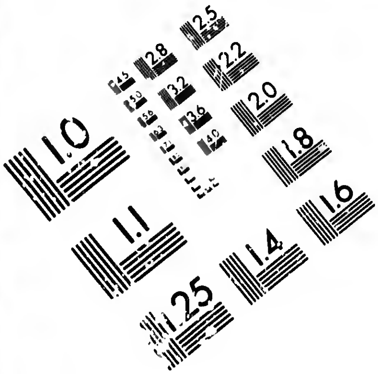


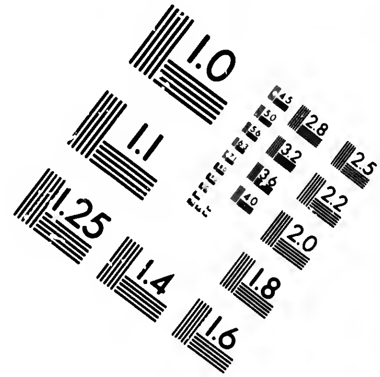
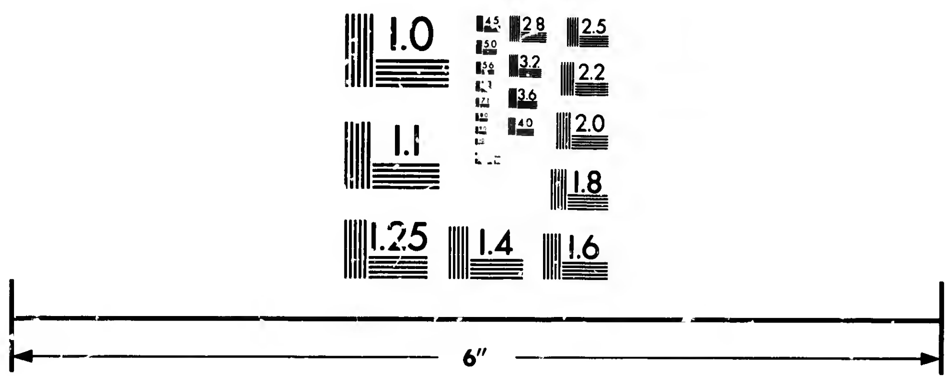
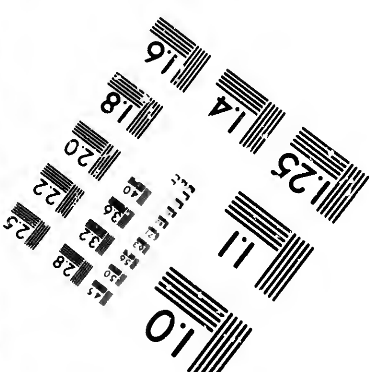
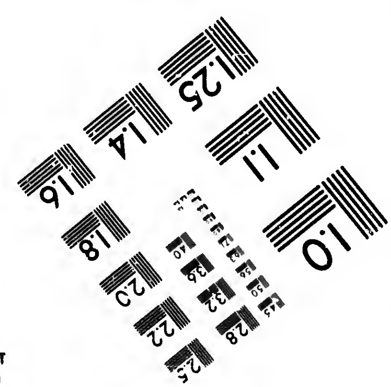


IMAGE EVALUATION
TEST TARGET (MT-3)







Technical and Bibliographic Notes/Notes techniques et bibliographiques

The Institute has attempted to obtain the best original copy available for filming. Features of this copy which may be bibliographically unique, which may alter any of the images in the reproduction, or which may significantly change the usual method of filming, are checked below.

L'Institut a microfilmé le meilleur exemplaire qu'il lui a été possible de se procurer. Les détails de cet exemplaire qui sont peut-être uniques du point de vue bibliographique, qui peuvent modifier une image reproduite, ou qui peuvent exiger une modification dans la méthode normale de filmage sont indiqués ci-dessous.

- [ ] Coloured covers/ Couverture de couleur
- [ ] Covers damaged/ Couverture endommagée
- [ ] Covers restored and/or laminated/ Couverture restaurée et/ou pelliculée
- [ ] Cover title missing/ Le titre de couverture manque
- [ ] Coloured maps/ Cartes géographiques en couleur
- [ ] Coloured ink (i.e. other than blue or black)/ Encre de couleur (i.e. autre que bleue ou noire)
- [x] Coloured plates and/or illustrations/ Planches et/ou illustrations en couleur
- [ ] Bound with other material/ Relié avec d'autres documents
- [ ] Tight binding may cause shadows or distortion along interior margin/ La reliure serrée peut causer de l'ombre ou de la distortion le long de la marge intérieure
- [ ] Blank leaves added during restoration may appear within the text. Whenever possible, these have been omitted from filming/ Il se peut que certaines pages blanches ajoutées lors d'une restauration apparaissent dans le texte, mais, lorsque cela était possible, ces pages n'ont pas été filmées.
- [ ] Additional comments:/ Commentaires supplémentaires:

- [ ] Coloured pages/ Pages de couleur
- [ ] Pages damaged/ Pages endommagées
- [ ] Pages restored and/or laminated/ Pages restaurées et/ou pelliculées
- [x] Pages discoloured, stained or foxed/ Pages décolorées, tachetées ou piquées
- [ ] Pages detached/ Pages détachées
- [x] Showthrough/ Transparence
- [ ] Quality of print varies/ Qualité inégale de l'impression
- [ ] Includes supplementary material/ Comprend du matériel supplémentaire
- [ ] Only edition available/ Seule édition disponible
- [x] Pages wholly or partially obscured by errata slips, tissues, etc., have been refilmed to ensure the best possible image/ Les pages totalement ou partiellement obscurcies par un feuillet d'errata, une pelure, etc., ont été filmées à nouveau de façon à obtenir la meilleure image possible.

This item is filmed at the reduction ratio checked below/
Ce document est filmé au taux de réduction indiqué ci-dessous.

10X		12X		14X		16X		18X		20X		22X		24X		26X		28X		30X		32X
										✓												

The copy filmed here has been reproduced thanks to the generosity of:

Library,
Geological Survey of Canada

The images appearing here are the best quality possible considering the condition and legibility of the original copy and in keeping with the filming contract specifications.

Original copies in printed paper covers are filmed beginning with the front cover and ending on the last page with a printed or illustrated impression, or the back cover when appropriate. All other original copies are filmed beginning on the first page with a printed or illustrated impression, and ending on the last page with a printed or illustrated impression.

The last recorded frame on each microfiche shall contain the symbol —▶ (meaning "CONTINUED"), or the symbol ▽ (meaning "END"), whichever applies.

Maps, plates, charts, etc., may be filmed at different reduction ratios. Those too large to be entirely included in one exposure are filmed beginning in the upper left hand corner, left to right and top to bottom, as many frames as required. The following diagrams illustrate the method:

L'exemplaire filmé fut reproduit grâce à la générosité de:

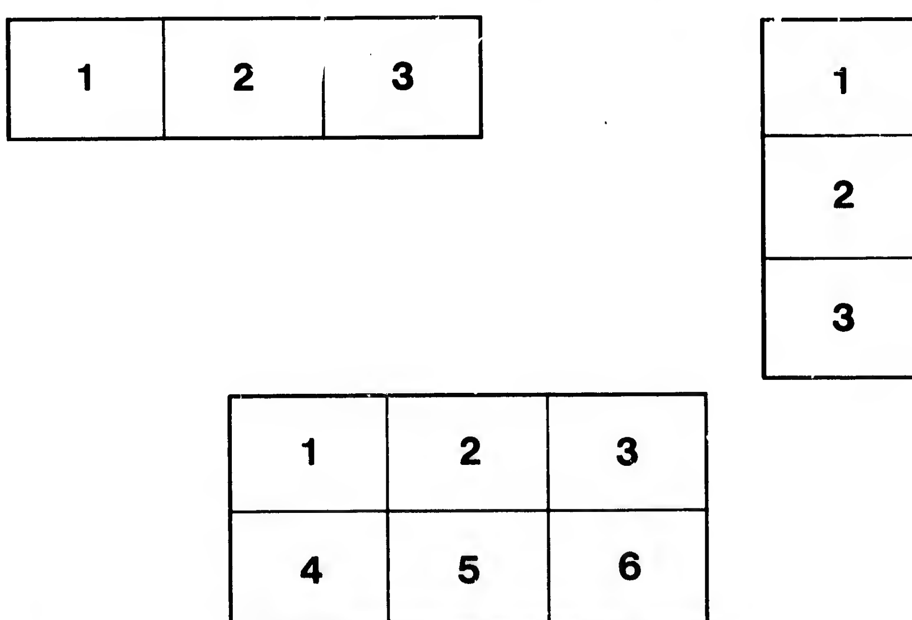
Bibliothèque,
Commission Géologique du Canada

Les images suivantes ont été reproduites avec le plus grand soin, compte tenu de la condition et de la netteté de l'exemplaire filmé, et en conformité avec les conditions du contrat de filmage.

Les exemplaires originaux dont la couverture en papier est imprimée sont filmés en commençant par le premier plat et en terminant soit par la dernière page qui comporte une empreinte d'impression ou d'illustration, soit par le second plat, selon le cas. Tous les autres exemplaires originaux sont filmés en commençant par la première page qui comporte une empreinte d'impression ou d'illustration et en terminant par la dernière page qui comporte une telle empreinte.

Un des symboles suivants apparaîtra sur la dernière image de chaque microfiche, selon le cas: le symbole —▶ signifie "A SUIVRE", le symbole ▽ signifie "FIN".

Les cartes, planches, tableaux, etc., peuvent être filmés à des taux de réduction différents. Lorsque le document est trop grand pour être reproduit en un seul cliché, il est filmé à partir de l'angle supérieur gauche, de gauche à droite, et de haut en bas, en prenant le nombre d'images nécessaire. Les diagrammes suivants illustrent la méthode.



FRONTISPIECE. Plate IX

Fig. 1.

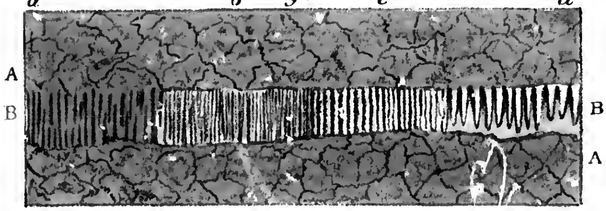


Fig. 2.

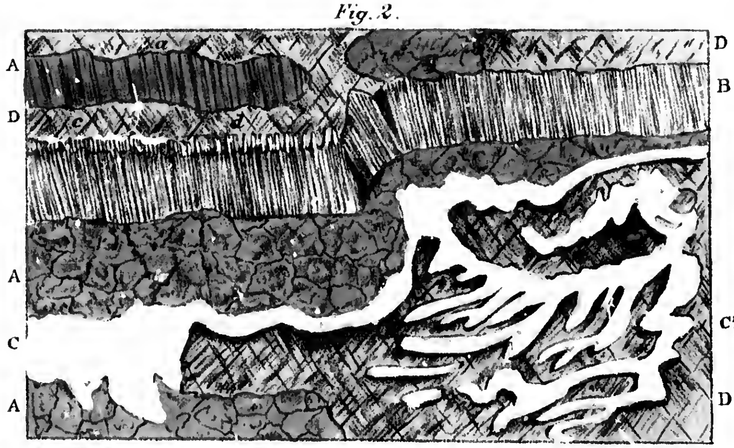


Fig. 3.

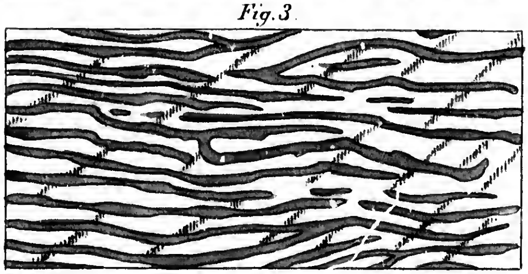


FIG. 1.–Development of Chrysotile, from the incipient (*a*) to the completed state (*d*); showing the origin of the "proper wall" of "*Eozoon*." (*Diagram*).

FIG. 2.–"*Eozoon Canadense.*" from Ottawa, Canada, showing the following changes; chrysotile (b) into "proper wall" (d), and flocculent serpentine (c) into "canal system" (cx).

FIG. 3.–Lamellar graphic granite from Tarbert, Hebrides: its lamellar and fibrous structures are considered to be organic by *Eozoonists*.

Pinx W.K. Hanhart lith

[illegible]

[illegible] ECORD

[illegible]

[illegible]

Pin

AN OLD CHAPTER

OF THE

GEOLOGICAL RECORD

WITH A NEW INTERPRETATION:

OR,

ROCK-METAMORPHISM

(ESPECIALLY THE METHYLOSED KIND)

AND ITS RESULTANT IMITATIONS OF ORGANISMS.

WITH

AN INTRODUCTION

GIVING AN

ANNOTATED HISTORY OF THE CONTROVERSY ON THE SO-CALLED

"EOZOON CANADENSE,"

AND

AN APPENDIX.

BY

PROFESSORS W. KING, Sc.D. ETC.,

AND

T. H. ROWNEY, Ph.D. ETC.,

OF THE QUEEN'S COLLEGE, GALWAY, AND THE QUEEN'S UNIVERSITY IN IRELAND.

LONDON:
JOHN VAN VOORST, 1 PATERNOSTER ROW.
MDCCCLXXXI.

ALERE FLAMMAM.

PRINTED BY TAYLOR AND FRANCIS,
RED LION COURT, FLEET STREET.

CONTENTS.

APPENDIX.

PREFACE.

SINCE the publication of Bischof's 'Lehrbuch der chemischen und physikalischen Geologie' (1847–54), seldom has any thing excited more sustained interest among geologists than the question as to the nature and origin of metamorphic rocks. At the Paris Exhibition, in 1878, an International Congress, comprising many eminent geologists, was convoked, one of the main objects of which was to consider the problem of metamorphism. Researches having the same purpose in view have been promoted by grants from the Government Scientific Research Fund at the recommendation of the Royal Society, and from the British Association. Some sixteen years past the alleged discovery of the so-called "*Eozoon Canadense*" gave a marked impetus to the study of metamorphic geology; and of late years microscopic observations on metamorphosed rocks and their component minerals have been sedulously pursued. The result of all this is that a vast body of evidence has been gathered together, throwing much new light on the subject in question.

Nevertheless, if the *latest* exposition of rock-metamorphism is to be taken as correctly representing its present state, the subject, it would rather appear, has all along been stagnant, having made no progress since Lyell began to write on it—more than forty years ago! Dr. Ramsay, in his Address lately delivered at Swansea as President of the British Association, declares, without any reservation, that in metamorphic rocks "there is little or no development of new material;" and he accordantly maintains that they have been simply mineralized —"sandstones have been converted into quartzites," and so on, —using almost the same terms as Lyell did, and after the lapse of nearly half a century.

This latter-day exposition of metamorphism, the writers feel, affords indubitable proof that the present work is imperatively called for to meet the requirements of a large body of geological students.

Having laboured at the subject for fifteen years (aided to some extent by a grant from the Government Fund), they have determined the existence of two strongly differentiated groups of metamorphic rocks—*mineralized* and *methylosed.* They are also enabled to show that the characters of the latter group have been developed by the decomposing action of carbonated solutions on siliceous minerals; that essentially silacid rocks, which have been permeated by solvents of the kind, have become variously transmuted and transformed—in the one case having had their mineral silicates for the most part replaced by mineral carbonates (calcite &c.),—in the other the same siliceous minerals, where simply affected by partial erosion and replacement, having become shaped into a variety of residual configurations that have been mistaken for organic structures, as in "*Eozoon Canadense.*" Moreover the above phenomena enable the writers to show that both bedded and dyke-shaped masses on a large scale exhibit corresponding chemical changes; so that what were once essentially siliceous rocks are now ophites, hemithrenes, and the like,—in which it cannot be said that "there is little or no development of new material," and which, in short, clearly prove that there are numerous other metamorphic rocks besides those that are simply mineralized.

Just before the "creature of the dawn" made its advent, mineral pseudomorphism was labouring under great bewilderment. The opinion on the subject, which had been founded on the researches of Blum, Bischof, Rose, and others, was encountering more or less hostility from Scheerer, Naumann, Delesse, and Sterry Hunt. The pseudomorphic origin of serpentine, which had been strongly contended for by the first group of scientists, was uncompromisingly opposed by certain of the latter, especially Sterry Hunt, who, with the fact before him that this mineral occurs, forming vast rock-masses, amongst the old stratified crystalline deposits (Archæans) of Canada, unhesitatingly declared it to be neither pseudomorphic, nor metamorphic, but a crystallized precipitate, chemically thrown down by the primæval ocean. At last "*Eozoon Canadense*" appeared on the scene. Chiming in to some extent with Sterry Hunt's "novel doctrine," it was at once enthusiastically accepted by the highest authorities in geology as resolving the vexed question attaching to serpentine and some other Archæan problems; at the same time it was held up before the eyes of a wondering and confiding world as the first-born of life on our planet—protoplasm in vast flakes invested with a calcareous covering, and rivalling coral reefs in magnitude!

It will be our object in the following pages to show that both doctrines are absolutely fallacious.

INTRODUCTION.

THE first announcement in connexion with the subject of "*Eozoon*" was made by the late Sir Wm. E. Logan, Director-General of the Geological Survey of Canada, in his Report of the year 1858. 1858.

Sir Wm. E. Logan exhibited at the Meeting of the American Association for the Advancement of Science at Springfield, in August 1859, some *Stromatopora*-like specimens (noticed in the above Report) from the Grand Calumet and Perth (Canada), which he was "disposed to look upon as fossils"*. 1859.

Report of the Geology of Canada, 1863. Sir W. E. Logan. 1863.

In this Report (pp. 48, 49) the discovery of specimens, supposed to be fossils, is noticed as having been made "by Mr. J. M'Mullen, of the Canada Geological Commission, in the crystalline limestone of the Grand Calumet (river Ottawa), which present parallel or apparently concentric layers, composed of crystalline pyroxene, while the interstices are filled with crystalline carbonate of lime. Dr. James Wilson, of Perth, found loose masses of limestone near the same place containing similar forms—the layers composed of dark green concretionary serpentine, while the interstices are filled with crystalline dolomite. If both are regarded as the results of unaided mineral arrangement, it would seem strange that identical forms should be derived from minerals of such different

* Quarterly Journal of the Geological Society, vol. xxi. p. 48.

composition. If the specimens had been obtained from the altered rocks of the Lower Silurian series, there would have been little hesitation in pronouncing them to be fossils."

1864. American Journal of Science, March 1864, p. 273.

Sir W. E. Logan announced that Dr. Dawson had discovered in the Canadian ophite structures which it was decidedly his belief were organic and foraminiferal.

1864. 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 by J. W. Dawson, LL.D, F.R.S., on the Structure, and by T. Sterry Hunt, F.R.S., on the Mineralogy of the same remains.

Paper read at the Bath Meeting of the British Association, September 1864.

1864. On the Structure of certain Organic Remains in the Laurentian Limestones of Canada. Dr. J. W. Dawson. Q. J. G. S. vol. xxi. pp. 51–59.

1864. Additional Note on the Structure and Affinities of *Eozoon Canadense*. Dr. W. B. Carpenter. Op. cit. pp. 59–66.

Both writers assume that the calcareous or dolomitic layers of the specimens brought under notice by Logan constitute the skeletal portion of "*Eozoon Canadense*," and that the siliceous layers, whether serpentine, white pyroxene, or loganite, are casts of its cells or chambers. Dawson, having detected branching configurations and rods or plates in the "skeleton," and taking them for casts of canals and stolons, identified them with the canal system and stolons of a foraminiferal organism; and Carpenter, observing a fibrous lamina often surrounding the "chambers," pronounced its fibres to be casts of tubuli such as characterize the proper wall of a nummuline foraminifer. The serpentine layers frequently present themselves more or less excavated and divided; but often they are broken up into short plates and detached spheroids irregularly lobulated. The presumed organism in the former case is said to be the "lamellated," and the latter the "acervuline" variety.

On the Occurrence of Organic Remains in the Laurentian Rocks of Canada. Sir W. E. Logan. Q. J. G. S. vol. xxi. pp. 45–50. 1864.

On the Mineralogy of certain Organic Remains from the Laurentian Rocks of Canada. Dr. T. Sterry Hunt. Op. cit. pp. 67–71. 1864.

On the Structure and Affinities of *Eozoon Canadense*. Letter to the President of the Royal Society. Dr. W. B. Carpenter. Proc. Roy. Soc. vol. xiii. pp. 545–549. 1864.

Geological Magazine. Vol. ii. pp. 87, 88, Dec. 27, 1864. 1864.

Announcement by Mr. W. A. Sandford, F.G.S., of his discovery of "*Eozoon Canadense*" in Connemara marble from the Binabola Mountains; which "T. R. J.," at the same time, announced he had "verified by experiment." "The various formed chambers, the shell of varying thickness, either very thin and traversed with fine tubuli, the silicate filling which (when bared) resembles white velvet-pile, or thick and traversed with brush-like threads, representing the pseudopodian passages of the 'supplemental shell' (or 'vascular system'), are all present."

"Appendix" to a reprint of Dr. Dawson's Memoir (A.D. 1864) in Canadian Naturalist, April 1865. 1865.

Dr. Dawson, who had previously observed "traces of organic structure in the Connemara marble, but not in so far as can be made out of the character of *Eozoon*," declares that "it is gratifying to find in recent British publications notices to the effect that Mr. Sandford has found the structure of *Eozoon* in the Laurentian limestones of Ireland."

On the Structure, Affinities, and Geological Position of *Eozoon Canadense*. Dr. W. B. Carpenter. Intellectual Observer, vol. vii. 1865.

On the oldest known Fossil, *Eozoon Canadense*, of the Laurentian Rocks of Canada; its place, structure, and significance. Prof. T. Rupert Jones. Popular Science Review, vol. iv. 1865.

1865. The following letter appeared in the 'Reader,' June 10, 1865, p. 660:—

"*The Eozoon Canadense.*

"Queen's College, Galway, June 3, 1865.

"We beg permission to publish the following statement through the medium of your widely-circulated Journal:—

"For several weeks past we have been engaged in investigating the microscopic structure of the serpentine of Connemara in comparison with that of a similar rock occurring in Canada, which has attracted so much attention of late. For a considerable portion of the time we entertained the opinion, in common with Sir William Logan, Drs. Dawson, Sterry Hunt, Carpenter, and Professor Rupert Jones, that the Canadian serpentine is of organic origin, the result of the growth of an extinct foraminifer called *Eozoon Canadense*; it was also our belief for a while that the Connemara rock had originated from a similar organism. Gradually of late, however, we have been reluctantly compelled to change our opinions.

"It is now our conviction that all the parts, in serpentine, which have been taken for the skeleton-structures of a foraminifer are nothing more than the effect of crystallization and segregation.

"It would have given us unalloyed pleasure, had we been able to state that our investigations had confirmed those of the eminent authorities to whom reference has been made, as it was purely in this spirit that we commenced our labours; and also, we may observe, with the desire to ascertain if the serpentine of Connemara and the other rocks with which it is interstratified, belonged to the Laurentian period.

"We purpose at an early opportunity to lay before the public all the evidences and considerations which bear us out in our present opinion.

"We are, Sir, yours very truly &c.,

"William King, Professor of Mineralogy and Geology.

"Thomas H. Rowney, Ph.D., Professor of Chemistry."

"The *Eozoon Canadense.*" A letter, signed "William B. Carpenter," appeared in a following number of the 'Reader.' 1865.

The writer asserts that the "conformity" between "Connemara serpentine" and "that of the *least* characteristic part of the Canadian fossil" is "so close as to leave no doubt in my mind as to the organic origin of the former." Next, he makes a characteristic personal attack on the writers of the preceding letter, "advisedly" remarking on the "audacity" of the one in presuming to dispute the organic origin of *Eozoon*, and impliedly charging the other with incompetency.

A short reply, signed "William King," appeared in the next number of the 'Reader'*.

The Cambrian Rocks of the British Islands. W. Hellier Baily. Geological Magazine, vol. ii. p. 388. 1865.

Mr. Bailey expresses his doubt that "*Eozoon*," "the thing in question, was a fossil at all" (Journ. Geol. Soc. Dublin, vol. i. N. S.). 1865.

"*Eozoon*" having been brought under the notice of the Geological Section of the British Association, held in Birmingham of this year, Professor R. Harkness declared his disbelief in it ('Reader,' Sept. 30, 1865). 1865.

On the so-called "Eozoonal Rock." Professors W. King and T. H. Rowney. Q. J. G. S. vol. xxii. pp. 185–218. 1866.

In this memoir evidences are adduced to show that the "calcareous skeleton" and the "chamber casts" of "*Eozoon Canadense*" stand in the same relation to each other as the calcitic matrix and its included mineral silicates in a number of rocks,—that the lamellated and the acervuline varieties are strictly paralleled, the one by a rock in Scandinavia consisting of alternating layers of calcite and a hornblendic mineral, the other by coccolitic marbles of Tyrol, Delaware, and elsewhere,—that the

* Another letter, dated July 24, 1865, on a subject arising out of our announcement, and introduced by Dr. Carpenter, was published in a succeeding number.

"canal system" is paralleled by ramose foliations of metaxite, and is analogous to the coralloids of the magnesian limestone common at Sunderland,—that the "proper wall" is a modification of chrysotile,—in short, that all the features diagnosed for *Eozoon* are of purely inorganic origin, resulting from chemical and structural changes in the minerals severally composing them.

