allied to those Foraminifera with thick supplemental skeleton[1] which had been described by Dr. Carpenter. At the same time, I suspected that those Stromatoporoids, like Cœnostroma, which possess thick laminæ penetrated by ramifying tubes, might be allied to the Laurentian fossil. Dr. Carpenter regarded the structures as combining in some respects those of Rotaline and Nummuline Foraminifera, and ably, and as I think conclusively, defended this view when attacked.[2] The Rotaline type of Foraminifera has since that time been traced by Cayeux and Matthew far down into the pre-Cambrian rocks. The Nummuline type is not known so early. As to the canal-bearing Stromatoporoids, none of them show the fine tubulation, though some have radiating and branching canals. Recent students of the Stromatopora seem disposed to refer them to Hydrozoa,[3] a conclusion probable in the case of some of the forms (especially those spinous ones incrusting shells), but doubtful in the case of others, and more particularly the oldest of all, belonging to the genus Cryptozoön of Hall, and Archæozoön of Matthew,[4] the structure of which seems, so far as known, to consist of very thin primary laminæ with a supplemental tubulated skeleton resembling that of the genus *Loftusia*, and which must, I think, be regarded as foraminiferal. In any case, whether these primitive forms are Protozoa or rudimentary Hydroids, they reach back in time nearly as far as Eozoön, and are equally massive and abundant, and may be regarded as analogous to it in magnitude, habitat, mode of growth, and function in nature.

These later discoveries are gradually widening the horizon of palæontologists in the direction of the dawn of life, and the studies of those who trace backward the history of the Invertebrates of the Palæozoic seas are demanding more and more the discovery of earlier forms than those yet known to complete the chain of life.[5] The field is a difficult one to cultivate, and demands both labour and patience, but it holds forth the prospect of great discoveries, and it has already become the duty and interest of palæontologists to

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[1] Calcarina, etc.

[2] Ann. and Mag. Nat. Hist, *loc. cit.*

[3] Nicholson, Monographs Palæontographical Society.

[4] Bulletin Nat. Hist. Survey of New Brunswick, 1894–5.

[5] See Dr. Woodward's Address as President of the Geological Society, 1895.

extend their inquiries as far back as the Laurentian in the search for Eozoic life.

In this respect the study and discussion of Eozoön have not been without use, in directing attention to the possibility of finding organic remains in the older crystalline rocks, to the danger of confounding them in their peculiar condition with merely mineral structures, to the state of preservation of organic remains in the older formations, and to the origin and significance of the large deposits of limestone, dolomite, hydrous silicates, iron ore, graphite, and apatite, laid up in certain horizons of the Eozoic rocks. Questions of this kind have been greatly advanced toward their satisfactory solution since the discovery of Eozoön in 1858, and in some degree at least in consequence of the interest excited by that discovery. It is hoped that the present notes may tend in the same direction, and that, whether or not they succeed in removing any existing scepticism in respect to Eozoön, they may help to stimulate and guide the search for those beginnings of life, which there are now the best reasons for believing are to be found far below the base of the Cambrian.

[Additional facts and illustrations, and references to previous papers on the subject, will be found in "Specimens of Eozoön Canadense," pp. 106, published by the Peter Redpath Museum (Notes on Specimens, Sept. 1888), which may be obtained on application to the Museum, or through W. Foster Brown, Bookseller, Montreal. See also, for a popular summary, Chapters v and vi of "Some Salient Points in the Science of the Earth," London, 1893.]

NOTE TO SECOND ARTICLE.

I should have mentioned in this article that Dr. F. D. Adams has shown, by comparison of a number of detailed analyses, that several of the gneisses of the Grenville Series have the chemical composition of Palæozoic slates, and thus that there can be no chemical objection to regarding them as altered sediments. This I consider a very important observation; and I may refer for details to his paper in the American Journal of Science, 1895, p. 58.

NOTE TO THIRD ARTICLE.

The tubes penetrating some of the larger specimens of Eozoön may perhaps be compared with the central canal in the modern *Carpenteria.*

Stephen Austin and Sons, Printers, Hertford.