Previously to the publication of our paper no reference had been made by Logan, Dawson, Carpenter, Sterry Hunt, or Rupert Jones, in their respective writings on "*Eozoon*," to the presence of chrysotile in frequent association with this presumed fossil. In fact, serpentine in all its forms and relations was altogether ignored.

At the time referred to, the subject of mineral pseudomorphism was in an extremely unsettled state. The opinion respecting it, as advocated by Blum and others, was being opposed by Scheerer, Naumann, and Delesse, and especially by Sterry Hunt, who was enthusiastically propagating his "novel doctrine"—the chemical precipitation of metamorphic rocks; so that the obvious facts connected with eozoonal features escaped being sufficiently examined from a mineral point of view. Moreover the origin of serpentine, one of the metamorphics in question, was equally a bone of contention—its protean character, both structural and chemical, its occurring indifferently as intrusive dykes and sedimentary beds, its playing a prominent part in what was taken to be the earliest sea-born organism of our planet, and the little then known with respect to chemical changes in rocks, all taken together, caused mineral pseudomorphism to be thrown into the background—to be repudiated as having any thing to do with the "creature of the dawn."

In addition to other points introduced by Dr. S. Hunt in his memoir of 1864, and which are duly noticed in the following pages, he describes the mineralogy of "*Eozoon*" from one of the specimens which first led Logan to suspect their organic origin. A specimen of the kind has been lately sent (April 1881) to us by Mr. R. Damon, F.G.S., who received it from Dr.

Dawson: it is labelled "*Eozoon*—special variety—mineralized with loganite;" but no locality is mentioned. Hunt's specimens were from Burgess, Canada. Their layers are of two kinds: one, "a somewhat ferriferous dolomite," yielded on analysis "carbonate of magnesia 40·7, carbonate of lime, with a little peroxide of iron, 59·0=99·7;" and the other, a dark green mineral silicate, called loganite, yielded "silica 35·14, alumina 10·15, magnesia 31·47, protoxide of iron 8·60, water 14·64=100·00." It is consequently a hydrous alumino-magnesian silicate related to chlorite, and a true serpentinous mineral (pp. 4, 5). The [illegible] loganite occurs in prismatic crystals, which, from their measurements, Dana does not hesitate to declare to be pseudomorphs after hornblende. Serpentine is another mineral equally pseudomorphic after hornblende. Therefore the fact that both serpentine and loganite (which are alike pseudomorphic after the same mineral) form "chamber-casts of *Eozoon*" affords no support to the presumed organic origin of these features. Besides serpentine and loganite, the mineral silicate referred to by Logan and Hunt under the name of "white pyroxene" also "occurs in immediate contact with a layer" of the former*. "White pyroxene," we have reason to consider, is another pseudomorph after either hornblende or augite; so that, to some extent, it also invalidates the organic hypothesis.

The specimen we have received from Mr. Damon does not quite agree with Sterry Hunt's. It is made up of two kinds of layers, not well defined, however, as such. The loganite, which forms one of the kinds, is in dark-green crystalloids, variously clustered together, and very seldom showing any traces of proper cleavage; as their "fracture is granular." The other layers have an opaque white colour; but, instead of consisting of calcite or dolomite (miemite†), they are composed of what appears to be "white pyroxene:" imbedded in these layers are siliceous crystalloids of a pale-green colour, in which respect

* Quart. Journ. Geol. Soc. vol. xxi. p. 67.

† We find it advantageous to restrict the term *dolomite* to rocks, and apply that of *miemite* (one of the names in use) to their mineral representative.

they appear to consist of serpentine. The crystalloids of "white pyroxene" are strongly affected with cleavage, which is more or less represented by open gashes—the openness of which is disclosed by an infilling of calcite: it frequently happens that the cleavage is imperfectly developed, especially when the mineral is in a translucent condition; which is occasionally the case. The crystalloids when much gashed are reduced to plates more or less separated; and in many instances the plates are converted into fibres, somewhat mimetic of those characteristic of the "proper wall" (see woodcut, p. lvii). No cases have occurred to us of typical "canal system." In numerous cases the reduction of the crystalloids has resulted in the complete removal of their substance, and its replacement by calcite.

Although our specimen of "*Eozoon* mineralized with loganite" differs from those which S. Hunt had under his observation, we can quite conceive the existence of specimens of the latter kind, inasmuch as the crystalloids through solvent action may have disappeared altogether, and been replaced by "ferriferous dolomite."

The specimen closely corresponds with a rock occurring in Connemara, made up of layers of serpentine and malacolite, and which we have elsewhere (p. 2) called malacolophyte: the resemblance is so close that the crystalloids of malacolite in the latter are widely gashed with corroded cleavage, and the gashes similarly filled with calcite. This peculiarity is so much developed that when it first came under our notice we were immediately struck with the idea that the calcite had originated from chemical changes in the malacolite. It is now fifteen years since we formed this opinion; and it has been completely established by our observations on malacolite or a closely allied mineral from Ceylon, Aker (Finland), Isle of Skye, New Jersey, Porthlisky (Pembrokeshire), and Mont St. Philippe (Vosges). We take the specimen of "*Eozoon* mineralized with loganite" as another evidence in our favour.

We now beg to call Dr. Hunt's attention to one other point in the mineralogy of "*Eozoon Canadense.*" He has brought under notice a specimen of the presumed fossil from the Calumet, which "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 white pyroxene."

There is very little difference, then, between the latter specimen and the one we have had under notice. Yes, we beg pardon, there is a difference: in Sterry Hunt's specimen there are "very thin" calcareous layers ("septa") which run "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." It is to be apprehended that Dr. Hunt, in bringing forward this specimen with its calcareous septa intersecting the serpentine layers, lays himself open to the doubt of his being sufficiently acquainted with the structure of "*Eozoon Canadense*" as diagnosed by his colleagues.

No view which contends for the inorganic origin of the different eozoonal features can be considered satisfactory unless it be consistent with facts pertaining to mineralogy, geology, or chemistry. With respect to the "chamber-casts" and the "proper wall," their origin, as products answering to these terms, will be made clear in the following pages; but as regards the "canal system," a point in connexion therewith requires some consideration; for we freely admit that this part possesses peculiarities which seemingly do not strictly accord with *ordinary* mineral developments, except, it may be, in the case of certain dendritic bodies characteristic of "moss agates." But although at the commencement of our examination of "*Eozoon*" we felt inclined to identify the "canal system" with the latter products, it was never quite clear to us that we were in the line of the correct view, especially when there were palpable evidences at hand showing that the variety which generally presents itself in the Canadian "eozoonal" ophite had originated through a wasting or decretory process of its component substance (flocculite), whereas the dendritic bodies referred to are unmistakably the indirect products of crystalline development.

The point now introduced consists of the flocculent variety of the "canal system," which, composed of a homogeneous or structureless substance, is unlike in its arborescent forms ordinary crystalline products; while its branchlets resemble casts of tubes and other cavities conceivably produced by tunnel-enclosed vessels of an organism, as predicated of them by eozoonists.

We must except in this connexion a variety of the "canal system" consisting of malacolite, as it is palpable beyond dispute that its branchlets have resulted from the decretion of clusters of irregularly arranged crystalloids of a mineral readily affected by solvent action along its eminent cleavage-divisions, and thus etched into shapes equally simulative of arborescent growths.

But in the case of the flocculent variety of the "canal system" we are dealing with bodies possessing forms which, although we maintain that they have been equally produced by decretion, cannot be positively said to have been predetermined by cleavage-structure *. We do not propose to enter on an explanation of this point; all we have to do is to prove the existence of examples simulative of organic features, in the elaboration of which crystalline forces alone have been concerned, and which are apparently as unlike crystalline products as the typical examples of flocculent "canal system." We refer to the foliaceous expansions characteristic of the mineral silicate metaxite, also the coralloids and other configurations of the Sunderland magnesian limestone.

First, the configurations in metaxite have a strikingly organic aspect; and it is undeniable that they are purely of mineral origin. It must also be remarked that this mineral, like flocculite, is without internal structure; properly speaking, it has a pasty consistency. Moreover it is closely related to, if not an

* Still we have already adduced the most conclusive evidence that rod-like *cylindrical* processes in serpentine (undergoing change into flocculite) have had their shape determined by *rectangular prismatic* cleavage.—See Proc. Roy. Irish Acad. vol. x. pl. xliii. fig. 8.

allomorph of, serpentine; and, what is equally significant, the expansions are included in a calcareous matrix. It may therefore be confidently assumed that the point which at first sight appears to favour organic intervention in the production of the flocculent "canal system," altogether ceases to be such in presence of the foliaceous configurations of metaxite.

Respecting the magnesian limestone coralloids, and other forms, we have on different occasions spoken of them as gigantic similitudes of the "canal system," "stolons," and "chambers" of "*Eozoon*." We cannot say of them, any more than it can be said of the metaxitic configurations, that they have been elaborated precisely in the same way as the "eozonal" structures. It is sufficient for our purpose that they strikingly resemble not only corals and other organisms, but *casts* of tubes, chambers, and other structures of the kind just referred to, in their external form, and have seemingly no relation in this respect to ordinary crystalline or mineral developments; yet every one who has studied them *in situ* is compelled to admit that they are solely the products of inorganic agencies. As such, then, it may be safely asserted that in relegating the "canal system" of "*Eozoon Canadense*" to the inorganic kingdom, we are supported not only by evidences of the most decisive character, but by facts strictly belonging to mineralogy and the related sciences. As further justifying this step, it may be mentioned that the coralloids, &c., and their matrix, are demonstratively secondary products that have resulted from chemical changes (Chap. XV. and pp. 118, 119).

Supplemental Notes on the Structure and Affinities of *Eozoon* 1866.
Canadense. Dr. W. B. Carpenter. Q. J. G. S. vol. xxii. pp. 219–228.

To which is added a note containing an extract from a communication, dated March 28th, from Dr. Dawson announcing his discovery of "the occurrence of *Eozoon* preserved simply in carbonate of lime."

In these "Notes" Dr. Carpenter declares that he is "prepared to maintain the organic origin of *Eozoon* on the broad basis of cumulative evidence afforded by the combination, in every single mass, of an assemblage of features which can only be separately paralleled elsewhere, and in the repetition of the combination with the most wonderful exactness over areas of immense extent" (will be further noticed, A.D. 1869).

1866. Ueber das Vorkommen von *Eozoon* in dem ostbayerisches Urgebirge. Dr. C. Gümbel. Sitz. des kön. bayer. Akad. d. Wiss. zu München, 1866.

The author makes known the occurrence in beds of serpentine marble in Bavaria of eozoonal structures, certain of which he considers to represent a new species—"*Eozoon Bavaricum.*"

We noticed in our memoir, last considered, as proving the mineral origin of "*Eozoon,*" the presence in various calcitic marbles (hemithrenes) in Scandinavia, Isle of Tyree, New Jersey, of rounded crystalloids of pargasite, chondrodite, hornblende, &c. Dr. Gümbel declares "there can scarcely remain a doubt that the curiously rounded grains imbedded in the crystalline limestones of Pargas represent the casts of sarcode-chambers, as in *Eozoon*; and that they are consequently of organic origin." (See translation of the paper in 'Canadian Naturalist,' Dec. 1866.) This point will be further noticed hereafter.

1866. Ueber das Vorkommen von *Eozoon* im krystallinischen Kalke von Krummau im südlichen Böhmen. Dr. F. von Hochstetter.

1866. Pusyrewski. Bulletin de l'Académie de St. Pétersbourg, vol. x.

1866. On the Metamorphic and Fossiliferous Rocks of the County of Galway. Prof. R. Harkness. Q. J. G. S. vol. xxii. pp. 510, 511.

"With reference to the occurrence of serpentine in connexion with the limestones of the metamorphic series of Connemara, this has of late become a matter of some interest, in consequence of the statement that these deposits afford the *Eozoon Canadense*. . . . The supposed organic portions of the serpentinous limestones of Connemara do not result from animal structure, but purely from mineral association. Had fossils of any kind presented themselves in this district, they ought to have occurred in that portion of the limestone which has been least affected by metamorphic action."

Mr. W. Warington Smyth, in his Anniversary Address 1867.
Q. J. G. S. vol. xxiii. p. lxiv) as President of the Geological Society, noticing the announcement made by Dr. Dawson of "the occurrence of *Eozoon* preserved simply in carbonate of lime," declared that this "discovery of *Eozoon* preserved in carbonate of lime pure and simple would appear to close the discussion."

Further Observations on the Structure and Affinities of *Eozoon* 1867.
Canadense. Dr. W. B. Carpenter. A letter to the President of the Royal Society. Proc. R. S. vol. xv. pp. 545–549.

The writer, who had previously made a similar acknowledgment in his "Notes" (A.D. 1866), declares:—"Yet the very exact correspondence in age and mode of aggregation between the serpentine granules of the Connemara marble and those of the 'acervuline portion' of the Canadian was sufficient to justify in behalf of the one the claim which has been freely conceded in regard to the other."

On new Specimens of *Eozoon*. Sir W. E. Logan. Q. J. G. S. 1867.
vol. xxiii. pp. 253–257.

Notes on Fossils recently obtained from the Laurentian Rocks 1867.
of Canada, and on Objections to the Organic Nature of *Eozoon*. Dr. J. W. Dawson. Q. J. G. S. vol. xxiii. pp. 257–264.

The paper is in a great measure taken up with a description of a specimen of "*Eozoon*" from Tudor (the one noticed by Carpenter A.D. 1866, Warington Smyth A.D. 1867, and Logan as above), stated to consist "simply of carbonate of lime."

Esquisse Géologique du Canada. ? Prepared by the Officers of 1867.
the "Commission Géologique du Canada."

Notices the Tudor and other specimens of "*Eozoon*."

1868. On the so-called "Eozoonal" Rock. Prof. W. King and Dr. T. H. Rowney. Abstracts of Proc. Geol. Soc. of London, No. 190. Q. J. G. S. vol. xxv. pp. 115–118.

A correct abstract (not prepared by us, and all that was published by the Society) of an elaborate memoir by the writers.

In the discussion which followed the reading of it, Prof. Ramsay stated he "had been struck long ago by the organic appearance of the structure now regarded as *Eozoon*. He had also felt a difficulty in accounting for the existence of large masses of limestone, except by the operation of organisms living in the sea, in which such deposits had been formed. He could not imagine the sea-water so overcharged with calcareous matter as spontaneously to deposit limestone."

Mr. Parker, Prof. T. R. Jones, Dr. Duncan, and Dr. Carpenter made some remarks, all favourable to eozoonism.

1868. Geognostische Beschreibung des ostbayerisches Grenzgebirges. Dr. C. Gümbel.

1868. The Microscope and its Revelations. 4th ed. 1868. Dr. W. B. Carpenter.

The beds of serpentine limestone in the Laurentian system of Canada "are found in many parts to contain masses of considerable size, but usually of indeterminable form, disposed after the manner of an ancient coral reef, and consisting of alternating layers (frequently numbering more than *fifty*) of carbonate of lime and serpentine (silicate of magnesia)."

1869. Arbeiten der geologischen Section der Landesdurchforschung in Böhmen. Prag, 1869.

1869. Die Gliederung der eozoischen Formationsgruppe Nord-America's. Halle. Hermann Credner, of Leipzig.

1869. *Eozoon* from Raspenau, in Bohemia. Robert Hoffmann. Journal für prakt. Chemie. May 1869.

An abstract is published in the 'American Journal of Science,' 3rd ser. vol. i. 1871.

Prof. Hull. Quart. Journ. of Science, July 1869. 1869.

"The researches of Sir William Logan and his colleagues of the Geological Survey of Canada, followed by other naturalists, have demonstrated that even the oldest known limestones on the surface of the globe owe their origin to *Eozoon*."

On "*Eozoon Canadense*." Drs. King and Rowney. Proc. Roy. 1869.
Irish Acad. vol. x. pp. 506–550.

Notices the Tudor specimen, which, Dr. Dawson asserted (A.D. 1866), "furnishes a conclusive answer to" our "objections." But, from the description (amply discussed in the memoir) and photograph given of it, we express "little doubt of its being any thing more than the result of infiltration of carbonate of lime, which has penetrated into a parting between two layers of laminated arenaceous limestone"—an opinion which remains neither controverted, nor even invalidated, though attempts have been made to do so.

The "cumulative" argument advanced, but not clearly expressed, by Dr. Carpenter (A.D. 1866) is discussed. It may now be mentioned that the fact of different eozoonal structures being often found in association must be *held as a proof* of their mineral origin, inasmuch as the mineral silicates composing them are in pseudomorphic correlation; while the calcite and miemite (either of which constitutes the "intermediate skeleton") are not only pseudomorphous after these silicates, but they stand in the same relation to each other. The "cumulative" argument is thus totally invalidated by purely chemico-mineralogical phenomena. Besides, Dr. Carpenter in advancing it has placed himself on the horns of a dilemma; for he is required to explain the occurrence of different eozoonal structures by themselves in widely separated countries. The "intermediate skeleton" includes the "canal system" and "proper wall." How does it happen that the last feature is absent in the eozoonal hemithrenes of Finland, Saxony, and Ceylon, and only the former one present? Why in New Jersey is it the same? We answer, because serpentine (which is necessary to form chrysotile, and this to form the "tubuli" of the "proper wall") is not present. And, next, how is it to be explained that the loganitic "*Eozoon*" only consists of "chambers" and "skeleton," and thus simulates the calcareo-amphibolic gneisses of Norway and other places? In a Supplement we notify the occurrence of a specimen of typical "canal system" in the chinks of a large crystal of spinel imbedded in hemithrene from New Jersey.

1870. On Laurentian Rocks in Eastern Massachusetts. Dr. T. Sterry Hunt. American Journal of Science, 2nd ser. vol. xlix. pp. 75–78.

Notices the discovery, near Chelmsford, by "Mr. L. S. Burbank, of Lowell, a zealous and successful teacher of geology and mineralogy," of "a mixture of limestone and yellowish-green serpentine," rich in "*Eozoon Canadense*," the "cylindrical diverging branching tubuli" of which are "injected" with "pure carbonate of lime." On seeing this note we immediately wrote to Mr. Burbank, begging of him to supply us with specimens of the kind. Some time after we received his answer, with specimens. In the beginning he informed us that he had totally changed his views as to the nature and "origin of the presumed fossil," and with respect to "the statement by Dr. Hunt that the tubuli are injected with carbonate of lime, it is incorrect," &c. On testing with hydrochloric acid the specimens ourselves, we found none of the "tubuli" had been affected.

1870. Note on *Eozoon Canadense*. [In reply to Professors King and Rowney.] Dr. J. W. Dawson, Proc. Roy. Irish Acad. ser. 2, vol. i. pp. 117–123.

We are credited with having introduced some "new features" into the discussion, most of which are met in the style of argumentation peculiar to eozoonism. One of the new features is the "remarkable case" of a spinel from Amity, New York, containing in crevices calcite, which encloses perfect "canal system" preserved in malacolite" (A.D. 1869). "I confess that until I can examine such specimens, which I have not yet met with, I cannot, after my experience of the tendencies of Messrs. Rowney and King to confound other forms with those of *Eozoon*, accept their determination in a matter so *critical* and *in a case so unlikely*." Brief reference is made to the occurrence of "*Eozoon*" in the Connemara ophites; but as these rocks are by most geologists believed to be post-Laurentian, and there are considerations connected with the presence therein of the presumed fossil *unfavourable* to its organic origin, the fact of course must be got rid of. Dr. Dawson, although having himself observed "traces of organic structure" in the Connemara marble (A.D. 1865), and having joyfully accepted the corroborative evidences discovered by Sandford and T. R. Jones (A.D. 1864), suppported also by the testimony of Dr. Carpenter (A.D. 1867), and in presence of perfect examples made known by ourselves (A.D. 1866, 1869), now declares, "I have never been able to satisfy myself of the occurrence of any definite organic structure in the Connemara specimens"!

Messrs. King and Rowney on *Eozoon Canadense*. Dr. T. Sterry Hunt. Proc. Roy. Irish Acad. ser. 2, vol. i. pp. 123–127. 1870.

The writer will "not even admit the pseudomorphous origin of serpentine itself, but believes that this, with many other related silicates, has been formed by direct chemical precipitation." Dr. Hunt has asserted the same of limestones: they "owe their origin to chemical precipitation;" "the often repeated assertion that *organic life has built up all the great limestone formations is based on a fallacy*;" "the occurrence therein of shells, corals, and *Eozoon* is only accidental." These dicta on the origin of limestones having been thus dogmatically pronounced, notwithstanding that many geologists (Ramsay A.D. 1868, Hull A.D. 1869) had accepted the "creature of the dawn" on the faith of its explaining the origin of the calcareous masses of the Laurentians, we brought under the notice of the latter the above view as being inconsistent with their belief. Doubtless, seeing that this point was not without force, Dr. Hunt, in the paper under notice, has been led to modify his doctrine on the origin of limestones most materially; and we feel that some credit is due to ourselves for having contributed to so desirable a result. He now admits that "thousands of feet of limestones have been formed from the calcareous skeletons of marine animals;" also that "the calcareous rhizopod '*Eozoon Canadense,*' might, and probably did, build up pure limestone beds, like those formed in later times from the ruins of corals and crinoids"! But he spoils a good thing in stating that our representation of his view of the origin of limestones is a "misconception;"—"nor is there any thing inconsistent" in the modified view with his original one! In speaking of limestones "formed without the intervention of life," Dr. Hunt refers to none but some "great beds of ancient marble:" these, there can be no doubt, are the "two great formations of limestone beneath the *Eozoon* horizon, in which this fossil has never been detected." So it turns out that it is only amongst the *pre-"eozoic"* Archæans that chemically precipitated limestones are found!

1870. Prof. F. Zirkel. Neues Jahrb. f. Mineralogie, 1870, p. 828.

After describing the roundish grains of serpentine (which are considered to have been originally peridote) occurring in the crystalline limestones (hemithrenes) of Aker, Pargas, Modum (Scandinavia), the author's investigations, it is stated, "did not reveal the canal system which is called eozoonal structure." But it must be mentioned that we have detected in specimens from Aker beautiful examples of "canal system."

1870. *Eozoon Canadense.* T. Mellard Reade. A letter in 'Nature,' Dec. 1870, vol. iii. p. 146.

A considerately-written communication, complaining that the replies to our objections, with few exceptions, "were literally little more than reiterations of previous statements;" that in them there is a "strange absence of any allusions to obvious objections," and a "persistent begging of the question involved in constantly speaking of the specimens as undoubted fossils."

Eozoon Canadense. Dr. W. B. Carpenter. Nature, vol. iii. 1871.
pp. 185, 186.

A letter in answer to Mr. T. Mellard Reade.

Eozoon Canadense. Dr. J. W. Dawson. Nature, vol. iii. p. 267. 1871.

A short note.

G. H. Kinahan. Nature, vol. iii. p. 267. 1871.

The writer draws attention to the fact of its having been announced that Mr. Sandford had "proved the existence of *Eozoon*" in the ophites of Connemara, which, according to Sir R. I. Murchison and Prof. Harkness, are of Lower Silurian (Cambro-Silurian) age. "In other parts will be found square miles upon square miles of rocks of the same geological age, often having inliers of limestone; yet in them there is no *Eozoon Canadense*, it only being found in a peculiar rock (pseudomorph dolomyte) in this small tract of Lower Silurian rocks, in Yar-Connaught."

Dr. J. W. Dawson. Nature, Feb. 9, 1871, vol. iii. p. 287. 1871.

A letter, replying to T. Mellard Reade's criticisms.

T. Mellard Reade. Nature, March 9, 1871, vol. iii. pp. 367, 368. 1871.

Dr. W. B. Carpenter. Nature, vol. iii. p. 386. 1871.

A letter, more *personal* than argumentative, which, of course, closed the discussion. The author announced that "Messrs. David Forbes and H. Sorby altogether disown *Eozoon* as a mineral."

On *Eozoon*. L. S. Burbank. Proc. Boston Soc. Nat. Hist. 1871.

The writer's main object is to show that "*Eozoon*" is found in ophi-dolomites, which occur filling cavities along the line of an anticlinal axis, and are therefore not true stratified deposits laid down with the gneiss associated with them.

Prof. John Phillips. Geology of Oxford and the Valley of the 1871.
Thames.

"Only in another part of the world among strata of gneiss as old, if not older, than these of Malvern, has one solitary organic body been found—*Eozoon Canadense*. This foraminifer or sponge has not obtained its certificate, 'proved by the ends of being, to have been,' without protest," p. 61.

1871. On the Geological Age and Microscopic Structure of the Serpentine Marble or Ophite of Skye. Professors King and Rowney. Proc. Roy. Irish Acad. ser. 2, vol. i. pp. 137–139.

This rock, which is well known to be of Jurassic age, contains all the "*Eozoon*" features—"chamber-casts," "intermediate skeleton," "canal system," and "proper wall;" and, as in specimens from Canada, the "chamber-casts" are occasionally preserved in, besides serpentine, a dark mineral resembling loganite, also white pyroxene or malacolite! This last mineral occurs in crystalloids which frequently exhibit themselves in a decreted condition internally and externally, the interspaces between them and their hollowed-out interior being filled with calcite: this substance has clearly resulted from the carbacidization of the calci-magnesian silicate, malacolite. Some of the crystalloids are in shapes strikingly resembling the "curiously curved canal system" of Gümbel's "*Eozoon Bavaricum*."

1871. Addendum to paper on *Eozoon*. Dr. J. W. Dawson. Proc. Roy. Irish Acad. ser. 2, vol. i. pp. 129–131.

Having examined specimens of the Amity rock containing spinel (A.D. 1870), Dr. Dawson admits, but *with some reticences*, the truth of our statement that "canal system" occurs in "unlikely" association with crystals of this mineral. "From the general structure and aspect of these specimens, however, I infer that they are portions of a bedded rock and not a veinstone"! Other inferences, quite as gratuitous, are added to destroy the force and significance of this "*remarkable, critical*, and *unlikely* case."

1871. On the Mineral Origin of the so-called "*Eozoon Canadense*." Drs. W. King and T. H. Rowney. Proc. Roy. Irish Acad. ser. 2, vol. i. pp. 140–152.

The authors notice the principal arguments and evidences adduced in favour of "*Eozoon*" by Dawson, Carpenter, and

Hunt in their recent memoirs, and conclude with a summary of those brought forward by themselves against the presumed fossil.

The "*Eozoon*" Limestones of Eastern Massachusetts. John B. Perry. Proc. Boston N.H. Soc. April 19, 1871. 1871.

Notices particularly the Chelmsford limestones announced, in January 1870, by Sterry Hunt to contain "*Eozoon*;" the organic origin of which is repudiated by Mr. Perry. The limestones occupy "pockets, irregular and uneven cavities, or in most cases, oven-shaped spaces, more or less lenticular," being "vein-rocks" of more recent origin than the gneisses which enclose them. The author "leaves undiscussed the question as to the mode of their origin—whether it were by infiltration, segregation, or sublimation." Mr. Burbank, in his letter (A.D. 1870), described the mode of occurrence of the same rocks in closely corresponding terms.

A Review of Sir Charles Lyell's 'Student's Elements of Geology.' John B. Perry. Bibliotheca Sacra. July 1872. 1872.

Notices unfavourably Sir Charles's acceptance of "*Eozoon*."

The Microscopic Characters of a Silo-carbacid Rock from Ceylon, and their bearing on the Methylotic Origin of the Laurentian "Limestones." Dr. W. King. Geol. Mag. vol. x. Jan. 1873. 1873.

The rock noticed (hemithrene) contains fine examples of configurations closely resembling the "canal system" in Canadian ophites. 1873.

Die mikroscopische Berschaff. der Min. und Gesteine. Dr. Ferdinand Zirkel. Pp. 313. 1873.

Eozoon Canadense. Prof. Max Schultze. Sitzungs. der niederrheinischen Gesell. für Natur- und Heilkunde. July 7, 1873. 1873.

A translation is published in the 'Annals and Magazine of Natural History,' ser. 4, vol. xiii. pp. 324, 325.

Prof. Schultze, having examined specimens of the presumed fossil, avers "there can be no serious doubt as to the foraminiferous nature of *Eozoon Canadense*."

1873. President's Address. Dr. A. Macalister. Journ. Roy. Geol. Soc. Ireland, new ser. vol. iii. p. 101.

A paragraph devoted to the "*Eozoon* controversy," and pronounced from the President's Chair of the Royal Geological Society of Ireland, requires some little notice. Referring to some memoirs (not named), it is stated that they "occasioned a controversy which, if it did nothing else, turned some attention to the study of micro-petrography, and some at least of the writers displayed a very considerable practical ignorance not only of the appearance of sections of large foraminifera, but also of sections of common forms of rock and of the interpretation of rock-forms as seen by the microscope. With a larger experience of micro-petrography will come, I believe, a full conviction of the true organic nature of *Eozoon Canadense*." It is now eight years since these remarks were made; and undeniably their author had taken considerable pains to master the bibliography of points connected with the subject matter he touched upon: it is therefore to be assumed that Dr. Macalister still takes a deep interest therein, also that he is perfectly aware his "full conviction" has not yet been realized; hence we would urge on him to endeavour himself to bring about the outcome which he so confidently predicted in his "Address."

1874. On the Structure called *Eozoon Canadense* in the Laurentian Limestone of Canada. (A letter to Prof. W. King, Sc.D., Galway.) H. J. Carter. Ann. & Mag. Nat. Hist. ser. 4, vol. xiii. pp. 189–193.

The writer pronounces decidedly against the structure of "*Eozoon Canadense*" being that of a foraminifer. "In vain we seek in the so-called *Eozoon Canadense* for the unvarying perpendicular tubuli, the *sine quâ non* of foraminiferous structure."

1874. Remarks on Mr. H. J. Carter's letter to Prof. King on the Structure of the so-called *Eozoon Canadense*. Dr. W. B. Carpenter. Ann. & Mag. Nat. Hist. ser. 4, vol. xiii. pp. 277–284.

After speaking of "the well-merited reputation which Mr

Carter has gained by his researches on Sponges and Foraminifera," and "whose additions to our knowledge of the minute structure of certain types of Foraminifera are estimated by no one more highly than by" himself, Dr. Carpenter enters into a long statement highly irrelevant in many respects, and containing much that is given in his previously published papers.

Eozoon Canadense. Prof. Max Schultze. Ann. & Mag. Nat. 1874.
Hist. ser. 4, vol. xiii. pp. 324, 325.

On the Structure called *Eozoon Canadense* in the Laurentian 1874.
Limestone of Canada. H. J. Carter. Ann. & Mag. Nat. Hist. ser. 4, vol. xiii. pp. 376–378.

The writer reiterates his former statement that the "character" of the aciculæ of the "proper wall" of "*Eozoon*" is "*utterly* incompatible with foraminiferal structure."

Latest Observations on *Eozoon Canadense* by Prof. Max 1874.
Schultze. (A letter to the Editors of the 'Annals and Magazine of Natural History,' by Arthur E. Barker, Surgeon to the City-of-Dublin Hospital, and Demonstrator of Anatomy in Roy. Coll. Surg. Ireland.) Ann. & Mag. Nat. Hist. ser. 4, vol. xiii. pp. 379, 380.

This communication contains a copy of a letter from Prof. Max Schultze to Mr. Barker. The former, acknowledging the receipt from the latter of a copy of our paper published in the 'Proceedings of the Royal Irish Academy,' July 1869, states that he "agrees with" us "in many important points, supported by my own investigations on *Eozoon Canadense*," and that our "treatise has made a very great impression upon" him. He begs Mr. Barker to obtain some specimens of Connemara ophite, "and to tell Messrs. King and Rowney that, with respect to the 'proper wall' of Carpenter, I am entirely of their opinion that it is of inorganic origin." Mr. Barker concludes:—"I may state that, through the kindness of Dr. King, I was enabled to send Professor Schultze some beautiful specimens of the stones he desired, and was expecting from him a letter of acknowledgment when I received the sad news of his death."

1874. Further Remarks on *Eozoon Canadense*. Dr. W. B. Carpenter. Report Brit. Assoc. Belfast Meeting.

Additional reasons are adduced "for concluding the organic nature of the organism"; and a contradiction is given to our "assertion" that Prof. Max Schultze had, just before his death, changed his opinion on "Eozoon." "Mr. Gwyn Jeffreys, Prof. Macalister, and Prof. Perceval Wright expressed their general concurrence in Dr. Carpenter's views."

1874. New Observations on *Eozoon Canadense*. Dr. W. B. Carpenter. Ann. & Mag. Nat. Hist. ser. 4, vol. xiii. pp. 456–470.

Dr. Carpenter in his usual style replies to Mr. Carter and the "two Galway Professors:" the summary of the arguments and evidences brought forward in our paper last noticed (A.D. 1871) is all but ignored; and l'affaire Max Schultze is thus disposed of:—"At any rate, there is no mention of the nummuline wall in his communication to the Wiesbaden Association —his acceptance of *Eozoon* as a foraminifer entirely resting on the 'canal system,' which he had minutely studied, and as to which *there is no evidence whatever that he had changed his opinion*, as asserted by Professors King and Rowney. Had he lived to see what I shall presently describe, I cannot doubt that he, in common with the numerous microscopists to whom I have recently shown it, would have accepted the 'nummuline wall' without the slightest hesitation." What we "asserted" was that "whatever opinion the late Prof. Schultze might hold in the autumn of last year respecting '*Eozoon*,' he subsequently changed it after reading our papers." There is not a word here about the "canal system"!

What Dr. Carpenter was to "presently describe," which is called a "probative fact," is seen in a "section of nummuline layer," in which "many of the tubuli remain empty; and *they can be distinguished as tubuli under any magnifying-power* that the thickness of the covering-glass allows to be used." We have on a former occasion stated our reasons for demurring to this case (Ann. & Mag. Nat. Hist. ser. 4, vol. xiv. p. 285), at the same time expressing ourselves as "not disputing that the section exhibits some structural peculiarity which gives rise to *appearance* of tubulation." In connexion with this matter, it may be mentioned that we have frequently observed in minerals a divisional structure which it is difficult to describe or designate. In our description of a specimen of peridote, represented on Plate I. fig. 3, mention is made of the occurrence therein of thin fibrous or striated undulating laminæ, the "striæ or fibres of which are at right angles to the surface of the laminæ." A similar structural character, seen on one of the two sets of eminent cleavage-planes, marks the felspar represented in fig. 4, Pl. I. For want of a better name, we stated that the laminæ are fibrous or striated; but we were quite aware at the time that the intersecting striæ or fibres are often separated, and seemingly tubiform: thus, where a transverse section of such fibres is exposed they appear like circular dots—even more decidedly than as represented in our figures. We draw attention to this peculiarity, as probably offering an explanation of the "*empty tubuli.*" What we strongly suspect will prove to be the same are the cuts or lines forming the "*first*" or incipient stage in the development of chrysotile (pp. 9, 14, &c.); especially as we are unable to detect any difference between them and the striæ, that are thread-like, of feldspar. Seemingly confirming our suspicion is the fact that the "striation" of a feldspar in graphic granite has actually been taken for "vertical tubular structure" by Dr. Carpenter, as will hereafter be seen.

Eozoon Canadense. Dr. J. W. Dawson. A letter in 'Nature,' 1874.
June 11, vol. x. p. 103.

"*Eozoon*" examined chiefly from a Foraminiferal Standpoint. 1874.
Drs. W. King and T. H. Rowney. Ann. & Mag. Nat. Hist. ser. 4, vol. xiv. pp. 274–289.

Final Note on *Eozoon Canadense.* Dr. W. B. Carpenter. 1874.
Ann. & Mag. Nat. Hist. ser. 4, vol. xiv. pp. 371, 372.

Dr. Carpenter, notwithstanding the many errors he has committed in describing the structure of the Foraminifera (we speak advisedly), holds a position in microzoology which justly entitles him to take rank as one of its very highest authorities. He does not, however, think it unbecoming to charge us with having, in our contest against Eozoonism, "betrayed a shocking state of ignorance of foraminiferal structure"—although, on the same page, as it were, in which this charge is preferred, it is too evident, from what is stated of the "parallel tubulation" of *Nummulites lævigatus* in comparison with that of "*Eozoon Canadense,*" that he is far from being an infallible authority in his own speciality. This must have been made palpable to himself, on reading our paper—"*Eozoon* examined chiefly from a Foraminiferal Standpoint." Hence this "Final Note." When, in his endeavours to set aside our remarks on certain "foraminiferal impossibilities," Dr. Carpenter talks about believing what he sees with his "mind's eye, rather than with" his "bodily eye," and considering his inability to comprehend that the truism "there is no end to the possibilities of Nature" does not teach the fallacy that Nature indulges in impossibilities, it is evident he was feeling that his discussion with us was becoming a hopeless task. What we say are impossibilities of the kind are:—a "canal system" abutting directly against the under and attached side of the "proper wall," instead of passing out to the surface of the organism; and the "tubuli" of the "proper wall" frequently lying horizontally against, or *parallel with,* instead of *standing perpendicularly on,* a presumed "chamber"*. Other cases of the kind could be adduced. It is a folly attempting to get over these things by

* Dr. Carpenter, in answer to this objection, urged by Mr. H. J. Carter (Ann. & Mag. Nat. Hist. 4th ser. vol. xiii. p. 192), states that the horizontality of the tubuli has its "precise counterpart" in *Nummulites lævigatus*; and in evidence of his statement he gives a figure, copied from MM. D'Archiac and Haime, of the tubulation of this foraminifer, and another of the presumed homologous structure in "*Eozoon Canadense.*" Dr. Carpenter, however, who of course cannot be accused of "shocking ignorance of Foraminiferal structure," was not aware that what he took to be "tubulation of *Nummulites lævigatus*" is actually the fibrous mineral (asbestine) structure of calcareous "solid pillars," as shown in our last-cited paper.

calling them "anomalies;" they are foraminiferal impossibilities. We therefore cannot but commend Dr. Carpenter's judgment in relinquishing all attempt to make them otherwise in his "Final Note." This would be a much more difficult matter than exclaiming: "As I should now no more think of attempting to convince the Galway infallibles than of trying to convert the Pope, I leave them in triumphant possession of the field!"

Estructura de las rocas Serpentinosas y el *Eozoon Canadense*. 1874.
Juan Vilanova y Peira. Soc. Españ. Hist. Nat. vol. iii. parts 2, 3.

"States reasons for considering the *Eozoon Canadense* no organism whatever, and asserts that what has been accepted as the remains of a foraminiferous animal is merely the peculiar mineralogical structure of serpentine and other allied rocks.—J. M'P." (See 'Geological Record' for 1874, p. 325.)

On the Occurrence of *Eozoon Canadense* at Côte St. Pierre. Dr. 1875.
J. W. Dawson. Quart. Journ. Geol. Soc. vol. xxxii. pp. 66–75.

One of the noticed specimens is of interest in showing a presumed case of pseudomorphic replacement—"*the change of calcite into serpentine;*" evidence of which consists in the "walls of the skeleton ['proper wall'] being represented by a lighter-coloured serpentine than that filling the chamber, and still retaining traces of the canals ['nummuline tubuli']. The walls thus replaced by serpentine could be clearly traced into connexion with the portions of those still existing as calcite." Until Dr. Dawson had penned these remarks he had nowhere admitted any process of chemical change in connexion with eozoonal structures; we were therefore considerably surprised to read what must be taken as placing him amongst advocates of "extravagant" pseudomorphism. Dr. S. Hunt, on one occasion, ridiculing the latter, exclaimed,—"In this way we are led from gneiss or granite to limestone, from limestone to dolomite, and from *dolomite to serpentine*." Yet Dr. Dawson has actually laid himself open to his friend's sally!

It is one of the most singular things connected with the eozoonal controversy that we have repeatedly asserted (and the assertion has been supported by evidences which have not been disproved) that the "proper wall" is nothing more than a modification of chrysotile; and it is equally singular that none of the "original workers" in eozoonism has made any signs of his having observed any such evidences, particularly considering that they present themselves to us in almost every specimen that has come under our observation. At last, however, and after the lapse of more than a decade, a specimen of the kind has occurred to Dr. Dawson—the one which he imagines exhibits the calcite of the "proper wall" replaced by serpentine.

Not having seen the specimen, it would, of course, be unsafe for us to offer any decided opinion upon it; but we are strongly tempted to suggest that it is nothing more than a corresponding one to cases which we have repeatedly brought under notice. Our first memoir contains a figure, which has been copied in our present Plate VI. fig. 2. It represents typical chrysotile in two places, particularly at *a*, in its incipient condition, passing insensibly into that of serpentine. Are not Dr. Dawon's "walls of the skeleton," "still retaining traces of the canals," an instance in point? If so, we should not hesitate to say that it consists of chrysotile in its incipient stage of development (*a*, fig. 1, Pl. IX.), and that, instead of being a case of "the change of calcite into serpentine," it is simply the latter mineral in the intermediate stage, between its amorphous condition and that of true chrysotile.

Dr. Dawson cannot see any relation between chrysotile and the "proper wall." Having observed "chrysotile veins" irregularly intersecting the lamellæ of "*Eozoon*," he remarks:—"I have no hesitation in stating that the assertion that these chrysotile veins are identical with or similar to the proper wall of *Eozoon*, either in structure or distribution, is wholly without foundation, other than that which may arise from corresponding dissimilar structures accidentally associated with each other." It is too much the habit of eozoonism to represent our evidences in a way to make it easy for them to be overthrown, at the same time ignoring our reiterated corrections, and repeatedly proclaiming in full blast that it has "overthrown" its antagonists. The very fact that we consider the "proper wall" to be a modification of chrysotile implies that layers of the latter may occur without displaying any modification of the kind; therefore we do not dispute that the intersecting "chrysotile veins" referred to by Dr. Dawson are precisely as he describes. Moreover we have nowhere asserted that such "veins are identical with, or similar to, the proper wall of *Eozoon*." What we contend for is that the "proper wall of *Eozoon*," in its typical condition, is a modification of chrysotile; and we again assert that this opinion is completely established by the specimens which Dr. Dawson sent to Mr. Damon (p. 18) as examples of genuine "*Eozoon Canadense*." They contain no intersecting "veins" of chrysotile: on the contrary, the specimens consist of layers of "chamber-casts," "proper wall," and chrysotile in *perfect parallelism*, in the manner exhibited in fig. 2, Pl. IX. But this is not all: the chrysotile is present in all stages of development, from the incipient to the pectinated—the latter having the aciculæ separated by films of calcite, and thus identical with the "proper wall." One of the specimens, which has a sectional face 3 inches long and 2 inches wide, contains in its width about 80 layers alternately in serpentine and calcite; nearly all the former are more or less chrysotilized, and have their surfaces in many instances converted into a fringe of typical "proper wall."

Relation of the Canal System to the Tubulation in the Foraminifera, with reference to Dr. Dawson's 'Dawn of Life.' H. J. Carter. Ann. & Mag. Nat. Hist. ser. 4, vol. xvi. pp. 420–424. 1875.

Dr. Dawson, in his 'Dawn of Life,' states that Dr. Carpenter, "in the Ann. & Mag. Nat. Hist. for June 1874, has given a crushing reply to some objections raised in that

During the discussion which followed the reading of the above paper Mr. Robert Etheridge advocated "Eozoon"

Journal by Mr. Carter. He first shows, contrary to the statement of Mr. Carter, that the fine nummuline tubulation corresponds precisely in its direction with reference to the chambers with that observed in Nummulites and Orbitoides &c." In reply, Mr. Carter, after giving his evidences, declares:—"I therefore most unhesitatingly state that there is no identity between this selected representation of the so-called '*Eozoon Canadense*' and Foraminiferal structure. Such a relation of 'canal system' to 'nummuline tubulation' could not exist in a Foraminiferal test either in theory or fact!"

1876. On Mr. Carter's Objections to *Eozoon*. Dr. J. W. Dawson. Ann. & Mag. Nat. Hist. ser. 4, vol. xvii. pp. 118, 119.

1876. The Dawn of Life. Dr. J. W. Dawson.

Mr. L. S. Burbank's statement (supported by Mr. J. B. Perry) respecting the occurrence of "*Eozoon*" in masses that are not true stratified rocks (A.D. 1871) is met by Dr. Dawson's assertion that the figures and descriptions supporting it "*lead to the belief that this is an error of observation* on his part."

1876. Correspondenzblatt des zoologisch.-mineralog. Vereins in Regensburg.

1876. Is there such a thing as *Eozoon Canadense*? A Microgeological Investigation. Dr. Otto Hahn. Ann. & Mag. Nat. Hist. ser. 4, vol. xvii. pp. 265-282; Württembergische naturwissenschaftliche, Jahresbefte, 1876.

Admitting that "a very great deal has been written on the question," the writer remarks:—"The results of my investigation have, I think, finally settled it. By my investigation it is established that there is no gigantic Foraminifer in serpentine limestone."

This "investigation" resolves itself into a "criticism of mineralogical, geological, and zoological facts." Much of what the author says of chrysotile, though he sees its relation to the "nummuline layer," is to be objected to. Our observations confirm Dr. Hahn's respecting olivine; we dissent, however, from his statement that "the serpentine undoubtedly originated from olivine." In his remarks and views on the "canal system" we differ completely from him. It is to be regretted that his account of the presence of examples of the "canal system" in the gneiss of Mont Blanc, the Schwarzwald, and the syenite of Planenscher Grunde (Saxony) is both vague and unsatisfactory.

Remarks on 'The Dawn of Life' by Dr. Dawson; to which is added a Supplementary Note. Drs. W. King and T. H. Rowney. Ann. & Mag. Nat. Hist. ser. 4, vol. xvii. pp. 360–377. 1876.

Dr. Dawson, in the work cited, replying to our statement that the laminated character of "*Eozoon*" is a mineralogical phenomenon (of which we had adduced instances), asserts that "the lamination is not like that of any rock, but a strictly limited and definite form, comparable with that of *Stromatopora*:" we draw his attention to a specimen of granite from Harris (Hebrides) which consists of alternating laminæ of feldspar and quartz, the lamination being ***strictly limited*** and of ***definite form***, and even far more "*Eozoon*"-like in this respect than *Stromatopora concentrica*. The specimen was presented to us by our respected friend the late Prof. R. Harkness.

Organic Remains in the Metamorphic Rocks of Harris. 1876.

A letter in the 'Annals and Magazine of Natural History,' ser. 4, vol. xvii. p. 414, signed "H. Alleyne Nicholson" and "James Thomson," announcing that they "have recently discovered evidence of life" in the Laurentians of Harris, the specimens being "as clearly organic in their nature, and as well preserved in their minute structure, as is the case with Silurian or Devonian fossils of an analogous structure (such, for example, as *Stromatopora*)." The specimens, "unequivocal organic bodies," are "little altered, the skeleton of the fossils being ***calcareous***, apparently dolomite, and exhibiting all the minute details of its structure; whilst the chambers are filled, as so common in organic remains from younger deposits, with transparent silica. Finally, though apparently differing from it in important respects, we believe that our specimens will contribute powerfully to the solution of the controversy which has been of late years carried on as to the true nature of *Eozoon*."

Be it observed that this announcement is inserted in the same number of the 'Annals' which contains our memoir above noticed. But more is to follow!

1876. New Laurentian Fossil. Nature, May 4, 1876.

Dr. W. B. Carpenter announces the discovery, in "Harris, of what is regarded by every palæontologist who has seen the specimen as an unquestionable *organism*." . . . "The fabric seems to have consisted of superposed layers of calcareous shell-substance," with spaces between them much thinner than the layers, "filled up with calcite." "Altogether I have no hesitation in concurring with Prof. H. A. Nicholson, Prof. Geikie, and Mr. Etheridge in affirming it to be so unmistakably organic, that, if it be claimed by mineralogists as a 'rock-structure,' a large number of universally accepted fossils will have to go along with it."

Our reference (preceding page) to what proves to be the same "unquestionable organism" brought out, as was to be expected, the following letters, which, though commendable in one respect, ignore altogether the brief remarks made by us respecting its being granite, consisting of layers of *quartz* and *feldspar*!

1876. Supposed New Laurentian Fossil. Nature, May 25, 1876. Dr. W. B. Carpenter.

"I lose no time in making known to the readers of 'Nature' that the notice of a New Laurentian Fossil which I published in its columns three weeks since, was written under a complete misapprehension of the real nature of the body. So far from being *calcareous*, as I had been led to believe by the information I had received from the geologist who found the specimen, it proves to consist of alternating layers of felspar and quartz—the former simulating an organic structure like that of *Stromatopora*, and the latter occupying what had been supposed to be cavities of that structure—together constituting what is known to petrologists as 'graphic granite;'" "and what had seemed to be a *vertical tubular* structure, proving to be *mere striation*" (see p. xxxiii). "The examination of numerous sections of this body, and a comparison of them with sections of the 'graphic granite,' has now satisfied me that the agencies which produced the 'graphic granite' were competent to have produced the supposed Harris fossil. *Whether these agencies were entirely inorganic, or whether the 'graphic granite' itself may not be a metamorphic form of an ancient organic structure* (metamorphoses as strange have undoubtedly happened), *is a question which is not at present to be decided by any one's ipse dixit*"* !

Supposed Laurentian Fossil. Dr. H. A. Nicholson. Ann. & Mag. Nat. Hist. ser. 4, vol. xviii. p. 75. 1876.

A letter withdrawing the statement that the specimens noticed in his former letter "were essentially calcareous in their composition," as "upon investigation, the specimens proved to be composed of alternating layers of felspar and silica." The writer concludes with a remark by which he identifies himself with Dr. Carpenter in HIS *ipse dixit* :—"Whether the peculiar arrangement of the minerals which constitute these specimens can be assigned wholly to the operation of inorganic causes or not, *is a question which does not in the meanwhile admit of solution*"!

We embrace the present opportunity to mention a few points connected with the Harris graphic granite. Fig. 1, Pl. I., represents a portion of the specimen presented to us by the late Prof. R. Harkness, showing lamellæ of quartz and feldspar (both represented vertically); also the striping or "striation" (characteristic of plagioclases) intersecting the feldspar layers nearly at a right angle, and taken by Dr. Carpenter for "*tubular structure.*" Fig. 3, Pl. IX., represents a small portion, slightly under the natural size, of a beautiful and interesting specimen (5 inches by 2 inches) which has been kindly placed, with others, in our hands by Dr. Heddle, the mineralogist of Scotland. The interlamellation of the quartz (brown in the figure) and the feldspar (purple) is both "strictly limited" and of "definite form." The feldspar, which, from its silvery appearance, seems to be

* The italics are ours.

of the variety called "moon-stone," is obliquely intersected by what appear to be laminæ of a triclinic feldspar, inasmuch as they are crossed with striæ: similar laminæ are seen in the specimens of orthoclase represented in fig. 4, Pl. I. Our figure of Dr. Heddle's specimen affords but a poor idea of its beauty and remarkable structural character.

1876. Notes on Otto Hahn's Microgeological Investigation of *Eozoon Canadense*. Dr. William B. Carpenter. Ann. & Mag. Nat. Hist. ser. 4, vol. xvii. pp. 417–422.

1876. *Eozoon Canadense* according to Hahn. Dr. J. W. Dawson. Ann. & Mag. Nat. Hist. ser. 4, vol. xvii.

1876. Review of Dr. Dawson's 'Dawn of Life.' T. R. J. Geol. Mag. Decade II. vol. iii. April 1876.

1876. Note on the Geological Position of the Serpentine Limestone of Northern New York, and an Enquiry regarding the Relations of this Limestone to the *Eozoon*-limestones of Canada. Prof. James Hall. American Journal of Science, 3rd ser. vol. xii. pp. 298–300.

Noticing the lower division of the Laurentian rocks in Northern New York, Prof. Hall states that they are "unconformably overlaid by massive beds of gneissic and labradoritic formations, associated with which are one or more bands of crystalline limestone: the latter "is usually and perhaps always permeated by serpentine in grains, bands, or what sometimes appear as concretionary or aggregated masses of that mineral." This serpentine limestone "has been reported as containing *Eozoon*." . . . "The simple point which I wish to demonstrate is that this limestone" of Northern New York "does not belong to the Laurentian limestone, either Lower or Upper, that it is a formation deposited along the flanks of and within the Laurentian area, at a period subsequent to the deposition, metamorphism, and disturbance of the rocks of authentic Laurentian age, and that it apparently holds a place in the series between the Laurentian and Potsdam periods, but whether Huronian or otherwise I do not pretend to say; and it may even prove of later date than this."

It will hereafter (A.D. 1880) be seen that the serpentine limestones of Northern New York are now held by the leading geological authorities in the United States to be of Upper Cambrian and Lower Silurian ages.

On the Serpentinite of the Lizard, its original Rock-condition, 1876.
Methylotic Phenomena, and Structural Simulations of Organisms. Drs. W. King and T. H. Rowney. Phil. Mag. ser. 5, vol. i. pp. 280–293.

The rock in many places has undergone a change into saponite, and occasionally into calcite. The former contains bodies of various kinds, strikingly simulating minute corals, vermiform and foraminiferal organisms; the latter contains cylindrical forms and clusters of spherical bodies, resembling Dawson's "*Archæosphærinæ*," and branching configurations identical with the "canal system" of *Eozoon*. What appears to be tremolite contains spherical and other bodies wonderfully mimetic of perforated foraminifers, also rods consisting of saponite, serpentine, flocculite, or calcite. The rods, especially those composed of the last mineral, throw some light on the origin of the "calcareous" examples of the "canal system," inasmuch as their component mineral carbonate is clearly the result of chemical alteration. The serpentine contains examples of chrysotile passing into the "nummuline" or pectinated condition.

New Facts relating to *Eozoon*. Dr. J. W. Dawson. Canadian 1876.
Naturalist, vol. viii. pp. 281–285.

"And though I must protest against the idea prevailing in some quarters, that there is any necessary connexion between serpentine and *Eozoon*, yet, as this mineral exists in connexion with many specimens of this fossil, it is time that geologists were warned against the extravagant ideas of pseudomorphism which have been promulgated in connexion with it"! References are made to "microscopical and palæontological evidences," which "completely vindicate the theory of aqueous deposition of serpentine as maintained by Dr. T. Sterry Hunt"! "The announcement by Prof. Karl Möbius of a recent sessile Foraminifer from the Mauritius, not very remote from *Eozoon* in its general mode of growth," is declared "to be an important contribution towards the history of the oldest fossil."

1876. On the Serpentine and Associated Rocks of the Lizard District. Rev. T. G. Bonney. Quart. Journ. Geol. Soc. vol. xxxiii. pp. 884–924.

During the discussion which followed the reading of this memoir, and in answer to a question put by the President, the writer replied that "for his own part he believed in the organic nature of *Eozoon*." How this reply is to be reconciled with the following statement Prof. Bonney has lately made—"I have *never myself seen a serpentine which was not intrusive*" (Geol. Mag., Feb. 1881, p. 94)—is a puzzle to us, as it must be to eozoonists, considering that their doctrine is based on the sedimentary or "*aqueous* deposition" of "eozoonal" serpentines (see last citation). But is not eozoonism full of inconsistencies?

1876. Otto Hahn. Württembergische naturwissensch. Jahreshefte, Jahrgang 1878.

1876. Supplement to the Second Edition of 'Acadian Geology.' Dr. J. W. Dawson.

Notices the occurrence of "somewhat obscure structures, which appear to indicate the presence of fragments of *Eozoon*," in one of the Upper Limestones, considered to be Upper Laurentian, near St. John's, New Brunswick.

1876.? Dr. T. Sterry Hunt, addressing a meeting of the Natural-History Society of Montreal, after his return from Europe, announced the cheering news that "the animal structure of *Eozoon* was now pretty generally admitted by European scientists" (Canadian Naturalist, vol. ix. p. 58).

Der Bau des *Eozoon Canadense* nach eigenen Untersuchungen verglichen mit dem Bau der Foraminiferen. Prof. Karl Möbius. (Besonderer Abdruck aus der Palæontographica Bande xxv.) Abstracted in 'Nature,' vol. xx. pp. 272, 297. 1878.

Having "investigated more closely and described more minutely its form and structure than any other naturalist," the author wishes it to be understood that he has "successfully eliminated *Eozoon* from the domain of organic bodies." For obvious reasons we regret that Möbius has been led to make these remarks, especially,—(1st) as in our opinion he has completely failed in explaining the origin of the eozonal structures, the necessity of which may be held to be of primary importance in any attempt to overthrow their asserted organic origin,—(2nd) with respect to what he says in connexion with chrysotile, we consider ourselves to have proved, in the earliest stage of the discussion, that the "nummuline layer" has resulted from structural modifications of this mineral,—and (3rd) as his foraminiferal arguments are little more than an amplification of a number of vital points that were advanced by Mr. H. J. Carter and ourselves long before he became a convert to his present views.

On the Microscopic Structure of Stromatoporidæ, and on Palæozoic Fossils mineralized with Silicates, in illustration of *Eozoon*. Dr. J. W. Dawson. Quart. Journ. Geol. Soc. vol. xxxv. pp. 48–66. 1878.

The entire memoir is interesting in connexion with one of the expressed subjects. We hold the stated facts, however, as affording no crucial evidence in favour of "*Eozoon*." But we are more directly concerned with the closing section (iii.) of the memoir, treating of "Imitative Forms resembling *Eozoon*." Of these one is a specimen from Gouverneur, St. Lawrence Co., New York. "It presents thick bands of a peculiar granitoid rock, containing highly crystalline felspar and mica, with grains of serpentine; these bands are almost a quarter of an inch in thickness, and are separated by interrupted parallel bands of calcite, much thinner than the others. The whole resembles a magnified specimen of *Eozoon,* except in the absence of the connecting chamber-walls and of the characteristic structures. A similar rock has been obtained by Mr. Vennor on the Gatineau; but it is less coarse in texture though equally crystalline, and appears to contain hornblende and pyroxene. These are both Laurentian; and I consider it not impossible that they may have been organic; but they lack the evidence of minute structures, and differ in important details from *Eozoon.*" These details are, presumably, the "proper wall" and "canal system." In what do the above specimens differ from the much-cited "Burgess *Eozoon*"? The mention of these two specimens is a *tardy* recognition of the facts, *first brought forward by ourselves,* but constantly pooh-poohed, notifying the occurrence in rocks of a definite lamination identical with that of "*Eozoon.*" But the literature of the subject hereafter is to contain a new chapter—"Imitative Forms resembling *Eozoon*"! As Dr. Dawson is *now becoming acquainted* with forms of the kind, there is some hope for the triumph of truth.

1879. Principal J. W. Dawson's criticism of my Memoir on the Structure of *Eozoon Canadense* compared with that of Foraminifera. Prof. K. Möbius. American Journal of Science, 2nd ser. vol. xviii. 1879.

1879. A notice by "T. R. J." of Möbius's Der Bau des *Eozoon,* in Ann. & Mag. Nat. Hist. ser. 5, vol. iii. pp. 314–316.

1879. Zur *Eozoon*-Frage. Otto Kuntze.
Anti-eozoonal.

1879. L'*Eozoon.* A. Six. Soc. Géol. du Nord, Annales, tome vi. 1878–79.

1879. Die Urzelle, nebst dem Beweis dass Granit, Gneiss, Serpentin, Talk, gewisse Sandsteine, auch Basalt, endlich Meteorstein und Meteoreisen aus pflanzen bestehen. Dr. Otto Hahn.

1879. On the Origin of the Mineral, Structural, and Chemical Characters of Ophites and related Rocks. Drs. W. King and T. H. Rowney. Proc. Roy. Soc. No. 197. 'Nature,' No. 544.

The present work is, to a great extent, based on the original

"The Eozoon Canadense", a letter versus Möbius from Dr. W. B. Carpenter including another letter from Principal Dawson Nature, July 31st 1879.

memoir, of which the paper under notice is an "abstract." The latter notices the occurrence of "beautiful examples of 'canal system,' resulting from the waste of crystalloids of malacolite, in the calcaire saccharoïde (hemithrene) of St. Philippe (Vosges), rivalling those in Canadian ophite."

When speaking of this hemithrene (pp. 51, 52) we omitted to mention that, besides the "canal system," there are also present rounded grains or crystalloids of pyrosclerite (a serpentinous mineral), occasionally invested with an asbestiform mineral related to, if not identical with, chrysotile: the investing fibres, usually in contact, are in many places separated by interpolations of calcite (Pl. III. figs. 2, 3), a fact proving them to correspond with those of the "proper wall" of "*Eozoon Canadense.*"

Möbius on *Eozoon Canadense.* Dr. J. W. Dawson. American 1879.
Journal of Science, March 1879.

The writer, as must have already been noticed (A.D. 1876), is evidently anxious to make out that there is no necessary connexion between serpentine and "*Eozoon.*" This anxiousness seems to have developed itself apace; for he now asserts that "only a few" geologists and mineralogists "have learned that *Eozoon is only sometimes* associated with serpentine"! Totally dissenting from such an assertion, we beg to draw Dr. Dawson's attention to the fact, which ought always to be uppermost in his mind, that "*Eozoon*" is *mostly present in metamorphic rocks,* especially ophicalcites and hemithrenes (the product of chemical changes), and is "best preserved in those that are highly crystalline." And by way of invalidating Dr. Dawson's assertion, we challenge the production (allowing certain exceptions, which are explainable) of an indisputable specimen of "*Eozoon*" with its "chambers," "canal system, and "proper wall" ("tubuli"), preserved otherwise than in serpentine or a serpentinous mineral. We admit occasional exceptions, because the mineral silicate forming these features is replaceable by calcite.

Dr. Dawson refers to the "cumulative force" of the eozoonal structures "when taken together. In this aspect, the case of

Eozoon may be presented thus:—(1) It occurs in certain layers of widely distributed limestones, evidently of aqueous origin, and on other grounds presumably organic." Our two last paragraphs completely invalidate number one "force;" but we may add that eozoonal structures also occur in *intrusive* serpentinyte (Cornwall). "(2) Its general form, lamination, and chambers resemble those of the Silurian *Stromatopora* and its allies, and of such modern sessile Foraminifera as *Carpenteria* and *Polytrema*." Mineral developments simulate the eozoonal features mentioned, and so closely, in many cases, that Dr. Dawson has repeatedly admitted that he cannot decide as to whether or not they are organic! Those who have studied the *organisms named* repudiate the resemblance stated. "(3) It shows under the microscope a tubulated proper wall similar to that of Nummulites, though of even finer texture." Reference to the two woodcuts of the "proper wall" of "*Eozoon Canadense*" and that of *Nummulites lævigatus* (Carpenter, Ann. Mag. N. H. 4th ser. vol. xiii. pp. 457), and our criticisms thereon (op. cit. 4th ser. vol. xiv. pp. 275-280), will completely invalidate this third "force." "(4) It shows also in the thicker layers a secondary or supplemental skeleton with canals." A like phenomenon is common in hemithrenes (Aker, Vosges, &c.). "(5) These forms appear more or less perfectly in specimens mineralized with very different substances." Are the forms, referred to, the "supplemental skeleton" and "canal system"? If so, their "very different substances" have a pseudomorphic correlation. "(6) The structures of *Eozoon* are of such generalized character as might be expected in a very early protozoan." This sixth "force" is verily so conclusive in favour of eozoonism that all opposition to it must cease, now and for ever! "(7) It has been found in various parts of the world under very similar forms, and in beds approximately of the same geological horizon." The present force requires this addition to its first unit—*but always in metamorphic rocks*, also its second unit corrected thus—*and in beds of the same rocks of widely separated geological horizons from the Laurentian to the Liassic.*

"(8)" and last, which need not be thought of, as "It may be added, though perhaps not as an argument." Thus all the forces which constitute eozoonism are individually invalidated; and, necessarily, "when taken together, are of no value whatever."

Handbuch der Paläontologie. Professors Karl A. Zittel and W. P. Schimper. 1879.

The authors reject the organic origin of "*Eozoon.*"

Note on Recent Controversies respecting *Eozoon Canadense.* Dr. J. W. Dawson. Canadian Naturalist, vol. ix. no. 4. 1880.

The writer notices Möbius's "Der Bau des *Eozoon Canadense*" and the "Abstract" by ourselves (A.D. 1879). He evidently prefers pronouncing our theory of methylosis, in its explanation of the origin of the Archæan "crystalline limestones," to be "stupendously absurd" rather than discussing it.

The facts we have made known in connexion with the different eozoonal features constitute, with others, the data on which our theory of their origin is founded. In the "Abstract" referred to we applied this theory as an hypothesis to account for the origin of the Archæan hemithrenes and ophites. Obviously, then, Dr. Dawson, carried away by his oracularism, was ignoring the question at issue, which is not the methylosis of those ancient rocks, but the *origin* of the different parts forming "*Eozoon Canadense.*" Therefore, instead of wasting some pages in fruitlessly criticising Otto Hahn's 'Die Urzelle,' which has nothing to do with the "recent controversies" Dr. Dawson had to notice, his attention ought to have been directed to the evidences on which our theory is founded.

Dr. Dawson has elsewhere (A.D. 1875) designated our explanation of the origin of the different eozoonal features a "complicated theory of pseudomorphism and replacement;" so he ordained that it be "dismissed at once"—a very convenient way of getting rid of a difficult point. We shall offer no protest against this designation, but simply mention that, compared with *his* explanation, ours is simplicity itself!

We explain the origin of all the features by chemical changes similar to those of pseudomorphism in the mineral kingdom—that is, by the removal of one, or more, or all of the original constituents of a mineral, and the replacement of the same by some other constituent or constituents.

Dr. Dawson has always been chary in stating any particular case on which to justify his designation. In the present paper, however, there is actually one; and it is put in such a way as to invite discussion. Speaking of the "proper wall" in its condition of "aciculæ separated by calcareous interpolations," Dr. Dawson says we "try to account for this structure by *complicated* changes, supposed to have occurred in veins of chrysotile subsequently to their deposition." What the complication is we are at a loss to understand, as in this particular instance the change is simply due to the chrysotile having been acted upon by "all-pervading" thermal water, containing bicarbonate of lime—a solution which necessarily corroding or decreting the fibres (silicate of magnesia), and penetrating the divisions between them, deposited calcite in the place of the silacid substance wherever it was removed. This is no mere supposition; for the clearest evidences have been adduced in its favour: and it is no more a complicated phenomenon than the replacement of the calcareous substance of a shell by calcedony, pyrites, miemite, barytes, and other minerals.

But considering how Dr. Dawson has spoken of our theory of methylosis, it will scarcely be imagined that he has actually committed himself to it in what Dr. Sterry Hunt would say its "extravagant" form. It would appear that he has observed, "in a portion of the fossil," that the calcareous "proper wall" is "entirely replaced by serpentine," but "still retaining traces of the tubuli," and that "the walls thus replaced could be clearly traced into connexion with the portions of those still existing as calcite." Dr. Dawson evidently must be an "extravagant" pseudomorphist, or none! He declares that "no replacement of serpentine by calcite is indicated by the relation of these two minerals to each other, while such replacement as does occur is in the other direction, or the change of calcite into serpentine, as evidenced by the state of preservation of some specimens of *Eozoon,* above referred to"! Had Dr. Dawson been aware that chrysotile is a fibrous form of serpentine, and that its fibrosity is a superinduced character (as any one conversant with the divisional structure of minerals must admit), he would have seen, what is highly probable, that the serpentine, "still retaining traces of the tubuli," is nothing more than chrysotile in its incipient stage of development. Which is the most complex explanation of this case—the one requiring no more than a structural change, or that which involves a chemical substitution totally unsupported by evidence so far as any thing has been adduced by its author?

Let us next consider the other eozoonal features. They consist of calcite, or miemite ("intermediate skeleton" and "proper wall"), serpentine, loganite, "white pyroxene," &c. ("chamber-casts" and "canal system"), which are notably secondary, or pseudomorphic products. But Dr. Dawson asserts that they "are all known to have been produced by aqueous deposition," without offering a particle of evidence in his favour. The assertion, moreover, is a mere repetition of the *dicta* which constitute Dr. Sterry Hunt's "novel doctrine"!

Our theory consistently accounts for the origin of all the features of "*Eozoon,*" whether occurring separately, or in the manner forming what has been termed the cumulative argument—also a number of adverse phenomena, which eozoonism is compelled to admit in the case of some to be "anomalies" (we say foraminiferal *impossibilities*), while in the case of others it has been under the necessity of leaving them out in the cold to support and defend themselves by begging the question.

How does Dr. Dawson explain the presence of "canal system" in calcite filling the interstices of a large crystal of spinel isolatedly imbedded in highly crystalline hemithrene, such calcite being the basic substance of the rock? the occurrence of this feature by itself, or unassociated with its correlatives, in rocks of the same kind in widely separated regions? the occurrence of "chamber-casts" under the same circumstances? and the existence of typical eozoonal features in ophite, originally an intrusive or igneous mass (Lizard, Cornwall)?

Does not Dr. Dawson's doctrine on one day joyfully accept a thing as "eozoon," and on the next day frown on it, because the rocks containing it happen to be younger than the Archæans, and therefore, as assumed of the latter, *not "precipitated"* under the peculiar physical and chemical "activities" required by the "novel doctrine"? How did it conduct itself in the presence of the clearest evidence of "*Eozoon*" occurring in the *Jurassic* ophite of the Isle of Skye? Does it not deal in *équivoques* in the case of specimens which contain in one part structures indisputably eozoonal, and in another part precisely the same structures incontestably of mineral origin? Or should any conceivable doubt attach to either, are they not pronounced to be "imitative forms resembling *Eozoon*"? But there is no need to repeat what has been already given in detail elsewhere. We cannot, however, avoid declaring that Dr. Dawson's explanation of eozoonal phenomena is inconsistently complicated, contradicts itself, and eludes all scientific and logical treatment! "*Quo teneam vultus mutantem Protea nodo*?"

1880. On the Organic Nature of *Eozoon Canadense*. Charles Moore. Brit. Assoc. Meeting, Swansea, pp. 582, 583.

"Possessed of only two slices, and two small blocks weighing but twelve ounces, both in their original condition," the writer detected in "separated twenty grains" belonging thereto "a clear siliceous-looking fibroid growth, scarcely more substantial than the motes or fibres seen floating in the sunbeam;" while "a close examination occasionally revealed another form not thicker than a spider's web, like mycelium growth of the present day," also what he takes to be "ova or gemmules" and a coloured filmy membrane, &c. We leave these evidences of organic structure to be appreciated by Eozoonists.

Lethæa Geognostica. Theil 1. Palæozoica. Textband, Lief. 1. Dr. F. Roemer. 1880.

"Eozoic and Palæozoic." A Letter by Dr. J. W. Dawson in 'Nature,' August 26, 1880. 1880.

It begins by "protesting mildly against" some reviewer of Roemer's 'Lethæa Palæozoica,' for having "stated with respect to *Eozoon Canadense*" that the latter "accepts the verdict of Möbius against its organic origin, and rejects it from the list of palæozoic fossils." Why Roemer should commit such a sin, is a matter which Dr. Dawson declares himself "at a loss to understand. As a writer on palæozoic fossils, Roemer has nothing to do with *Eozoon* [eozoonism is strangely unreasonable]. It belongs to a great series of eozoic or archæan formations which precedes the palæozoic, and which probably represents quite as long a period. Little comparatively is known of the fossils of these oldest rocks; but what we do know of their *Eozoon, Archæospherinæ, Spiral Arenicolites,* and *Aspidella* [this last, and probably the preceding one, may be fossils; but it has yet to be proved that they do not belong to Dr. Dawsen's Acadian group, which he regards as Cambrian], and of their immense deposits of graphitized plants [?], is sufficient to assure us that the life of the eozoic period was very different from that of the palæozoic; *Eozoon,* whatever its nature [which *now* seems to be doubtful], is one of the most characteristic of these eozoic fossils. It has been recognized through a great vertical thickness of beds, and over so wide areas that it is now equally characteristic of eozoic rocks in Canada and Brazil, in Bavaria and in Scandinavia [Ceylon, Skye (Jurassic), Aker, India, New Jersey, Warren and other counties in Northern New York, Connemara (Lower Silurian), Reichenstein, and the Vosges contain metamorphosed rocks *demonstratively* eozoonal]. Further, it has obviously been connected with the accumulation of some of the greatest limestones of the eozoic time." The reader, by referring to A.D. 1876, will find that Prof. J. Hall, who believes in "*Eozoon,*" has argued for its being a *palæozoic* fossil; therefore why he has escaped being "mildly protested against," Dr. Roemer may reasonably be "at a loss to understand."

We shall now conclude by drawing up a conspectus of the various points of importance which have been advanced by us against the organic origin of "*Eozoon Canadense*;" and it is greatly to be desired that the upholders of this view, instead of continually begging the question, introducing irrelevancies, or being too often reticent in their replies, will endeavour to overthrow them in a manner becoming their scientific reputation.

Our points arrange themselves as follows:—

Foraminiferal.

(1) The existence of an *upper* and an *under* "proper wall" in immediate connexion with a "chamber," and the frequent occurrence of this same part, with its "tubuli" (aciculæ) passing continuously, or without interruption, from one "chamber" to another, to the exclusion of the "intermediate skeleton"*; also the frequent horizontality of the "tubuli" to their adjacent "chamber."

(2) The configurations presumed to represent the "canal system" have no constant correlativeness, and are totally devoid of any regularity of form—in the one case emanating indifferently from chambers, or from "tubuli" of the "proper wall," and in the other being incompatible with the feature with which they have been identified.

The above points, admitted to be "anomalies," but not yet explained, establish the "*essential*" parts of "*Eozoon Canadense*" to be foraminiferal impossibilities.

* Quart. Journ. Geol. Soc. vol. xxii. p. 191. Proc. Roy. Irish Acad. vol. x. p. 517. Ann. & Mag. Nat. Hist. ser. 4, vol. xiv. pp. 274–289. This work, p. xxxiv.

Mineralogical and Chemical.

(3) The four or more parts constituting "*Eozoon*" are identifiable with mineral developments more or less common in crystalline rocks that have undergone *chemical changes,* as ophites and hemithrenes. Serpentine, which is an important component of eozoonal parts, is notoriously a protean mineral, a product of chemical alteration in other minerals (pseudomorphism), and a prey to structural changes: chrysotile (a fibrous form) and flocculite (a flocculent form) are examples of the latter.

(4) "*Chamber-casts.*" Those constituting the acervuline variety of "*Eozoon*" are identical with the rounded and variously lobulated crystalloids of hornblende, augite, chondrodite, and other minerals characteristic of hemithrenes of Scandinavia, Massachusetts, Saxony, Ceylon, Connemara, Tyree, and the Vosges. Those of the lamellated variety are strictly paralleled by the layers of similar minerals in the silo-carbacid gneisses of Norway, Bavaria, North America, and elsewhere. All these examples are demonstratively of mineral origin.

(5) Eozoonists (Dawson, Sterry Hunt, Gümbel), in taking the rounded cylindrical and tuberculated "grains" of pargasite &c. in the coccolitic marbles of Scandinavia to be "chamber-casts" and other organic structures, are obviously in error,—the said "grains" being crystalloids decreted by solvent action, as proved by their often retaining not only the crystalline faces, angles, and edges of the original mineral but by the flocculent residuum, on their surface, of the portions that have been removed.

(6) "*Proper wall.*" The typical form (separated aciculæ with calcareous interpolations) can be proved to be a modification of *true* chrysotile; moreover it occurs in *cracks* that have been *mechanically produced.*

(7) "*Canal system,*" including "stolons." Clotules of flocculite (plainly resulting from serpentine that has undergone a change) are frequently shaped into irregular configurations (taken for this part) by some solvent or decreting process which affected their component substance. Similar configurations

are produced by the same process acting on clusters of crystalloids of malacolite and other related mineral silicates of *secondary* origin and characteristic of *chemically changed rocks*, in Finland, Ceylon, Saxony, New Jersey, &c. Examples of the kind have actually been found in calcite occupying chinks in crystals of spinel. Analogous bodies occur as metaxite in a rock of the same kind; others, consisting of carbonate of lime, are also common in dolomite near Sunderland.

(8) "*Intermediate skeleton.*" This corresponds to the calcareous layers alternating with hornblendic augitic and feldspathic minerals, characteristic of silo-carbacid gneisses (Canada, State of New York, Vigan, Pic d'Eridlitz, &c.); and it is the same as the calcareous matrix, containing mineral crystalloids, constituting hemithrenes. In typical specimens of "*Eozoon*" the calcite composing this part is plainly a replacement pseudomorph after serpentine.

(9) The alleged cases of "chambers" and "canal system," preserved in calcite (assuming them to be correct), are explainable by the fact that this mineral occurs as a pseudomorphic replacement after serpentine and other mineral silicates.

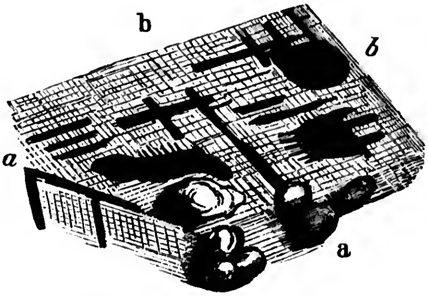
Geological.

(10) The presence of "best-preserved specimens" of "*Eozoon*" in highly *crystalline rocks* that are *chemically altered* sediments—its absence (the Tudor case we have shown to be untenable) in ordinary unaltered beds—its presence in ophites originally igneous (Cornwall), and in dyke-shaped masses of hemithrene originally silacid gneisses (Vosges, Massachusetts, and elsewhere), must be accepted as irreconcilable facts totally subversive of the eozoonal doctrine.

(11) The occurrence of eozoonal features in crystalline ophites and hemithrenes belonging to the Laurentian, Cambrian, Silurian (Connemara, Massachusetts, &c.), and Liassic (Skye) systems, and the fact of their being absent in unaltered rocks of the same and intermediate rock-systems, completely establish their mineral origin.

POSTSCRIPTS.

A.—"*Eozoon*" *in loganite* (antè, p. xvi).



Portion of a specimen (highly magnified) of "*Eozoon Canadense*," with "chamber-casts" (a) in dark green loganite, imbedded in "white pyroxene" or (?) malacolite (b). The last mineral has undergone in places (*a*, *b*) a chemical change (pseudomorphic replacement) into "ferriferous dolomite" —the substance of the "intermediate skeleton." The fine lines are cleavage-divisions: the thick black lines (*a*) were originally the same; but having become widened into gashes by carbacid solvent action, they are now filled with "ferriferous dolomite": the irregular-shaped dark spaces (*b*), enlargements of the latter, are also filled with the same mineral.

N.B. The loganite is in irregularly rounded crystalloids. Specimens proving the same pseudomorphosis, viz. calcite or miemite after a similar mineral silicate, occur in Connemara, Scandinavia, New Jersey, Ceylon, Vosges, and other places (*antè*, p. xvii &c.).

B.—Considering the statements made by Drs. Carpenter, Dawson, and Sterry Hunt as to the "general acceptance" of "*Eozoon*," it would be a beneficial amusement for them to count up, according to the facts given in the preceding pages, how many "scientists" have written in its favour, and how many against it: possibly it will be found that the former are in the minority!

CORRIGENDA.

Page xxiv, 2nd line from bottom, *alter* New York *into* New Jersey.
xxix, 14th line from top, *after* (A.D. 1870) *insert* and paper (A.D. 1871).
xxxvii, 8th line from bottom, *after* "proper wall," *insert* During the discussion which followed the reading of the above paper, Mr. Robert Etheridge advocated "*Eozoon.*"
xlvi, *insert* "The *Eozoon Canadense*," a letter *versus* Möbius from Dr. W. B. Carpenter, including another letter from Principal Dawson. Nature, July 31, 1879.
5, 26th line from top, *add* chlorite.
10, 15th line from top, alter *f** *into* C.
10, in footnote §, *alter* 1 *into* 2.
12, 3rd par. 3rd line, *alter* (a) into (*a*).
12, 3rd par. 4th line, alter (*a*) *into* (a).
12, 4th par. 5th line, *alter* one *into* two.
13, 12th line, *alter* Siberia *into* Astracan.
14, 9th line from bottom, alter *a** into *a*.
15, 1st line from bottom, alter *b* into *c*.
15, 2nd line from bottom, alter *a* into *b*.
16, 1st line from top, alter *c* into *d*.
16, 4th line from top, *after* calcite, insert (*a*).
16, 9th line from top, alter (*b*) into (*c*).
17, 2nd line from top, alter *a* into *b*.
17, 3rd line from top, *after* tile *insert* Under the polariscope.
17, 18th line from top, *after* cracks *insert* under polarized light.
17, 21st line from top, *alter* 4 *into* 3.
17, 7th line from bottom, alter *b* into *c*.
18, 17th line from bottom, *after* half *insert* (a).
18, 16th line from bottom, *after* half *insert* (b), and *after* uppermost layer *insert* (*a*).
18, 7th line from bottom, *after* half *insert* (under *c*).
18, 4th line from bottom, *alter* on *into* further to *and dele* half.
19, in footnote, *alter* 1878 *into* 1875.
37, 24th line from top *alter* wakite *into* waekite.
47, 10th line from top, *alter* Uhrkalk *into* Urkalk, here and elsewhere.
48, 17th line from top, *after* continuity *insert* occurring in Tiree.
48, 2nd line from bottom, *after* published) *insert* in a cove (A).
49, 1st line from top, *after* Glassillaun *insert* B.
49, 2nd line from top, *after* channel *insert* (C).
49, 3rd line from top, *after* metamorphics *insert* (*b*).
49, 7th line from bottom, *after* side *insert* (E).
50, 5th line from top, *after* its *insert* polarized.
51, 2nd line of footnote, *alter* Reusch *into* Reinsch.
78, 5th line from bottom, *alter* geographical *into* geognostical.
104, 15th line from bottom, alter *Goniatidæ* into *Goniatitidæ*.
113, 17th line from top, *alter* Daykins *into* Dakyns.

ROCK-METAMORPHISM.

CHAPTER I.

THE DIFFERENT KINDS OF ROCKS TREATED OF.

THE term *ophite*, first employed by Vitruvius, is used in this work with a wider meaning than is usual, so as to be applicable to rocks that consist of various kinds of serpentine, a number of closely related hydrous silo-magnesian minerals, and some anhydrous siliceous species—associated, in many instances, with mineral carbonates.

In rocks of the kind, the serpentine minerals are to be regarded as essentials, irrespective of their holding a dominant, or a subordinate place; while the related minerals and the dry siliceous species are to be looked upon as accessories. The mineral carbonates, on account of their playing an important part in a large section of ophites, must also be considered essentials.

There are certain rocks, composed of dry mineral silicates, in which serpentine (and even a mineral carbonate) is known to occur, but only in such small quantities as to rank no higher than accessories. Cases of this kind, and others which could be noticed, show the difficulties there are in drawing a sharp division between any given class of rocks and the group under consideration.

The following arrangement of ophites and related rocks is offered more for practical purposes than as being a natural one, though it is not altogether devoid of the last character :—

A. Silacid Ophites*.

Serpentinytes.
Talc-schists, Rensselaeryte (potstone).
Sepiolytes, Magneso-argillyte (" Argile magnésienne," *Delesse*).

a. Sub-silacid Ophites†.

Chlorargillytes.
Agalmatolytes.
Chlorite-schists, Hydro-phlogopiteschists.
Talc-gneisses (Protogines).
Peridolytes (Lherzolyte, Dunyte, Picryte, Ossipyte, &c.).
Ophi-euphotides.

B. Silo-carbacid Ophites‡.

Ophi-calcites.
Ophi-magnesites.
Ophi-dolomites.

b. Sub-silo-carbacid Ophites §.

Malacolophytes.
Hemithrenes.
Calci-micaschists.
&c. &c.

The first section (A) graduates through certain of its members into ordinary metamorphic rocks—hornblendic, augitic, and other gneisses, and the various crystalline schists; also into euphotides, diorites, dolerites, and related plutonic masses. There are serpentinous schists (chlorargillytes) that link the subsection to common clay-slates ||.

The second section (B) is closely allied to the carbacid metamorphics—dolomites and carrarites ¶.

* Composed essentially of siliceous minerals. See 'Geological Magazine,' January 1873, vol. x.

† The subdivisions *a* and *b* contain the least amount of water. In *a* alumina and oxides of iron are present.

‡ Consisting of mineral silicates and carbonates.

§ Serpentine (or a related mineral) is usually a subordinate constituent in this subsection.

|| See a paper by J. Arthur Phillips in 'Philosophical Magazine,' February 1871.

¶ The statuary-marble of Carrara and other places.

It will thus be seen that ophites are not ordinary rocks.

In some of the silo-carbacid ophites the presence of a mineral carbonate is feebly expressed; but in others it is decidedly more pronounced. So abundantly calcareous are some in Northern Italy that they might be taken for carrarite, or dolomite. To the ordinary tourist the cathedral of Milan is built of "white marble;" nevertheless this material is so streaked with serpentine as to require its being regarded as an ophi-calcite. On the other hand, in Connemara there is a remarkable snow-coloured rock, worked for a while under the belief of its being a "white marble," that is essentially an aggregation of the anhydrous mineral silicate, malacolite, and holding little more than a fraction of diffused calcite. It is through such a rock as this that the passage is open, not only into the ophicalcites, but into the purely siliceous metamorphics.

CHAPTER II.

THE MINERAL CHARACTERS OF OPHITES AND RELATED ROCKS.

OPHITES, especially some belonging to the silo-carbacid section, contain a number of mineral species; and, with the exception of certain kinds of veins, they take no unimportant rank amongst the richest depositories of minerals.

Serpentine is considered to be pure or typical when it is of a yellowish-green colour, subvitreous, somewhat unctuous, sectile, and of a moderate specific gravity: such is the "noble serpentine" of Snarum in Norway, New Jersey, and other places. This consists of MgO 43·32, SiO_2 43·68, H_2O 13·00, which makes it a hydrous silicate of magnesia. Still seldom, if ever, does serpentine occur pure, as even the "noble" kind is vitiated by the presence of foreign substances: oxides of iron *, carbonate of lime, carbonate of magnesia, alumina are of frequent occurrence; and occasionally oxides of chrome, manganese, and nickel †: it is these compounds that often give rise to minute portions, intermixed with the serpentine, of peridote, magnetite, magnesite, and other minerals.

The species and varieties of serpentine minerals are of all colours, densities, and consistencies; and they differ much from one another in composition. Many of them occur crystallized; but serpentine itself, in the normal state, is never otherwise than amorphous or colloidal.

Including the type, serpentine minerals may be divided into two groups:—I. containing species and varieties the difference

* "The green colour of the Galway serpentine is produced chiefly by protoxide of iron. The serpentine of Penzance" (? the Lizard) "is chiefly coloured by peroxide of iron" (Alphonse Gages in Phil. Mag. 4th ser. vol. xvii. p. 175).

† Nouemite (Liversidge) is a nickeliferous serpentine, in which oxide of nickel replaces a portion of the magnesia, in some instances, to the extent of about 21 per cent.

between which is that their constituents are quantitatively varied:—II. containing those in which the magnesia is variously decreased by the introduction of other bases.

Group I. comprises the following four sections:—

A, represented by typical serpentine, includes species or varieties (retinalite, vorhauserite, bowenite, marmolite, thermophyllite) in which the magnesia and silica stand to each other in about equal proportions, and the water, from 11 to 14 per cent., is pretty constant in quantity.

B contains those in which the silica approaches to, or in a few cases exceeds, 60 per cent., and the magnesia is reduced to about [illegible]. Aphrodite, sepiolite, and spadaite are examples.

C comprises talc, steatite, pyrallolite, picrosmine, rensselaerite (in general highly siliceous), with from 23 to 35 per cent. of magnesia; but subhydrous, containing only from 3 to 7 per cent. of water.

D includes deweylite and cerolite, which are not much removed from serpentine in the proportion of their base; but they are superhydrous, holding somewhat over 20 per cent. of water.

In group II. a quantity of the magnesia is frequently more or less replaced by alumina, oxide of iron, lime, and alkalies (singly or associated), with variations in the amount of water, giving rise to the following sections:—

A. *Aluminous.*—Saponite, pyrosclerite, ripidolite, loganite, leuchtenbergite, pseudophite, chlorite.

B. *Ferruginous.*—Antigorite, villarsite, hydrophite, pseudo-diallage (*Heddle*), monradite, bastite.

C. *Alumino-ferruginous.*—Penninite, prochlorite, tabergite, corundophyllite, vaalite, neolite*, &c.

D. *Calcareous.*—Totaigite (*Heddle*).

E. *Alumino-calcareous.*—Chonicrite, seybertite, baltimorite (*Hauer*).

F. *Alumino-calcareo-alkaline.*—Biharite, groppite.

G. *Alumino-chromiferous.*—Kammererite, rhodochrome.

H. *Nickeliferous.*—Nouemite.

I. *Alumino-cupriferous.*—Venerite.

Being essentially hydrous, it was to be expected that some of

* Neolite, strictly speaking, is not an ophite-forming mineral but its constituents relate it to serpentine.

the present minerals would occur with evidence of their having been in a fluidal or gelatinous condition. Thus it is that serpentine, pyrosclerite, saponite, deweylite, and some others are frequently seen occupying what may be considered to have been cracks, cavities, and other openings; while their substance has a streaked, wavy, or an irregularly netted appearance, as if it had flowed, sometimes continuously, at other times intermittently, into these receptacles, or had been deposited on their sides *. In connexion with this matter it may be mentioned that Alphonse Gages has succeeded in making a gelatinous substance with the composition of deweylite †. It has often been stated that serpentine has infiltrated itself into tubuli and canals of shells and other organisms; but it is extremely doubtful that the substance, so called, was originally any thing else than an aluminous ferrugino-alkaline deposit, which has become changed into some variety of glauconite ‡.

Though serpentine is characteristically colloidal, that is, without crystalline structure, *other forms* (allomorphs) and related varieties are known. Thus chrysotile, thermophyllite, marmolite, metaxite, and flocculite are respectively asbestiform, columnar, laminar, dendro-foliaceous, and granular or flocculent.

Certain serpentine minerals, as ripidolite, are characteristically crystallized. But, as will be more fully explained hereafter, there are others, *e. g.* pyrallolite, picrosmine, bastite, rennselaerite, loganite, &c., including the type species, which occasionally present themselves under crystalline forms: in such minerals, however, more or less of their original substance has been removed; or it has become serpentinized through chemical changes.

It would not be difficult to name some fifty or more kinds of hydrous silo-magnesian minerals that have serpentine for their type, and belonging in most cases to both sections of ophites.

Passing to the mineral carbonates (which, with the silicates already mentioned, constitute the silo-carbacid ophites), these

* Philosophical Magazine, 5th ser. vol. ii. pl. 2 (bottom of plate), p. 283.

† British-Association Report, 1863, p. 204.

‡ I have elsewhere mentioned that the spines of a palliobranch (*Siphonotreta*) contain an infilling consisting apparently of "one of the numerous varieties of glauconite" (W. K.): see Geol. Mag. new ser. 1877, vol iv. p. 14; also Introduction, A.D. 1878.

form a small group which includes calcite, miemite, and magnesite—also their hydrated allies hydrocalcite, predazzite, hydromagnesite, and one or two more.

In addition to the hydrous mineral silicates containing magnesia, ophites include a number of accessory species, all understood to be normally anhydrous: such are malacolite, sahlite, funkite (coccolite), diallage, smaragdite, enstatite, diaclasite, peridote, chondrodite, phlogopite, biotite, anthophyllite, idocrase, and several others. Many of these are occasionally found hydrated*; and when in this state they might, without much disadvantage, be classed with serpentine minerals. Wollastonite and scapolite, though essentially consisting of silicate of lime, require to be noticed in this connexion.

Intimately related to the anhydrous magnesio-siliceous minerals are certain species common to ordinary metamorphics, viz. augite, hornblende, hypersthene, muscovite, &c. Though far removed from serpentine, and not unfrequently present in ophites, but occurring therein occasionally more or less altered and hydrated, they are not to be overlooked in connexion with the essential minerals of these rocks, as will be seen hereafter.

Other minerals, more interesting as natural chemical products than of present importance, occur in ophites, viz. brucite (hydrous magnesia), volknerite (hydrous aluminate of magnesia), spinel (aluminate of magnesia), apatite, sphene, sapphire, tourmaline, zircon, graphite, and diamond.

Considering that silicate of magnesia is a common constituent of minerals belonging to ordinary metamorphic rocks, that it runs through the entire range of percentages in species occurring in ophites, also that water exists in the latter minerals in proportions varying between opposite extremes, it is not to be wondered at that some ophitic species are difficult to formulate, and that there are rocks containing more or less of a hydrated silo-magnesian mineral associated with aluminous mineral silicates (as is the case with ophi-euphotides and other sub-silacid ophites).

* Dr. Heddle finds nearly 5 per cent. of water in malacolite from between Glen Elg and Totaig (Trans. Roy. Soc. Edinburgh, vol. xxvii. p. 456).

CHAPTER III.

STRUCTURAL CHARACTERS OF OPHITES AND RELATED ROCKS.

As already stated, serpentine is the most important mineral constituent of the rocks under consideration. It is, moreover, of especial interest in being represented, besides its typically amorphous form, by some remarkable allomorphs.

The best-known allomorph is chrysotile. This in its typical state is fibrous or asbestiform; and it occurs as layers of a silky or metallic lustre, varying in colour from silver-white to bronze or golden. The colour and lustre are doubtless due to the peculiar divisional structure of the allomorph. The layers are included in, and frequently alternate with, amorphous serpentine, so as to affect a parallel arrangement; the parallelism, however, is often interfered with by the layers of chrysotile coming together, or coalescing at irregular distances, or by others intersecting them obliquely. Often two or more layers are in close contact.

The layers vary much in thickness, running from less than one eighth of an inch to one or more inches. The fibres cross the layers at a right angle, occasionally obliquely or slightly undulating.

Chrysotile occurs beautifully developed in a number of localities—the original one being Reichenstein, in Silesia, which yielded the specimens first analyzed by Kobell. The analysis proved it to be identical in composition with serpentine. Typical specimens also abound in Canada, New Jersey, and a great many other places. The specimen represented in fig. 1, Plate I., is from Colafirth, one of the Shetland Isles*. A description of the rock from which it was taken has been given by Dr. Heddle in the 'Mineralogical Magazine,' vol. ii. p. 183.

Although usually taken to be a fibrous mineral, chrysotile occurs under certain modifications, each representing a stage in the process of development from incipiency to completeness.

* The specimen was presented to us by our late respected colleague Professor Harkness, F.R.S. &c.

Reserving a fuller description for the next Chapter, we shall here give a brief notice of the different stages.

First. In the incipient stage chrysotile, very unlike what it is as usually represented, consists of a layer of colloidal serpentine penetrated vertically by separated thread-like lines *.

Second. The lines are increased to an indefinite extent, dividing the layer so as to destroy its ordinary serpentine character, and making it to consist of a dense mass of fibres †: this constitutes typical chrysotile.

Third. The fibres have become definitely acicular, and are in close contact ‡.

Fourth. The fibres or rather aciculæ (as they must now be called) are more or less separated by interspaces filled in with calcite §.

These four modifications are represented by the divisions lettered *a, b, c, d* in fig. 1, Plate IX. Other modifications occasionally occur, as the complete fusion of the fibres into a solid mass, which may retain traces of the original fibrosity, or have lost them altogether.

It may now be mentioned that the acicular modifications correspond to one of the essential structures, the ("tubulated") "nummuline wall," of what was once generally believed to be a gigantic fossil foraminifer, viz. "*Eozoon Canadense.*"

Ophites frequently consist of interlamellations of serpentine and calcite (or the latter may be micmite), with little or no chrysotile. Attention will be drawn to cases of the kind hereafter.

Serpentine frequently exhibits a cracked structure, which, though we hold gives rise to some important features, cannot be considered a physical character proper to it. The cracks, varying much in width, are in general exceedingly irregular: often they are confusedly reticular, curving, and radial, and in

* See Quart. Journ. Geol. Soc. vol. xxii. pl. xiv. fig. 2 *a*; Proc. Roy. Irish Acad. vol. x. pl. xli. fig. 2 *a*; also this work, Plate IX. fig. 1*a*.

† See Plate IX. fig. 1 *b*.

‡ See Quart. Journ. Geol. Soc. vol. xxii. pl. xiv. fig. 1 (closed aciculæ); Proc. Roy. Irish Acad. vol. x. pl. xli. fig. 1 *c*; Ann. & Mag. Nat. Hist. ser. 4, vol. xiv. pl. xix. fig. 4 *a*; also this work, Plate IX. fig. 1 *c*.

§ See Quart. Journ. Geol. Soc. vol. xxii. pl. xiv. figs. 1 & 4 (separated aciculæ); Proc. Roy. Irish Acad. vol. x. pl. xli. fig. 2 *d*; Ann. & Mag. Nat. Hist. ser. 4, vol. xiv. pl. xix. fig. 4 *b*; also this work, Plate IX. fig. 1 *d*. It is necessary to mention that the last figure cited in these notes diagrammatically represents the changes of chrysotile.

some instances lying in parallelism. Most of them contain a white, granular, flocculent material, which, from what Sterry Hunt states of the similar substance forming the "canal system of *Eozoon*"*, will have to be taken for another allomorph: we have elsewhere distinguished it by the name of flocculite†. Also many of the cracks are filled with calcite.

The interpolated flocculite and calcite frequently occur to such an extent as to make the serpentine a subordinate constituent of ophite—occurring therein as separated plates, lenticuloids, and spheroids, variously excavated or lobulated, and imbedded in a matrix composed of either of the above minerals.

The calcitic interpolations may often be observed containing portions of flocculite assuming a variety of shapes simulative of microscopic branching algæ and corals, such as those under fig. 2 X, Plate IX.: they are considered to represent another important "eozoonal" structure—the "canal system."

Similar configurations, consisting of saponite, and imbedded in calcitic interpolations, have occurred to us in Cornish serpentine‡. Metaxite, another closely related mineral, if not an allomorph, similarly presents itself—that is, as multifoliaceous expansions. And we have made known that aggregations of crystalloids of malacolite (a white variety of augite), assuming the most beautiful arborescent or dendritic shapes, are not uncommon in the hemithrenes of New Jersey, Aker, and Ceylon; while a similar rock in the Vosges has lately yielded them to our investigations.

The presence of spheroids, lenticuloids, and plates of serpentine imbedded in calcite brings us into view of the frequent interlamellation, in ophites, of these two widely different minerals, especially in those characteristic of the Archæan group of rocks in Canada. The phenomenon is well displayed in what is called the "laminated variety of *Eozoon*"§—the layers of calcite being regarded as the "intermediate" or "supplemental skeleton" || of this presumed fossil, and the layers of serpentine as casts of its

* Intellectual Observer (Dr. Carpenter on "*Eozoon*"), vol. vii. p. 294.

† Quarterly Journ. Geol. Soc. xxii. p. 193.

‡ Phil. Mag. ser. 5, vol. i. pl. 2. fig. 13.

§ See Plate I. fig. 1. 2.

|| It is presumed that a layer of calcite ("intermediate skeleton") was bounded on each surface by a "tubulated" lamina ("nummuline wall"), and that the latter enclosed the "chambers" occupied by the sarcodic divisions of "Eozoon."

"chambers." Such layers of serpentine are admitted to graduate into the plates, lenticuloids, and spheroids above mentioned, and thus to constitute the "acervuline variety of *Eozoon.*"

Interlamellations of the kind are not confined to the Archæans of Canada, as they, with other eozoonal features, have been made known by us to be present in the *post-Archæan* green marbles of Connemara and the *Jurassic* ophite of the Isle of Skye*. They have been observed by one of us in a hydrous dolomite in contact with an igneous rock near Predazzo; and he was shown by Prof. Müller a specimen in the museum at Basle, from Kalkgebirg, Todte Alps, Davos, in the Engadine. A similar rock, we suspect, occurs somewhere in Southern Italy; for the fragments of coarse verd antique lying amongst the ruins of Pompeii and Herculaneum consist of rude alternations of calcite and serpentine; and the "marble" columns, perforated by pholases, still standing erect in the ruined temple of Serapis, at Puzzuoli, have been formed out of a rock apparently of the same kind.

The serpentinyte of the Lizard, Cornwall, has afforded us a great variety of bodies, consisting of serpentine, saponite, and other mineral silicates, and resembling corals, foraminifers, worm-tubes, as will be seen in our paper published in the 'Philosophical Magazine,' ser. 5, vol. i. pl. 2. Other simulations of organisms have lately occurred to us in the same rock: one, a plate (apparently of feldspar undergoing a change), is riddled in the most regular manner, so as to have the closest resemblance to a leaflet of *Retepora cellulosa.*

A number of silacid ophites (ophi-euphotides &c.) have quite a porphyritic structure—a common occurrence in those of Central Italy. We have, in the paper just referred to, shown that the serpentinyte of the Lizard is porphyritic, containing crushed crystals, originally of augite, but now possessing the cleavage and lustre of chlorite†.

* Proc. Roy. Irish Acad. new ser. vol. i. (January, 1871).

† Since this paper was published, the Rev. Prof. Bonney and Mr. W. Hudlestone have noticed these crystals, in the 'Quarterly Journal of the Geological Society,' vol. xxxiii., the former stating that they are altered ustatite (pp. 921, 922), and the latter that "their chemical composition is similar to that of bastite; and they are probably the result of the hydration of a variety of enstatite" (p. 926). The latter statement may be taken as confirmatory of our earlier idea that the crystals are pseudomorphs of chlorite after augite.

CHAPTER IV.

ORIGIN OF CERTAIN MINERAL, STRUCTURAL, AND CHEMICAL CHARACTERS OF OPHITES AND RELATED ROCKS.

Thin sections of peridote from Elfdalen, in Dalecarlia, exhibit this mineral in an amorphous or finely granular condition, and not unfrequently containing thin fibrous or striated undulating laminæ, more or less separated and subparallel: the striæ or fibres are at right angles to the surfaces of the laminæ (Plate I. fig. 3).

A similar structural character, seen on one of the two sets of eminent cleavage-planes, marks the feldspar exhibited in fig. 4, Plate I.

From Harris (Hebrides) we have a remarkable quartzose feldspathic rock, called "graphic granite" (see Plate I. fig. 5): its feldspar, of a white colour, is in layers (*a*) transversely intersected by striated laminæ (*a*), which alternate with others (*b*) devoid of structure, except occasionally a platy kind. The striæ, which lie at right angles to the boundary-planes of the laminæ, are of the kind called "striping," characteristic of triclinic feldspars*.

This graphic granite also contains layers of quartz (b) alternating with those of the feldspar, the latter being the thickest. The striated laminæ contained in the feldspar layers meet those composed of quartz at a few degrees from a right angle: in the example figured two of the striated laminæ abruptly terminates against a quartz layer.

These three cases, with others that could be adduced, offer a striking similarity to the amorphous and fibrous interlaminations of the Colafirth ophite. The fibrosity, or call it striation,

* We have studied in this connexion the *striping* of feldspars, but without arriving at any satisfactory conclusion as to its nature, save that it may be related to striation and fibrosity. Looking at the fibrous cleavage characteristic of selenite, possibly we have in these different structures modifications of typical mineral cleavage: the stylolitic structure of rocks seems to be another form.

of peridote and feldspar may be safely assumed to be genetically identical with that of chrysotile, taking the incipient variety of the latter into consideration; moreover, we hold it to be in all three a superinduced divisional structure. In short, the fibrous laminæ of peridote and feldspar have as much right to bear a distinctive name as the fibrous allomorph of serpentine.

Reverting to the alternation of two distinct minerals, viz. feldspar and quartz, in the graphic granite of Harris, the case affords a parallel to the interlamellation of the serpentine and calcite in the Archæan ophites, as already noticed. The same phenomenon is also instructively displayed in ared quartzose feldspathic rock from ~~Siberia~~ Astracan, of which a portion is represented under fig. 6, Plate I. The layers of quartz and feldspar exhibit such a definite alternation that in this respect the calcareo-serpentine interlamellation of the "eozoonal" ophi-calcite of Canada does not surpass it. The remarkable character last referred to, which first gave rise to the idea that it is due to organic formation, does not, according to Dr. Dawson, occur in any rock of purely mineral origin; the instances already adduced will show that this is an entirely erroneous statement*. Besides, we are now in a position to demonstrate more clearly our point; Professor Heddle having kindly placed in our hands a remarkably beautiful specimen, from another locality, Tarbert, in Harris, which consists of white quartz and a silvery feldspar (? moonstone), alternating so definitely as to be identical in this respect with the interlamellation of serpentine and calcite in type specimens of "*Eozoon Canadense*" †. No wonder that this lamellar graphic granite has been pronounced to be of organic origin by believers in the eozoonal doctrine ‡!

But it may be urged that in these examples the alternation consists of two siliceous minerals. Granted. Still we are able to dispose of this objection. There is a large specimen from near Vigan, Department du Gard, under a glass shade in the centre of the Geological Museum of the Jardine des Plantes, and another one in a wall-case from the Pic d'Eridlitz, Pyrenees, both consisting of feldspar and calcite definitely interlamellated §.

* See Introduction, A.D. 1879.

† See Plate IX. fig. 3.

‡ See Introduction, A.D. 1876.

§ M. Edouard Jannettaz very kindly showed me the specimens. The Vigan specimen, according to its label, was procured by M. Cordier.—W. K.

And rarely is a good collection of Norway minerals without specimens exhibiting layers of crystalloidal hornblende alternating with others composed of calcite. Specimens of hemithrene, collected by one of us near Dunglow, in Donegal, have the calcite sharply alternating with layers of small crystalloids of idocrase. Interlamellations of calcite and malacolite (serpentine is occasionally present), from Connemara, constitute a variety of what we have called malacolophyte.

It will thus be seen that a lamellar alternation such as characterizes the "laminated variety of *Eozoon*" is not an uncommon rock-phenomenon; also that the interlamellation of a mineral carbonate and a mineral silicate, respectively answering to the "skeleton" and "chamber-casts" of this "fossil," is to be observed in rocks every structure of which is entirely of mineral origin.

Reverting to chrysotile, briefly noticed in the last Chapter, we may be permitted to give a more detailed description of its four stages of modification; for, in doing so, we shall be able to show them in their course of development.

In the *first* stage, chrysotile consists of a layer of serpentine penetrated at right angles to its two surfaces by parallel filiform darkish-coloured lines or cuts; and, though for the most part of uniform length, they are often individually broken into two or more short lengths (Plate IX. fig. 1 *a*). The cuts are more or less separated, with the intervening space consisting of serpentine in its ordinary condition—amorphous, subvitreous, and of a green colour. Occasionally this variety assumes a rude, irregular columnar structure, due, we suspect, to the cuts falling into contact, and ranging themselves into divisional planes, which meet one another at no definite angle: the planes are separated by widish structureless interspaces, which constitute the body of the columns (Plate IX. fig. 2 *a*). Strictly speaking, it cannot be said that chrysotile in either of these states is fibrous—rather that we have examples of chrysotile in its incipient stage of development.

In the *second*, the cuts are indefinitely increased, so that they cause a layer to appear as if it consisted of a dense mass of fibres (resembling those of asbestos—an allomorph of hornblende). The fibres vary in colour from silver-white to a golden hue, and in lustre from silky to metallic (Plate IX.

fig. 1 *b*): it is necessary to mention that they have no definite form as in the case of crystals.

In the *third*, the fibres are comparatively stout, appearing like cylindrical aciculæ; they closely adhere to one another, and are usually of a glistening white colour (Plate IX. fig. 1 *c*).

In the *fourth*, the aciculæ, still retaining their colour, are more or less separated, and the spaces between them are occupied with calcite. Immersed for a short time in a weak solution of hydrochloric acid, a layer of chrysotile in this stage has its calcite dissolved out, leaving the aciculæ separated—thus becoming pectinated (Plate IX. fig. 1 *d*).

It is now necessary to mention that the aciculæ under the two last forms have been taken for organic structures—casts of fine tubuli penetrating the calcite in immediate contact with and covering the spheroids and layers of serpentine. Hence they have been identified with the fine tubulation characteristic of the "nummuline wall" of the Nummuline group of Foraminifera.

Specimens are common showing all the varieties of chrysotile graduating into one another—satisfactorily demonstrating that they are simply modifications of one and the same divisional structure.

But it will be necessary to show how the difference between the second and third stages in the modifications of chrysotile has been produced, also the greater difference which distinguishes the third from the fourth.

In respect to the first difference, the explanation is afforded by the fact, made known by Delesse, that in chrysotile occurring in the Vosges the fibres are swollen and changed to a white colour when exposed to the atmosphere* (thus made acicular) —also by what has already been stated (and to be more fully noticed presently) of the fibres in a specimen of chrysotile from Reichenstein, which are occasionally fused together into solid pillars: in certain cases the original fibrous structure has disappeared.

As regards the second, we hold that it, too, is demonstratively explained by the specimen just referred to. Fig. 1, Plate II., represents a layer of chrysotile between two of serpentine. The specimen, for the purpose under consideration, was placed in a weak solution of hydrochloric acid: *a* represents chrysotile in its typical state; *b*, the same passing into the state of closely-

* Ann. des Mines, sér. 4, t. xviii. p. 328.

adhering aciculæ; d, the latter separated by vacant interspaces, the separations having contained calcite before the specimen was decalcified *: underneath, the chrysotile has been entirely replaced by calcite, (a) except in one place, as where the fibres remain attached to the subjacent layer of serpentine. In another part of the same specimen the chrysotile retains its characteristic features and colour; but some of the layers are brown and porcellaneous, and the fibrous structure is either faint or obliterated. The layers, besides having the fibres (c) changed into aciculæ in close contact, have them forming solid pillars; the fibres are also transformed into aciculæ, individually separated by calcareous interpolations, and passing completely across a layer or only reaching about halfway—appearing, where the interpolated lime is dissolved out, like a fringe hanging from the adjacent surface, and in the same way as they are (*c*) in the instance just noticed.

In all the above cases we have clear demonstrations that the typical "nummuline wall" of "*Eozoon Canadense*" is a pectinated form of chrysotile, and consequently a product of purely inorganic agencies.

To continue, under polarized light serpentine differs importantly from chrysotile. The former in its *ordinary state* shows no bright colours—merely pale yellow, passing, on rotating the analyzer, through light grey, dark or bluish grey, and returning to pale yellow; whereas the latter (beginning with parallel prisms) shows pale green, bright green, purple and blue, dull green, purple and blue (with crossed prisms), crimson, yellow, and green, returning to pale green, each change being variously tinted—the whole reminding one of the still more beautiful colouring got by polarizing peridote. Calcite, which is often associated with chrysotile, shows nothing but different shades of grey; and when intermixed with chrysotile its presence vitiates the bright colours of the latter mineral, turning them into pale yellow and dark grey.

Fig. 2, Plate II., represents a portion of one of three slides received from Canada, specially selected for us, we suspect, by one eminently distinguished for his advocacy of "*Eozoon Canadense*," as proving the organic origin of the structures diagnosed

* A similar case has been noticed by Prof. Heddle in amianthus from Unst, in which "there is generally more or less fibrous calcite between the filaments of the mineral" ('Mineralogical Magazine,' vol. ii. p. 33, March 1878).

for this reputed fossil. The margins of the layers of serpentine, *a*, are each unmistakably converted at the borders into chrysotile. This allomorph, in some of the layers, is characterized with bright colours; but in others, where a calcareous layer is in immediate contact, the fibres are more or less separated, and thus converted into a "nummuline wall," as shown by the dark-coloured lines between them. It will also be observed that the fibres have been abruptly bent where they are acicular, which, though evidently due to pressure, causes them to appear as if they were structures distinct from the chrysotile fibres: this abrupt bending, however, has not always taken place; for it often happens (as occurs in other specimens we have figured*) that such fibres pass into the aciculæ without losing their continuity of direction. In some places the fibres are undulating or curved, as has been observed in numerous instances that have passed under our notice. The serpentine layer on the right-hand side of the figure appears to have been in a fluidal condition, and on consolidation to have become cracked: the cracks are brightly and variously coloured, indicating the presence of another substance (peridote) hereafter to be noticed.

Fig. [illegible], Plate II., represents a portion of a slide from Canada, presented to one of us (T. H. R.) some years ago by Dr. Carpenter. The portion is part of a thick layer of serpentine, bounded on each side by a calcareous layer. The serpentine-layer is transversely intersected by separated and parallel laminæ of chrysotile in its various modifications. Certain of the laminæ have become openly divided; and the resultant opening filled in with calcite. In the instance represented at *a*, the divided lamina we hold to have originally consisted of chrysotile: strictly parallel with the others, its fibres not only graduate into closely-packed and separated aciculæ, but they pass without break of continuity into the latter variety. Moreover the overlying lamina, *b*, is in the condition of incipient chrysotile, consisting of separated lines so finely cut as to be scarcely visible except by polarized light. Obviously the calcite which occupies the opening in the lowest lamina had been introduced; and it is also inferable that the calcitic films between the separated aciculæ are nothing more than infiltrations of the same mineral carbonate.

Although the last is an instance which may be safely accepted

* Proc. Roy. Irish Acad. vol. x. pl. xli. fig. 2, *d*.

as showing how the aciculæ forming the "nummuline wall" of "*Eozoon Canadense*" have originated, we admit, from its position, and from apparently being no more than a mere crack across a "chamber cast," that it cannot be recognized as containing genuine examples of aciculæ belonging to this "wall." It is therefore some feeling of satisfaction to us to find that we are enabled to bring forward a case against which no objections of this kind can be urged.

A number of specimens, some of which have been added to the geological museum of Queen's College, Galway, were lately received by Mr. Damon, F.G.S., of Weymouth, from Principal Dawson, as indisputable examples of "*Eozoon Canadense*," collected in the type locality, Ottawa.

Fig. 2, Plate IX., represents a portion of one of the specimens. It consists of interlamellations of serpentine and calcite in mutual parallelism, the former being often converted entirely, or partly into chrysotile. In many instances a layer of serpentine consists of separated but contiguous laminæ of chrysotile parallel amongst themselves. This parallelism of arrangement between the calcite, serpentine, and chrysotile is the general rule in the present specimens, as it is in others we have at different times brought under notice.

Of the two layers, coloured green in the figure, the undermost one consists—the lower half of colloidal or amorphous serpentine, and the upper half of typical chrysotile: the uppermost layer is composed of what at first sight might be taken for ordinary serpentine, but which, on close examination with powers of 25 and 40 diameters, turns out to be in the state of incipient chrysotile, being traversed by separated fine filiform cuts, which seem to give rise to a columnar structure. The direction (which slightly deviates from the perpendicular) of the cuts and the columns, it is noteworthy, is the same as that taken by the fibres of the underlying chrysotile.

On the left half of the upper surface of the layer containing typical chrysotile may be clearly seen the fibres passing continuously into a series of definite but closely adhering aciculæ, and on the right half into similar aciculæ: here, however, they are distinctly separated by interspaces filled in with calcite. In eozoonal parlance the latter aciculæ are "casts of tubuli" in undisturbed relation to the "intermediate skeleton" and its integral "nummuline wall," just as would be the case when the latter was penetrated by the formative pseudopodial processes of the animal.

We cannot conceive how any impartial investigator, having an acquaintance with mineralogy, and in face of the evidences placed before him, can resist the conclusion that this "nummuline wall" is the product of structural changes *characteristic* of chrysotile. By way of disposing of these evidences, the advocates of "*Eozoon*" have made a leap from Scylla into Charybdis. The "nummuline wall," it is argued, has been altered by crystallization and pseudomorphism, so that it, originally lime, has been converted into chrysotile or its modifications. Nay, our "complicated theory of metamorphism" has actually been adopted by Dr. Dawson to explain this "change of calcite into serpentine" and its allomorph, chrysotile—which change it appears, he has seen in some specimens of "*Eozoon*"*! As to the argument based on the idea that the "nummuline wall" has become accidentally associated with the chrysotile, the fact is of such common occurrence, as are also the concomitant parallelism of the layers showing the two modifications, and the continuity both laterally and lengthwise of their respective aciculæ and fibres, as to completely destroy this and any other argument offered in support of eozoonism, based on these considerations.

A few more remarks on this specimen. Mention has already been made of the serpentine often passing into the flocculent state. In the specimen which has supplied us with the portion last considered, flocculite is rather common in the layers of calcite, filling them here and there (as near the bottom on the left side of the figure), or bordering the serpentine enclosing these layers—occurring therein as simple or segmented clotules, which here and there graduate into configurations varying from the simplest rods to much-divided or branching shapes. It is necessary to mention that both the clotules and configurations enclose portions or cores of serpentine.

The configurations have been taken for casts of tubes penetrating the calcitic layers, and to represent the canal-system present in the calcareous skeleton of certain existing foraminifers. But their characteristic irregularity of form, their gradation into the clotules, and their agreement in composition with the

* See Introduction, A.D. 1875.

latter completely prove that they are a genetically identical series, and of purely mineral origin, having no relation to organic structures. No field-mineralogist can look upon the flocculite without seeing at once that it is disintegrated serpentine undergoing waste or removal, such as may be seen on rocks of this substance where they are exposed to atmospheric action. Now, disintegrating forces (produced, doubtless, by chemical reactions) having set in, the flocculite of itself must necessarily become more or less a prey to dissolution. Hence we feel certain that the configurations, whether simple, or branching in their form, have been etched out of serpentine or flocculite by chemical processes dissolving or removing this substance: in short, they may be confidently pronounced to be nothing more than "*figures de corrosion*" of French mineralogists. The beautiful example of "eozoonal canal-system" given in the right corner of the bottom of our figure, though not exhibiting a complete series of the formative changes, is nevertheless of considerable interest as showing it to be an integral portion of a border of flocculite which is significantly penetrated by extensions or lobes of serpentine from the adjacent parent layer*. Configurations of the kind are generally white and opaque, with a core of green serpentine; but frequently they are colourlessly translucent, as is the case with two or three of the branches in this example.

The process which converted the serpentine into its flocculent variety by entirely removing the latter would affect the plates, lenticuloids, and spheroids, causing their surfaces to be irregularly corroded into hollows and projecting lobes. These bodies are regarded as "casts" of the "chambers of eozoon;" but, holding to the view above given, we have no hesitation in relegating them, in respect of their origin, to the category of mineral structures.

In some instances the flocculite has not been removed (see left side of the figure), but remains as a layer between two other layers of serpentine.

It will be seen hereafter that there is strong presumptive

* The example does not belong to the place in which it is represented, but to one close by: it is truthfully represented in its relation to the adjacent border of flocculite. Another example, represented in a former paper (Proc. Roy. Irish Acad. vol. x. pl. xliii. fig. 7), is an intermediate modification.

evidence that thermal waters aided the assumed chemical reactions.

Having now disposed of all the serpentinous structures of "*Eozoon Canadense*" in strict conformity with the mutations known to characterize the minerals composing them, we shall next offer our explanation of the origin of the calcitic layers which form the "intermediate skeleton" of this reputed fossil.

With respect to the interchanges between a mineral silicate and a mineral carbonate, often obtaining in ophite, we find that the calcite which frequently holds a place in the layers of chrysotile is fibrous in certain instances, and retains the original structure of the latter mineral. Generally, however, the characteristic rhombohedral cleavage of calcite is developed. This replacement of chrysotile by a mineral carbonate retaining its typical fibrosity, and therefore possessing a fibrous structure similar to that of aragonite, has occurred to us in specimens of ophi-euphotide from the north of Italy, as already noticed in one of our previous memoirs*.

We have also become acquainted with a similar fact occurring on the shore east of the Lizard, Cornwall, where serpentinyte, undergoing change, contains layers of different colours—white and red. Some are coarsely fibrous, others amorphous, a few rudely laminated: often the different kinds may be seen passing into one another. It is only of late that we have observed in the euphotide or "Crouza stone" of the Lizard another modification, consisting of dull white, also blue fibrous layers, with occasionally an imperfect platy structure: in many instances the white layers may be observed assuming a silvery lustre and changing into chrysotile. Moreover, specimens of the latter kind, after having been slightly acted upon by dilute hydrochloric acid, show here and there vacant spaces between the fibres, and other evidences of the removal of a mineral carbonate.

The mineral silicate, malacolite or white augite, undergoes similar changes. A variety of ophite occurring in Connemara contains layers formed of crystalloids of this mineral. In most instances, besides being widely gashed, and the gashes filled up with calcite, the crystalloids are separated from one another by the same mineral carbonate; and they exhibit their angles and

* Proc. Roy. Irish Acad. vol. xx. pl. xliv. fig. 9.

edges more or less rounded off, evidently by corrosion. Decalcification exposes these facts most instructively*. The origin the calcite must be obvious to any one who has studied pseudomorphism.

The same phenomenon is displayed, though under somewhat modified circumstances, in the hemithrene ("calcaire saccharoïde," Delesse) of certain localities in the Vosges. At St. Philippe, near Ste. Marie aux Mines, this rock is filled with crystalloids of malacolite and other mineral silicates, often almost to the exclusion of calcite. Confining ourselves for the present to the malacolite, its crystalloids, or aggregations of them, are more or less affected by corrosion or decretion, beginning with the rounding-off of their angles and edges; next, reducing the aggregations, it forms them into rude, irregular, geniculated shapes; and next etches them into somewhat definite configurations—foliaceous, dendritic, plumose, radiate, and often beautifully arborescent. The configurations vary much in size, some being observable with a hand magnifier, others so minute as to be only made out by a good microscope. Fig. 1, Plate III., represents one of the aggregations, which has taken the shape of a branching configuration†: its component crystalloids, in a corroded condition, are well seen.

Guided by a remark made by Delesse, we expressed our suspicion some time ago that the "calcaire saccharoïde" of the Vosges would yield on examination these and other structures ‡; but we had no idea that it was so rich in examples rivalling, and in no way surpassed in beauty and imitativeness, the configurations ("canal system of *Eozoon*") which at that time had become known as occurring in Canadian ophite,—though since then we have published the fact, previously unknown, that precisely the

* Heddle mentions what appear to be similar examples, occurring at Muir and Midstrath, in which the "lime is little more than granular malacolite with but little lime between the crystals" (see Trans. Roy. Soc. Edin. vol. xxviii. p. 461).

† Zirkel has represented a portion of a crystal of mica (fig. 35, p. 87, 'Die mikrosk. Beschaffenheit d. Min. u. Gesteine') which, through corrosion or decretion, has assumed a dendritic or branching form. This example shows very well how crystals and other mineral bodies have taken the remarkably imitative shapes often displayed by malacolite and serpentine.

‡ Quart. Journ. Geol. Soc. vol. xxii. p. 188, footnote. The "nummuline wall" is also present. See Introduction, A.D. 1880.

same bodies are present in hemithrenes from Ceylon, Aker (Södermanland in Sweden), and New Jersey*. The Vosges is an additional locality, which we have only of late become acquainted with.

The question naturally suggests itself as to how the separated aciculæ in pectinated chrysolite, the arborescent configurations in flocculite and malacolite, and the plates, lenticuloids, and spheroids in serpentine have been produced. From the evidence, so far adduced, our view will have been to some extent anticipated—that it is by chemical reagents involving the removal of serpentine or other mineral silicates, and their replacement by calcite or other mineral carbonates.

Chemical changes of the kind, known as pseudomorphism, are not uncommon in the mineral kingdom. They may, for our purpose, be arranged under two heads—*entire* and *partial*. The first consists of cases in which all the original constituents of a mineral having been abstracted, are substituted by other substances; the second consists of cases in which the removal of certain constituents of a mineral, and their replacement by other substances, have taken place.

As an example of the first, crystals are found in Cornwall consisting of cassiterite or oxide of tin; but, instead of representing the form proper to this mineral (viz. a modification of a square prism), they occur under a *false* form—the one that characterizes orthoclase, which is a silicate of alumina and potash: in this instance an entire change of substance has taken place. The second may be illustrated by selenite—a hydrous sulphate of lime, well known as crystallizing in right rhomboidal tabular crystals; but occasionally such solids are found consisting of carbonate of lime, the basic constituent remaining, but the acid and water eliminated, both having been replaced by carbonic acid. Karstenite, an anhydrous sulphate of lime, when converted into selenite, as it often is, is also a partial pseudomorph; though the change has been effected simply by the admission of water †.

* Geological Magazine, vol. x. no. 1, January 1873.

† Because a few cases have occurred of what appears to be one mineral enveloping another without change of crystalline form (*e.g.* prisms of andalusite ferruginated into a substance having the composition of staurolite), Dr. Sterry Hunt has "confidently affirmed that the obvious facts of envelopment," which have led Delesse to limit pseudomorphism, as advocated by

Serpentine, which has never been found in a crystalline form proper to itself, not unfrequently occurs in forms characteristic of other minerals, as peridote, augite, hornblende, chondrodite, phlogopite, garnet, diallage, spinel, feldspar, &c. In the case of a mineral so prone to assume false forms as serpentine is, it might be expected that some of the varieties and related species would also display the like protean character. As cases in point, loganite and picrosmine are pseudomorphs after hornblende; while crystallized rensselaerite and pyrallolite occur in the form of augite.

The opinion that serpentine is in all cases a chemically changed or secondary product involves the idea that its substance is a soluble compound. It is commonly stated, however, that silicate of magnesia, the substance in question minus H_2O, is insoluble—that it is one of "the most stable" compounds*. Hence there are some who assume that serpentine cannot be affected by ordinary chemical reagents.

In denying the solubility of silicate of magnesia, it does not follow that serpentine is also insoluble: besides, in this connexion, there are some other considerations not to be overlooked.

1st. Serpentine is a hydrous silicate of magnesia, generally adulterated with alumina, protoxide of iron, or other accessories (see *antè*, p. 4), the presence of which make it liable to chemical reactions.

2nd †. It has existed under conditions of pressure and temperature capable of materially augmenting the potency of the weakest dissolving agent that may have been in contact with its constituents.

Blum, "are adequate to explain all the cases of association upon which this hypothesis of pseudomorphism by alteration has been based." Moreover, although there may occur occasionally serpentine surrounding a nucleus of peridote, such as led Scheerer to imagine that it "was a case of envelopment of two isomorphous species" (serpentine has no *proper crystalline form of its own*; therefore no other species can be isomorphous with it), it may be regarded as certain, taking the consensus of opinion entertained by the highest authorities, that the frequent *entire* replacement of the latter mineral by the former is solely the result of chemical changes.

* Bischof's 'Chemical and Physical Geology,' vol. ii. p. 113.

† We speak of the condition of serpentine before it became exposed at the earth's surface.

3rd. It has been buried at great depths, and presumably in a somewhat softened condition—thereby rendering it, especially where fibrously divided or intersected by cracks (as it frequently is), an easy prey to dissolving and decomposing agents.

Moreover it is generally admitted by chemical geologists that thermal waters containing carbonic acid, or a carbonate in solution, are present in deep-seated rocks. It must also be considered that the terms soluble and insoluble are merely conventional, being applied to substances only known as such in the laboratory, and that they do not preclude the idea that substances capable of resisting powerful acids at the earth's surface may be unable to resist the weakest when existing under the conditions stated.

Notwithstanding the difficultly soluble character of silicate of magnesia, it has been "proved" by Bischof that an artificial preparation of the kind "when dissolved in water by carbonic acid" is decomposed: he thinks, however, that this "is owing to the silica being in the soluble modification." While "the natural silicate of magnesia (steatite, the silica of which is in the insoluble modification), when finely powdered and suspended in water containing carbonic acid for twenty-four hours, did not show the slightest effervescence"*.

But even absolute *decomposition* of serpentine was proved some thirty years ago by the Professors Rogers, who submitted several mineral silicates (the present one being of the number) to the analytic action of carbonated, and even simple water: the result in every case was a residue of magnesian and other carbonates, showing that decomposition had taken place†.

There is one mineral, peridote, which is frequently converted into serpentine. If it were a pure silicate of magnesia, all that would be required to effect such change would be the hydration of the latter compound; but as it contains a considerable quantity of protoxide of iron, this may have been peroxidized, or changed into a carbonate, in the one case by the addition of oxygen, in the other by carbonic acid contained in the penetrating water, a portion of the magnesia being removed at the same time. The process is so simple as to excite surprise that it has been unnoticed by the advocates of the envelopment doctrine.

* Chem. and Phys. Geology, vol. i. p. 3, vol. iii. p. 164.

† Edinburgh New Philosophical Journal, vol. xlv. pp. 163–168 (1848).

But, having in view the mineral changes which chrysotile and the associated serpentine undergo in the process of developing the separated aciculæ and arborescent configurations of "Eozoon," we are more especially concerned with the fact that these changes have been accompanied by the substitution of calcite for a hydrous silicate of magnesia, *unassociated* with calcium in any form of combination.

A very simple *modus operandi* in this case would effect the substitution, nothing more being required than for water, holding carbonate of lime in solution, to penetrate into the linear openings of the chrysotile and the cracks of the serpentine: a portion of the silica and magnesia of these minerals would be removed in the soluble state, the carbonate of lime taking their place. According to this view, the calcite between the aciculæ in a layer of pectinated chrysotile, also that in which the configurations are imbedded, has been conveyed thereto in solution from an independent or extraneous source—that is, from the calcium silicate common to minerals of metamorphic rocks.

Feldspars, hornblendes, augites, and several other minerals, it is well known, are pseudomorphosed by the carbacidizing of their calcium silicate. Crystals of hornblende occur filled with calcite (Bischof, op. cit. vol. ii. p. 315); labradorite has been found having some of its own constituents replaced by the same mineral; augite is frequently more or less calcitized; it is the same with garnet, epidote, wollastonite, and others. As in most of these cases the pseudomorphs contain more lime than could be yielded by the calcium silicate of the original mineral, it may be assumed that the solvent by which the latter were affected supplied the additional quantity.

Even the minerals forming syenite, diorite, and other rocks, *in situ*, on becoming subject to carbacidizing processes are replaced by calcite.

We have diorite from Jersey: amidst its component hornblende &c. there frequently occur patches of calcite associated with epidote and serpentine. Little or no doubt can be entertained as to the hornblende in this case having supplied the magnesia for the serpentine. It is therefore highly probable that the calcium silicate of the hornblende has been transmuted, through the introduction of carbonic acid, into the associated calcite, especially as there are no limestones nor other calcareous rocks in the island. In one place near Galway, the glacial drift has been broken up, and its finest materials, clay and sand, washed off—leaving a mass of pebbles, cobbles, and large erratics, consisting of granite, syenite, and other rocks, piled up into an esker. This deposit has lately yielded to our examination several pebbles and blocks of syenite, in which are veinlets and isolated patches of calcite, obviously the result of changes effected in the component hornblende and oligoclase,—these minerals, where the calcite is present, being more or less corroded, and having a spongy structure. Minute patches of serpentine associated with the calcite are also occasionally seen. When the calcite has to some extent been removed by dilute acid, there are generally left siliceous bodies in the form of rude arborescent configurations rising out of the remaining calcitic matrix,—in one instance strikingly like those that are common in the cases elsewhere mentioned. Later investigations on the massive diorite, which has been excavated during the past year (1880) in the construction of the new dock in Galway harbour, have yielded us a number of specimens containing calcite in abundance, the secondary origin of which is indisputable.

We have also found very recently *in situ*, near Salt Hill, Galway, a porphyritic feldsyte more or less serpentinous, at a spot where a quarry has been opened in a fruitless search for copper-ore. The serpentine is generally seen lining fissures, often superficially but occasionally to a depth of a few inches: it also occurs in detached pieces of rock lying about. A loose block a cubic foot in size, and altogether serpentinous, was taken out of an adjacent wall. The mass—greyish, brownish, and olive-green in colour, has in some parts quite a soapy feel, an oily lustre, and a coarse fibrous or slickenside-like structure, resembling in these respects baltimorite and pyrosclerite.

These are examples of changes effected by chemical reactions in igneous rocks, certain of whose original mineral substances having undergone replacement by serpentine and calcite*.

We are now, however, trenching on chemical changes that have taken place *in rock-masses*—a subject which properly belongs to the next Chapter.

* Specimens of the examples referred to are deposited in the geological museum of the Queen's College, Galway.

CHAPTER V.

MINERALIZED AND METHYLOSED METAMORPHIC ROCKS.

METAMORPHIC rocks may be divided into two groups—mineralized and methylosed, differing from each other, the one in having had the original substance of its members crystallized into minerals of various kinds, and the other in having had the same minerals altered or replaced by chemical reactions.

The name pseudomorphosis, occasionally applied to the last group, is inappropriate, as the rocks to which it has been given possess no form to be imitated, and therefore no false form is involved. Influenced by this consideration, we have of late years employed the term methylosis in the case of metamorphic rocks which have had more or less of their minerals transmuted*.

Ophites, which we include in the methylosed group, are so intimately related to the mineralized metamorphic rocks, that, in treating of the origin of the latter, the same subject in regard to the former forces itself on our consideration.

Passing over the various views that have been held on the origin of the mineralized metamorphics, from the remarkable one held by Leibnitz in his 'Protogæa' (1717) to the latest, as set forth by Dr. Sterry Hunt †, we propose to consider the latter, it having been contended for with a persistency and an array of argumentation that have won, if not their conviction, seemingly the favourable consideration of many geologists.

* The term *methylosis* (μετα-, change, and ὕλη, substance) was first proposed in my paper "On a Silo-carbacid rock from Ceylon," published in the 'Geological Magazine,' vol. x., January 1873. The term *metasomatosis* (μετασωμάτωσις), applied to the same class of rocks by Von Lasaulx and Knop, is of subsequent date, and had already been employed by myself in a memoir "On the Trimerellidæ" (Quart. Journ. Geol. Soc. No. 118, p. 140, 1874), in which I am associated with Mr. T. Davidson.—W. K.

† The principal views are given by Delesse in his memoirs on metamorphism in the 'Annales des Mines,' sér. 5, t. xii. 1857, &c.

Notwithstanding the weight of authority on the side of Vulcanism, Sterry Hunt maintains what he calls a "novel doctrine," but which seems to be similar to the one taught by Werner, and accepted to some extent by De la Beche and others, —that the vast masses of ancient crystalline rocks known as "Azoic," "Fundamental," "Laurentian," "Eozoic," and "Archæan," have been "directly deposited as chemical precipitates from the seas of the time" *; to be particular, that the Canadian Archæans, comprising granitoid gneisses, syenites, chlorite-, talc-, mica-, and hornblende-schists, and ophites, have had their component minerals (steatite, serpentine, talc, chlorite, phlogopite, augite, hornblende, orthoclase, labradorite, quartz, epidote, and other species †) "formed, not by subsequent metamorphism in deeply buried sediments, but by reactions" ‡, "by a crystallization and molecular rearrangement of chemically formed silicates, generated by chemical processes in waters at the earth's surface" §.

As our reasons have been given elsewhere for decidedly rejecting this doctrine, it being altogether unsupported by acceptable evidences ||, there is no necessity for us to do more on

* Canadian Naturalist, n. s., vol. iii. p. 125 (1866).

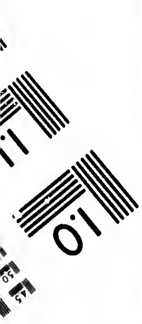
† As hemithrenes are Archæan rocks, calcite, miemite, and some other mineral carbonates ought to be added to the list.

‡ Quart. Journ. Geol. Soc. vol. xxi. p. 70 (1865).

§ Geological Survey of Canada, Report, 1866, p. 230. Sterry Hunt, in the preface (p. 20) of the second edition, 1879 (the latest), of his Chemical and Geological Essays, expresses himself thus:—"The crystalline stratified rocks were originally deposited as, for the most part, chemically formed sediments or precipitates, in which the subsequent changes have been simply molecular, or at most confined to reactions, in certain cases, between the mingled elements of the sediments."

|| See 'Proceedings of the Royal Irish Academy,' vol. x. p. 540. Sterry Hunt has adduced in his favour the existence of Tertiary sepiolyte in the Paris basin and at Vallecas near Madrid, "together with the formation, at the present time, of a hydrous silicate of alumina and magnesia, named neolite, a deposit from the waters in certain mines," and probably resulting from the "decomposition of the magnesian minerals hornblende, augite, and talc." But both cases may be safely set aside as totally inapposite. The sepiolyte, instead of being a "direct chemical precipitate," has been shown by Dr. Sullivan, President of Queen's College, Cork, and Professor J. P. O'Reilly to be a secondary product, due to chemical alteration of the original deposit ('Notes on Spanish Geology,' p. 171, 1863); and as

2.8
2.5
3.2
3.6
2.2
2.0
1.8



1.1
1.0

this occasion than to briefly show that it is totally invalidated by Dr. Hunt's own *dicta*.

Thus, quoting from a lately published exposition of it (in 'Nature,' No. 460, Aug. 22, 1878), we proceed:—"Plutonists begin to understand that water cannot be excluded from rocky strata, but is all-pervading, and that at great depths, kept by pressure in a liquid state at an elevated temperature, and having its solvent powers augmented by alkaline salts, it plays a most important part in metamorphism." Nevertheless, from the absence of any references to the matter, the minerals forming the Archæan stratified crystallines cannot, as *must be understood* from the quotations in the preceding page, have been formed in "deeply-buried sediments" by "subsequent metamorphism," consequent on *their* being "situated at great depths"!

Dr. Hunt continues, "If, as most Neptunists maintain, the great crystalline series have been derived from the alteration of uncrystalline ones, which were not only similar to those of palæozoic and more recent times, but are, in fact, portions of those which in adjacent regions are still known to us in their original unchanged condition, how are we to explain the genesis of the feldspathic and hornblendic rocks which predominate in these crystalline formations? The sandstones and shales from which, on this view, they are supposed to be formed, could never by themselves give rise to the rocks in question, since they are deficient in the alkalies, and to a greater or less extent in the other bases required for the production of the constituent silicates." He further remarks:—"There is no good and sufficient reason for believing in the present existence of any uncrystalline representatives of these crystalline formations, or of any such formation which is not pre-Silurian if not pre-Cambrian in age. There are, however, many examples of local alteration of later sediments by hydrothermal action which have developed in these many crystalline minerals identical with those found in the more ancient rocks."

---

to neolite (which is a very exceptional case), if it have been formed as stated, "through the agency of infiltrating waters" holding its constituents in solution, the great probability is that, so far from their having been precipitated in consequence of "chemical reactions," these constituents would have been deposited, like sinters (stalactitic, calcitic, &c.), by the evaporation of the water.

We certainly cannot admit that "later sediments" are without alkalies; for there are several known cases which testify to the contrary: one, the Taunus slates, contains a large amount of alkalies, "more even than some crystalline rocks, such as trachyte, syenite, granite, &c." *. However, admitting for the moment that these "later sediments" were originally deficient in alkalies, and that in their altered form they contain hornblende with feldspar, mica, and other alkaliferous minerals, we may be permitted to ask What constitutes the force of the last argument? If such minerals can be generated in "later sediments" that have undergone "local alteration" by "hydrothermal action," Why cannot the same action have generated the "identical" minerals which characterize the Archæans of Canada and other regions?

As to the contention that the examples of "later sediments" are nothing more than "local," we do not understand how Sterry Hunt (admitting some of the examples to which he may be referring to be such) can set aside the contrary testimony of the most eminent field geologists (Elie de Beaumont, Bonnard, Froisset, Studer, Delesse, &c.) that in France and Switzerland there are Palæozoic, Triassic, and Jurassic rocks, occupying wide regions, which have been converted into arkoses, crystalline schists, and other rocks containing oligoclase, damourite, sericite, and some other minerals, all of which are rich in alkaline constituents.

It may be, as contended by Gastaldi, Wick, and Baretti, that there are gneisses and various crystalline rocks of pre-Cambrian or pre-Silurian (Archæan) age in the region of the Central Alps. The same may be admitted for the "pre-Carboniferous" gneisses in the Mont-Cenis district. But it does not necessarily follow that there are no rocks of the kind belonging to the Palæozoic and Mesozoic periods in the same areas.

Because Alphonse Favre has detected a specimen pronounced to belong to "*Eozoon Canadense*" in the "calcaire crystallisé associé avec serpentine enclavée dans le gneiss" in the ravine of the Mettenbach on the flanks of the Jungfrau†, Sterry

* Bischof, op. cit. vol. iii. p. 129.

† Rapport sur les travaux de la Société de Physique et d'Histoire naturelle de Genève de Juin 1866 à Mai 1867, p. 282.

Hunt assumes that the rock is Archæan*. Setting aside the question whether a specimen of the kind is of any value in determining the age of a rock†, it may be mentioned that Studer long ago discovered ammonites and belemnites in a similar but less crystalline deposit, lying between gneisses, at Mettenberg near Grindelwald, only a few miles (as the crow flies) from Mettenbach‡.

Hoffmann expressed his astonishment on meeting, at Carrara, with clay-slate, mica- and talc-schists and gneiss, not only following and alternating with saccharoid marble, but passing into and blending with it intimately§. This same marble, which in many places contains or is associated with serpentine, is of Carboniferous age, as is shown, from its fossils, by Coquand and Cocchi. This is no case of "local alteration;" nor is it even pre-Carboniferous. But what shall we say of the vast region stretching from Central Italy far into the "Dolomites" of Tyrol, where similar metamorphosed rocks, containing Triassic and Liassic fossils, are predominant?

It has long been known that in the Mont-Cenis district there are beds more or less altered—talc-schists, ophites, micaceous limestones and saccharoid marbles, intimately associated with beds containing belemnites and infra-Liassic fossils. To those who are wedded to the "novel doctrine," there is no difficulty in their squaring even this case with it. Its author states—they "may correspond to the anhydrites which, with gypsum, dolomite, serpentine and chlorite slate, are met with in the primitive schists of Fahlun in Sweden" ‖ Conceiving it to be "improbable" for such rocks to be "of palæozoic age," as held by Gastaldi and others, he contends for the correctness of his view, that they "are eozoic" ¶ (Laurentian or Archæan).

But even should the infra-Liassic and Jurassic fossils, referred to, be able to recover their inalienable right to stand as witnesses in this case, it would not surprise us, from what may be gathered

* Chemical and Geological Essays, p. 342.

† Structures identical with those regarded as "eozoonal" have been discovered by us in ophite of Jurassic age in the Isle of Skye (see Proc. of the Royal Irish Academy, n. s. vol. i. pt. 2).

‡ Lehrbuch der Physikal-Geographie und Geologie, vol. ii. p. 158.

§ Karsten's Archiv für Mineralogie, vol. vi. p. 258; Bischof, op. cit. vol. iii. p. 142.

‖ Chemical and Geological Essays, p. 336.

¶ Ibid. p. 347.

from the 'Chemical and Geological Essays' (pp. 340, 341), if an attempt should be made to set aside the crystalline character of the rocks in question by teaching that it is not due to metamorphism at all,—in short, that these rocks are no more than the ruins of adjacent pre-existing or Archæan masses, produced by the mechanical degradation, and retaining, with little or no alteration, the original mineral constituents of the latter.

But passing from European metamorphics, we beg to draw attention for a moment to evidences which exist on Dr. Hunt's side of the Atlantic. Referring to "an array of facts," he declares they "lead me to conclude that the whole of our crystalline schists of eastern North America are not only pre-Silurian but pre-Cambrian in age"*. Hence they can only belong to "pre-Cambrian times," when, as he has stated, "there are reasons for believing there prevailed chemical activities dependent upon greater subterranean temperatures, different atmospheric conditions, and abundance of thermal waters"†, presumably exceeding in energy those of later periods. Now, as the metamorphics of Westchester and other neighbouring counties are a portion of the crystallines in question, and lie within the "eastern" region specified, we may safely leave it to Dr. Hunt to uphold his conclusion against the evidences of late years brought forward by Professors J. Hall, J. Dana, and others in support of their determination that the rocks under notice, consisting of mica- and hornblende-schists, hemithrenes, and ophites, similar to those characteristic of true Laurentians, belong to the Upper Cambrian and Lower Silurian periods‡.

It is obviously unnecessary to prolong these remarks; for we have only to appeal to the zone of chlorite and mica schists, gneisses, quartzites, and subcrystalline limestones (Lower Silurian by their fossils), stretching from Sleat in Skye to Loch Eribol in Sutherlandshire, to make palpably erroneous the doctrine that metamorphic rocks on a regional scale have only been developed during pre-Cambrian periods.

* Chem. and Geol. Essays, 2nd edit. p. 276.

† Address Brit. Assoc. Dublin, 1878.

‡ Hall, American Journal of Science, ser. 3, vol. xii. p. 300; Dana, op. cit. ser. 3, vols. xix. & xx.

CHAPTER VI.

WHY SOME METAMORPHIC ROCKS HAVE BEEN MINERALIZED AND OTHERS METHYLOSED.

We adopt the general opinion that all stratified metamorphics have been in the first instance aqueous sediments, and that heated water has been concerned in developing their present features. Moreover we assume, though without knowing whether others are of the same opinion, that, before their metamorphism took place, these aqueous sediments retained more or less of the water they originally contained, and that, on their becoming buried at great depths, where necessarily an elevated temperature and other favourable conditions prevailed, this original water played a part in mineralizing them*.

Adhering to the foregoing as postulates, and limiting ourselves to a well-known case in point, we offer it as our opinion that the Archæan argillytes, sandstones, &c. became mineralized, when at great depths, by means of the water they were originally charged with, and in consequence of the high temperature and great pressure under which they were placed.

As the water in such cases must have extended over vast areas, its action has necessarily been on a regional scale.

Although, on our view, mineralized metamorphism has been effected to an important extent by the intervention of water, it must be admitted that the evidences are not very abundant; for the resulting minerals are wholly anhydrous. The strongest evidence consists in the presence of liquid bubbles (well known from the researches of Sorby, Zirkel, Allport, and others, as occupying cavities) in the quartz, feldspar, and other minerals characteristic of the mineralized metamorphics†.

* It was to be expected that Scheerer, who advocates the aqueous origin of granite, would make this rock to contain its "primitive water."

† Natrolite, talc, chlorite, and other hydrous minerals in granite, accord-

The anhydrous character of the minerals referred to seems to favour the idea that heat and pressure, more than water, have been the agents in effecting the change we have assumed. On this account the change may be termed xerothermal, particularly as the aquosity of the rocks in question seems to be but slightly more than would be an accompaniment of dry heat.

The methylosed section, there can be little or no doubt, has been largely under the influence of water; for a great portion of the minerals composing its members are more or less hydrous. This fact, and a number of relevant considerations, warrant us in assuming it to be extremely probable that water derived from extraneous or foreign sources, as seas and lakes, has copiously permeated mineralized rocks,—thus giving rise to various chemical reactions within them, ending in their methylosis. The change produced in methylosed rocks, compared with that which has taken place in the mineralized section, justifies the use of the generally adopted term hydrothermal*.

Since the important discoveries made by Daubrée, showing that various minerals (zeolites, hyalite, calcite, diopside, &c.) have been developed among the bricks and mortar of the old concrete work of the Roman baths at Plombières, in the Vosges, through the action of subterranean alkaline water, with a temperature of from 59° to 172¼° F.†, it can no longer be held as an unwarranted assumption that similar chemical changes have been effected in rocks through the latter becoming saturated with superadded heated watery solutions‡.

---

ing to Sterry Hunt, show that water was not excluded from the original granite paste (Chem. & Geol. Essays, p. 5). We regard these minerals as of secondary origin, resulting from the admission of water into the granite after its formation.

* We find that Bunsen has designated this change *hydatothermic*, and its opposite *pyrocaustic*.

† Ann. des Mines, 1858, &c.

‡ Daubrée has already suggested that the water mechanically contained in rocks, commonly termed quarry-water ("eau de carrière"), appears to be all that is required to develop, when assisted by heat, very energetic action (Quart. Journn. Geol. Soc. vol. xvii. p. xlix).

CHAPTER VII.

THE METHYLOTIC ORIGIN OF OPHITES.

With respect to the rocks now entered upon, we have evidences in the pseudomorphic origin of their essential mineral, serpentine, that something more than ordinary metamorphism has been concerned in developing their present chemical characters.

According to Bischof, "When pseudomorphs show that a mineral, B, may originate from another mineral A, it is possible that, under suitable conditions, all minerals corresponding to A, may undergo such an alteration in the rock where they occur. This may be the case even where the former mineral is not in a crystalline state, but exists in the rock as an amorphous mass"*. Hence, as serpentine is always the product of chemical change, it follows that a rock, when it is entirely or essentially composed of this mineral, must have had a pseudomorphic or, more properly speaking, a methylotic origin.

This doctrine, applied to ophite, has been decidedly opposed by Sterry Hunt, who, having rejected the pseudomorphic origin of serpentine, both as a mineral and a rock, maintains that, in the latter case, it is a chemical precipitate, like the gneisses and other metamorphics usually associated with it. On the contrary, it is seldom that any other mineralogical geologist speaks of serpentine or ophite otherwise than as being a product of chemical alteration.

Blum considered there was good reason for believing all serpentine rocks, including their contained minerals, to be of this origin. Referring to the presence of pseudomorphs after augite at Monzoni, in the Tyrol, he states "it is not merely the

* Chem. & Phys. Geology, Engl. ed. vol. iii. pp. 65, 66.

fine augite crystals (fassaite) which occur, mixed with calc-spar, in the drusy cavities and fissures, but the whole mass of the rock is converted into serpentine"*.

The change of bedded diorite into serpentine, in the Saxon Voigtland, led Breithaupt to suggest that the latter is the result of an alteration of the former.

Gustaf Rose and Bischof even went so far as to maintain that serpentine may have originated not only from the most widely diverse minerals, but from widely different kinds of rock†. Evidences favouring or demonstrating this conclusion have been made known by Blum, H. Müller, Naumann, Bernard von Cotta, Fallon, Delesse, F. Sandberger, Allport, Cunninghame, Heddle, Bonney, and others. The Galway examples we have cited induce us to take the same view.

Sedgwick declared that he was "disposed to consider certain varieties of serpentine as a modification of diallage rock, rather than a formation distinct from it"‡. Sedgwick, no doubt, included the serpentinyte of the Lizard in this view; and we should readily have agreed with him as to the character of this rock, but for the fact that what seems to have been taken for diallage we have shown to be pseudomorphic after crystals of common black augite§.

The fact, also stated by us, that the Lizard serpentinyte closely agrees in its porphyritic structure with the dolerite (wakite or melaphyre) of Bufaure, in the Tyrol, inclines us strongly to the view that the former was originally a rock similar to the latter.

Moreover we are prevented from agreeing with the Rev. Prof. Bonney, who, though tacitly adopting our view as to the methylotic origin of the Lizard rock, concludes, from finding it to contain what he regards as enstatite (which we take to be the pseudomorphs named above) and peridote, that it is an altered mass corresponding to lherzolite‖.

Other testimonies in favour of the methylotic origin of ophites have of late years appeared. Professor Heddle, who has lately

* Bischof, Chemical and Physical Geology, vol. ii. p. 322.

† Ibid. vol. ii. p. 417.

‡ Trans. Cambridge Phil. Soc. vol. i. p. 321 (1821-22).

§ London and Edinburgh Phil. Mag. ser. 5, vol. i. pl. 2. fig. 2. See also concluding portion of Chapter III. and footnote †.

‖ Quart. Journ. Geol. Soc. vol. xxxiii. p. 921, &c.

published some important and reliable details on the phenomena in question in his fourth chapter on "the Mineralogy of Scotland," thus expresses himself:—"All the serpentines of Scotland which I have had opportunities of properly studying are metamorphic rocks, formed for the most part by a change of angitic and hornblendic rocks—as diallage, euphotide, and diorite.

"The serpentines of Unst in Shetland are derived from diallage. Of the two beds to the west of Portsoy, the first from gabbro, the latter apparently from euphotide; the beds to the east, from a rock chiefly augitic.

"The peculiar structure of the serpentine of the hill of Towanrieff would lead to the conclusion that gneiss was the original; but the nearest rock is a laminated diorite, composed of labradorite and black mica. Though these conclusions are chiefly the result of geognostic observations of the district, there are many localities where the transition may be traced through a gradual change in the minerals composing the rock. Such comparatively molecular transformation may be well studied on the north shore of Swinaness, in Unst, in several places in the neighbourhood of Portsoy, on the north side of the hill of Towanrieff, and on the northern slopes of the Green Hill of Strathdon. At the last-mentioned locality there may be obtained unaltered, or apparently unaltered, diorite;—the same with the hornblende duller in lustre and softer than normal, and the felspar dull, semi-opaque, and of a greasy lustre;—and lastly, almost perfectly formed serpentine, in which, however, the granular structure of the altered rock is plainly visible. These three occur within the space of a few feet of each other. It is not, however, easy to select for analysis, from rocks—the several crypto-crystalline ingredients of which give way to the transmuting agent at different periods of time—specimens at once typical and sufficiently pure. I have met with more success in this direction in working among the serpentinous marbles—those which contain imbedded granules or patches of serpentine—than I have among the larger masses of the serpentine rock itself.

"One fact I would direct attention to, seeing that it has perhaps not been clearly enough considered, namely, that great beds of serpentine must have been formed by the metamorphism of pre-existent rocks as a whole; that although the change took place step by step, one ingredient giving way before another, still, ultimately, all participated more or less thoroughly in the change. The molecular or crypto-crystalline transformation had thus as its result a lithological transmutation. To be more precise, where a great bed of diallage rock has been converted into serpentine, the felspar as well as the augite has gone to form the latter. This magnesian metamorphosis of labradorite does not seem to have been sufficiently recognized; but though the general rule is that the augitic mineral is the first which suffers alteration, there are localities in which the felspar would seem to have been first affected. It is true, that in many cases the felspar may not have been converted into true serpentine, but merely into an impure kaolin, which, disseminated throughout a serpentinous basis, may defy individual recognition, from the similitude of kaolin to serpentine itself. Such an intermixture may account for the large quantity of alumina in some serpentinous rocks; indeed, any serpentine rock which contains much alumina may be held to have originated from a primary rock, of which one or other of the felspars was an ingredient"*.

Some years ago Mr. G. H. Kinahan, District Surveyor of the Geological Survey of Ireland, directed our attention to some interesting points in the geology of South Cannaver Island, in Lough Corrib, which "show the gradual change of hornblendic rocks into serpentine." Since then he has published a brief notice of the island in the 'Explanation to accompany Sheet 95 of the Map of the Geological Survey of Ireland,' p. 33 (1870).

Having examined this island, we fully agree with Mr. Kinahan in the view he has taken of this case. Much of it undoubtedly consists of "metamorphic irruptive rocks;" and the one with which we are more particularly concerned was undoubtedly a hornblendic mineral *en masse* before it assumed its present character.

Plate VII. represents a specimen, now a dark olive-green serpentine, having a well-developed crystalline structure. Plate VIII. represents a specimen of grey tremolite, a variety

* Trans. Royal Society of Edinburgh, 1878, vol. xxviii. pp. 491, 492.

of hornblende, from St. Gothard*. There is nothing by which the eye can detect a difference between these specimens, except colour†: both consist, for the most part, of bundles of slender radiating prisms, with frayed-out or divided terminations and a distant transverse cleavage; and so strikingly alike are the specimens as to make the one appear as if it were a *facsimile* of the other.

No clearer proof of the pseudomorphosis of serpentine after tremolite could be adduced; nor could a more decisive case be brought forward showing a dioritic rock methylosed into ophite‡.

Of late years there has been a growing disposition among geologists to look favourably on the view that ophite, or its essential component, serpentine, has originated from peridote or from rocks (peridolytes) rich in this mineral. F. Sandberger, G. Tschermak, Zirkel, and Bonney may be classed in this school. It cannot be denied that the common occurrence at Snarum of pseudomorphs of serpentine after peridote, and the frequent association of the two minerals in other places, may be taken as good evidence in favour of this view; but it would be just as reasonable to assume that basalt, because it usually contains a large proportion of peridote, was generated out of masses of this mineral.

Zirkel has noticed, in a precited memoir, the occurrence of "small, roundish, sharply defined crystalloids of serpentine" in the "crystalline limestone" or hemithrene of Aker and Sala in Sweden, Snarum and Modum in Norway, Pargas in Lapland, and Lough Derryclare in Connemara; and he maintains that they are the product of alteration in peridote, this mineral often being present in the crystalloids as a core.

We shall endeavour to show in another Chapter that peridote is as much a secondary product as serpentine, and that, on this

* According to Damour (Bischof, Chem. and Phys. Geol. vol. ii. p. 348), the St.-Gothard tremolite consists of SiO_2 58·07, MgO 24·46, CaO 12·99, FeO 1·82.

† In some instances the prisms retain their original colour.

‡ Mr. Frank Rutley, who takes this to be a serpentinous rock, states that some of the long radiating crystals it contains "display magnificent variegations of colour under polarized light" ('The Study of Rocks,' p. 131). Sections examined by us show nothing more than the colours of ordinary serpentine: probably Mr. Rutley's case contains peridotic matter.

view, it has been generated out of minerals containing silicate of magnesia and oxide of iron, such as hornblende and augite: it is rocks composed of minerals of the kind, and which are frequently methylosed, that form the principal repositories of peridote. We feel certain that Zirkel will not be able to explain the origin of the "crystalline limestone" which encloses the pseudomorphosed crystalloids without availing himself of the aid of methylotic processes. Moreover it may be considered that the presence of peridote in rocks which have undergone chemical changes is a barrier to this mineral being regarded otherwise than as a concomitant product of such changes.

For our part, we are acquainted with sufficient evidence to sustain us in the conclusion that serpentine, instead of originating from any one mineral in particular, is polygenetic. The numerous examples we have lately found around Galway (and their number increases by every fresh examination) of serpentinized granite, diorite, porphyry, and feldsyte, may be safely accepted as completely confirming the view, held by Rose and Bischof, that serpentine may be generated out of widely different rocks and minerals, admitting at the same time the magnesian constituent to have been derived from foreign sources.

We are even not averse to the view that serpentine or ophite, hitherto limited in its derivation to silacid rocks, has in some instances been produced from chemical changes in carbacid deposits. From what may be observed in the dolomitic limestone in immediate contact with the diorite of Conzocoli (at which junction, a few hundred feet up on the flanks of this mountain, one may sit on both rocks at the same time), near Predazzo, no doubt can prevail that the layers and patches of serpentine present in the limestone are a local development, due to discharges of silica, in some form or other, from the adjacent igneous rock*.

This is the only instance that has come under our notice of a

* On a former occasion we made known that the Isle-of-Skye Jurassic ophite is in some places, as near Torrin, lamellated with the same mineral substances, and in a similar style, as "eozoonal" ophite: specimens collected by one of us at the Conzocoli junction are precisely similar. It is noteworthy that the serpentine is occasionally replaced by a mineral substance, seemingly loganite (as at Burgess in Canada), the latter occurring interlamellated with hydrous dolomite (predazzite).

carbacid rock having become serpentinized, unless it be the "*oficalces*" that hang on to the dykes of euphotide, and the adjoining disrupted beds of alberese limestone, in different places between Genoa and Spezzia.

In this connexion it may be remarked that such instances may be taken to support the view, held by J. Dana, that the Westchester hemithrenes were originally limestones, and have since been impregnated with silicic acid.

Another idea as to the origin of ophitic rocks was broached by the late Prof. R. Harkness. It is thus expressed:—"The serpentinous limestones of Connemara are of local occurrence; they usually appear in such districts as exhibit the strata highly contorted and broken up. The lines of lamination in the limestone strata have been opened, and the laminæ have been fractured across, in consequence of the contortions to which the strata have been subjected; and into these openings and fractures the serpentine has been subsequently introduced. . . . In the calcareous band which lies east of Lisoughter, and which extends to near Oughterard, the laminæ have not been opened and broken by contortions; and from it the serpentine is absent"*. This hypothesis, which appears to us to be more ingenious than sound, we consider is based on insufficient data obtainable in the field and the cabinet.

* Quart. Journ. Geol. Soc. vol. xxii. pp. 509 & 511.

CHAPTER VIII.

SERPENTINIZATION EFFECTED IN DEPOSITS WITHOUT THE INTERVENTION OF MINERALIZATION.

As certain formations, such as coal, anthracite, dolomite *, &c., are methylosed products, and nevertheless possess no evidence of their having been otherwise than in the ordinary amorphous rock-condition, it may be fairly expected that there are formations, closely related to the ophites, which have undergone chemical changes without having been previously mineralized. Many argillytes are known to contain silicate of magnesia, which makes them more or less steatitic, talcose, chloritic, or serpentinous, against which objections might be raised as to their being alloeated amongst typical ophites.

Mr. J. Arthur Phillips has made known several cases of Cornish "killas," which, through a decrease of alumina and an addition of magnesia, departs from its normal condition, and passes into a substance approaching to ophite †. In these cases the rock approximately retains its original amorphous condition, having, in most cases, little more than the ordinary texture of slate or argillyte. Some of the agalmatolytes have all the appearance of being similarly magnesiated formations.

There seems to be no reason, then, why the serpentization of killas, or any other argillaceous rock, may not become so far advanced as to convert it into an ophite. We are, accordingly, led to conclude that certain rocks of the kind,

* Beds of argillaceous limestone are occasionally converted, as in Derbyshire and other places, into rottenstone (essentially aluminous) through their calcareous portion having been removed by water containing carbonic acid. And much of the alabaster of Northern Italy, the Tyrol, and the Thuringerwald may be methylosed limestone; but in this case sulphuric acid and water have replaced carbonic acid.

† Philosophical Magazine, 4th ser. vol. xli. pp. 87-106 (Feb. 1871).

originally argillaceous, have passed directly from the earthy condition into their present form. "A very homogeneous slate, from the Villa Rota, on the Po, was found by Delesse to have a composition so closely resembling serpentine, that it might be regarded as schistose serpentine"*.

But a more decisive case may be predicated of one lately made known by Achiardi of Pisa, occurring at Podermo in Tuscany: it consists of argillaceous schist methylosed into a green translucent serpentine by the action of subterraneous water holding magnesia in solution, this substance having gradually replaced the alumina of the schist †. Delesse, who has noticed the case, mentions that he has observed a similar change at Odern in the Vosges ‡.

The hydrous silo-magnesian marl, sepiolyte (classified by some writers with the minerals aphrodite, talc, spadaite, and others, but differing from them mainly in containing more water), which occurs as a Tertiary deposit in the Paris basin, and at Vallecas near Madrid, is another instance of a formation which, although it has undergone a chemical change §, still retains its original earthy or amorphous condition.

Reverting to the case made known by Achiardi, it may be mentioned that Bischof has shown, from the presence of chloride of magnesium in the water of many springs, that "the formation of silicate of magnesia may take place by the action of such water upon silicate of alumina in the form either of *clay* or compound silicates" ||.

* Bischof, *op. cit.* vol. ii. p. 416.

† R. Com. Geol. d'Italia, Bollettino, 1876, p. 11.

‡ Revue de Géologie, 1878, p. 191.

§ See footnote, p. 28.

|| Chemical and Physical Geology, vol. i. p. 344, and vol. ii. p. 107.

CHAPTER IX.

MANY OPHITES WERE SEDIMENTS, AND OTHERS IGNEOUS ROCKS ORIGINALLY.

UNTIL the discovery of stratified ophites in the Laurentian series of Canada, few geologists thought otherwise than that the rocks under consideration were of igneous origin. Most of the ophites known on the Continent favoured this view; and, notwithstanding their mineral and plainly bedded characters, the ophi-calcites of Connemara, it was conceived, were no more sedimentary than the whin-sills of the north of England and other stratified dolerites.

The discovery that the Canadian ophites were the products of sedimentation, it may well be imagined, greatly perturbed the opinion which had prevailed previously.

It next behoves us to mention that for many years before Canada had been geologically surveyed, mineralogists, through the researches of Blum and others, had become acquainted with the fact that serpentine, the essential mineral of the rocks in question, is a product of the chemical alteration of other minerals. Still few geologists seemed to appreciate in full the bearing of this fact upon rock-masses of serpentine.

Again, the discovery of the presumed organic structures in the Canadian ophites by Logan, Dawson, and Carpenter, was generally admitted to be a fatal blow to both the igneous and the chemical-alteration theories.

The evidences educed by our investigations connected with the last-mentioned discovery, however, have unexpectedly led to conclusions totally different from those which originated in the Canadian school of geologists. What has already been stated makes it quite unnecessary to dwell further on this point: suffice it to say, that the conclusion we have adopted as to the origin of ophites is the same as the one foreshadowed by the results which attended the labours of Blum and others on mineral pseudomorphism.

Having already noticed in detail the ophites of sedimentary origin, we shall merely make a few brief remarks on those which were originally ordinary igneous rocks.

As seemingly favourable to the general view formerly held respecting the origin of the Connemara ophites, our attention, as already stated, was called some years since to the occurrence of the Cannaver serpentinyte under circumstances demonstrative of its being an "irruptive rock" that had undergone metamorphism. We agree with Mr. Kinahan in this view; for, whether originally consisting of tremolite or common diorite, the rock, which must be regarded as having been igneous in the first instance, has become changed, through methylosis, into a mass of serpentine*.

In 1876, after an examination of the Lizard in Cornwall, we showed in a precited memoir that the serpentinyte occurring there was originally an igneous rock, related to the porphyritic wackite or dolerite of Bufaure.

Continental geologists have been largely influenced in their belief as to the origin of ophites by the occurrence of rocks of the kind, in the form of dykes, in Northern and Central Italy and other countries. At Prato, Impruneta, Volterra, &c., in the Bay of Spezzia and the adjacent districts, euphotides, dolerites, and other eruptive masses are more or less serpentinized into ophites; so that the Chevalier Jervis, in stating that the latter are direct igneous products, expresses the opinion prevalent among Italian geologists †.

Allport, whose microscopic researches among the basaltic dykes of England, Scotland, and Ireland have done much to establish the pseudomorphic origin of serpentine as a mineral, has brought forward numerous evidences which equally show that these masses are convertible into ophites.

Dr. Heddle, one of the latest writers on the subject, has made it clear, as previously noticed, that many of the ophites of Scotland were originally true igneous rocks.

But for the eozoonal school it would seem superfluous to add that the fact of some ophites having been originally *sedimentary*, and others *igneous*, may be held to demonstrate that in both kinds of rocks their *mineralogical identity* can only be due to one and the same causation, methylosis.

* The terms eruptive and igneous are to be taken in a conventional sense, as applying to rocks *not* of sedimentary origin.

† Mineral Resources of Central Italy, chap. iii. 1868.

CHAPTER X.

THE METHYLOTIC ORIGIN OF HEMITHRENES AND OTHER RELATED CALCITIC ROCKS.

In Norway there are in several places, associated with metamorphic rocks, crystalline calcareous masses, called by Scandinavian geologists "urkalk" or primary limestone. Besides containing a large number of rare and interesting minerals well developed, it is highly charged with ordinary mineral silicates, often minute or microscopic, and distributed throughout the calcareous matrix. Urkalk is thus a mixed metamorphic rock, consisting of mineral silicates and mineral carbonates; and in this respect it answers to the hemithrenes and calciphyres, respectively hornblendic ("amphibolique") and augitic ("pyroxénique"), of Alexander Brongniart*.

Having paid some attention to rocks of the kind, we are of opinion that the distinction formulated by Brongniart cannot be maintained for practical purposes; we therefore prefer including them in one group, retaining for it the name hemithrene, this being the first introduced by the author in his 'Classification et caractères minéralogiques des Roches homogènes et hétérogènes' (Paris, 1822).

We have already shown that calcite has supplanted minerals which do not contain a trace of carbonate of lime. As pseudomorphs are developed from the change in question, it may be legitimately inferred that if a certain rock-forming mineral silicate, say augite, has the substance of its crystals replaced by calcite, there can be no reason why a rock essentially composed of the same mineral, and occurring under suitable conditions, cannot become calcitized. Bischof, it would appear, was not averse to this view; for in speaking of granular limestone or

* The name akerlyte was proposed for these rocks in my paper already referred to; but, from what is stated in the text, my colleague and I feel it right to adopt Brongniart's earlier name in preference.—W. K.

saccharoid marble when it occurs as "subordinate beds in crystalline slates," he considers that in this case "the carbonate of lime may have originated from the decomposition of calcareous silicates"*, which, it must be understood, are frequently present in the latter rocks.

That such cases have already been made known by Scheerer, Delesse, and others, though their origin has not been rightly understood, seems highly probable.

Leonard Horner, in his Presidential Address to the Geological Society, 1861, remarked that "many instances have been met with of granular limestone occurring under circumstances that can only be explained by supposing them to have had a subterranean origin." Besides other instances, which Horner might have had in his recollection, probably the following, cited from MacCulloch, was not unknown to him: it consists of an "irregular or nodular mass of limestone (pink coccolite marble) enclosed in gneiss without any connexion or continuity"†.

Recently, Professor Heddle, referring to the "primary limestones" of Shetland, has stated that they are "often very obscurely or imperfectly stratified, while occasionally they show no marks of that deposition, but rather seem to form, like serpentine, large imbedded shapeless masses, or huge irregular nodules"‡.

Selwyn, speaking of the dolomites and limestones associated with the "diorites, dolerites, amygdaloids, and volcanic agglomerates," presumed to belong to the Lévis division of the Quebec rocks in Canada, has lately remarked that they "have much more the appearance of great lenticular, vein-like, calcareous masses than of beds belonging to the stratification"§.

Putting aside a number of cases which could be adduced from different writers, we shall confine ourselves to a few with which our personal observations have made us intimately acquainted.

In the summer of 1877, F. Twining, Esq., of Cleggan Tower, north of Clifden, Connemara, drew our attention to a dyke (not marked on the map of the district by the Irish Geological Survey, which had just been published) on the north shore of Cleggan Bay, immediately adjacent to a small rocky islet or,

* Chem. & Phys. Geology, vol. iii. p. 140.

† Western Islands of Scotland, vol. i. p. 48 (1819).

‡ The Mineralogical Magazine, vol. ii. p. 118 (September 1878).

§ Canadian Naturalist, vol. ix. p. 24 (February 24, 1879).

rather, promontory (called Glassillaun), separated from the mainland by a ditch-like channel, containing water only at high tide.

The rocks of the locality are well-bedded metamorphics, slightly developed as such, consisting of quartzites, micaceous and hornblendic schists: they dip to the north at an angle of 60°, and strike east and west. Here and there they possess some exceptional features.

Plate IV. represents a ground-plan, and Plate V. a natural vertical section of this case. The dyke, which is 20 feet wide, intersects somewhat obliquely the metamorphics at the head of a small cove or inlet in a north and south direction. It is seen in the face of the cliff, which is about 20 feet in height; thence it passes southward into the sea. The cove is bounded on its east side by a narrow projecting mass of rock, and on its west by Glassillaun and a portion of the mainland.

The dyke, of a dark grey or nearly black colour, and finely crystalline in structure, consists essentially of the mineral silicates—augite (or hornblende)—in long crystals, a granular feldspar (possibly labradorite), and a platy one looking like orthoclase. A little magnetite is also present. Calcite often occupies narrow interspaces between the siliceous minerals, causing the rock, on the application of a weak acid, to effervesce slightly.

The metamorphics of the promontory, principally of the kind common on the adjacent mainland, are strongly bedded, with indications of lamellation; but in certain places immediately adjoining the dyke the beds become changed into bands and intrusive-like masses, distinctly striped with green and pale brown (due to the alternation of layers respectively distinguished by these colours), and varying from an eighth to an inch or more in thickness. The ditch-like channel was at one time entirely occupied by one of the bands; but, owing to the softness of its component layers, the band has been in great part washed out, and an open separation has taken its place. On the east side of the cove the same striped rock is also seen, but in small portions, enclosed, as it were, in the gneiss, into the bedding of which the layers pass uninterruptedly: on the west side it forms intrusive-like masses, which pass imperceptibly, occasionally abruptly, into the adjacent gneiss; but their striping is in some places strikingly undulated, and appears to be independent of the lamellation of the gneiss.

Examined by the microscope, the green layers are seen to consist of flattened radiating tufts of tremolite and long crystals of hornblende, both tufts and crystals lying with their long axis parallel to the lamination. Intermixed with these minerals are peridote (beautiful in its colouring), serpentine in grains and flattened lumps, a variety of the latter (apparently pyrosclerite) forming veinlets, and chlorite in small quantity; the latter mineral, however, is abundant in some specimens, associated with serpentine. The pale brown layers consist of malacolite, a striped feldspar, and calcite. The malacolite, translucent and opaque, is in different-sized crystalloids confusedly aggregated: those that are opaque have usually a flocculent coat; while their angles and edges are more or less rounded, giving rise to interspaces, which are filled with calcite: occasionally the calcite increases to such an extent as to form thin layers, deviously dividing those of the malacolite; and where this happens the crystalloids of the latter mineral are greatly eroded and reduced in size. The calcite is decidedly more abundant in these layers than in those consisting of tremolite &c. Grains and granular aggregations of serpentine, occasionally intermixed with tremolite, are also present in the former.

Thus the Glassillaun rock is an intimate mixture of mineral silicates and a mineral carbonate; and as such it must be considered to be a true hemithrene.

Mr. Twining's observations, kindly made at our desire, make the promontory 200 feet in width, and projecting 40 feet into the water at high tide. The hemithrene occupying the ditch-like channel becomes on the west side of the promontory a more dilated mass, much of which, except at the edge of the cliff, is obscured by a growth of seaweed, boulders, and beach-sand.

An opportunity will occur hereafter, enabling us to account for the presence of peridote in methylosed rocks; we may therefore confine ourselves to the serpentine and calcite of the hemithrene in this instance. The serpentine is so associated with the tremolite as to make it evident that the former has resulted from chemical changes effected in the latter: and there is nothing more certain than that the calcite stands in the same relation to the malacolite.

That water has accompanied the changes is proved by the presence of serpentine in the hemithrene; and the fact that calcite occurs in the dyke may be taken as positive evidence that this mass has also to some extent undergone a chemical transmutation. In short, we feel it a safe conclusion that the change in both rocks is due to their having been penetrated by heated water containing a carbonate or carbonic acid in solution*.

In addition to the important evidence which the hemithrene of Mont Saint-Philippe has afforded in connexion with the chemical changes effected in minerals, we have next to make known some facts from the same place which bear directly on the matter under consideration.

The region of the Vosges, which embraces Wisembach, Chippal near Croix-aux-Mines, Laveline, Gemaingoutte, and Mt. St.-Philippe near Sainte Marie-aux-Mines (Haut-Rhin), consists principally of gneiss, with here and there intrusive masses of igneous rocks (syenites and dolerites); but in the places named there is a development of hemithren

A large quarry of this rock ("calcaire saccharoïde") is worked at St.-Philippe. It is a nearly rectangular excavation, about 60 or 70 paces long, 30 paces wide, and 15 feet in depth. The rock, of a highly crystalline character, is for the most part well stratified, as is also the associated gneiss: both dip in the same direction (south-east), at an angle of about 20°. The hemithrene, light in colour, is more or less charged with pyroselerite, chiefly in granules; and the same mineral occurs, but rarely, in the immediately adjacent portions of the gneiss. The pyroselerite and other mineral silicates, as previously notified, are irregularly intermixed with calcite; but very often the different kinds (carbonates and silicates) are disposed in layers: on account of the latter arrangement the beds have assumed a laminated structure. The lamination is often irregular, being variously undulated, and separating here and there through the interposition of compressed lumps which consist internally of a white granular or

* Quart. Journ. Geol. Soc. vol. xvii. p. lviii. A short time ago Brœgger and Reusch observed at Hiasen, in Norway, "a vein of hornblende changed into a mass of calcspar" (Canadian Naturalist, n. s. vol. viii. p. 430). Both this case and the calcified doleritic dyke at Cleggan may be taken to prove that the well-known calcitic dyke, traversing metamorphic rocks near Auerbach in Bergstrasse, first described by Von Œynhausen more than fifty years ago, was originally a silicid igneous mass, and since converted into hemithrene: its accessory minerals (hornblende, tremolite, idocrase, wollastonite, epidote, and the like) favour this view.

amorphous mineral, considered by Delesse to be feldspathic and related to hälleflinta: this part passes insensibly into a coat of pyrosclerite; and the latter is surrounded by phlogopite. These lumps have consequently a concentric structure.

The gneiss, dark in colour, consists of layers of opaque orthoclase, translucent plagioclase, dark bronzy mica, and dark green hornblende: quartz is more or less irregularly intermixed with these minerals; also, as accessories, garnet, pyrites, graphite, and sphene. Where the gneiss and hemithrene are in immediate contact, their respective minerals are intermixed; nevertheless both rocks are well differentiated, and readily distinguished from one another. The hornblende unmistakably changes into pyrosclerite, as is also the case with the augite; and the least reflection must make it clear that the two minerals plagioclase and malacolite have contributed to produce the calcite: besides, according to Delesse, the dark bronzy mica of the gneiss has become magnesiated into the lighter-coloured phlogopite which characterizes the hemithrene. Moreover it is highly probable that the calcite, where it is the dominant constituent, has been increased by carbonate of lime brought in by water from extraneous sources.

Figure 1, Plate VI., represents a section, about 13 feet in height, showing the gneiss and hemithrene in contact, as seen on the right-hand side of the quarry near its entrance. The beds of gneiss (coloured red in the figure), it will be seen, come in between two masses of bedded hemithrene (coloured green) rudely jointed. There is no appearance of a fault bringing the two rocks into their present relative position; nor, considering the perfect continuity between their respective beddings (which, it is to be remarked, have a uniform dip), can it be said that the hemithrene is in detached masses that have been let into a synclinal hollow and by this means preserved in their present position.

The bedding of the hemithrene is in other parts of the quarry somewhat obscure; and so is the limestone, especially where the interposed concretions are present.

Delesse, who had favourable opportunities for examining the geology of the Vosges, where the hemithrene occurs, states that the "calcaire saccharoïde est toujours complétement enveloppé par le gneiss dans lequel il forme des flambeaux irréguliers ou lenticulaires tels que ceux qui ont été signalés dans la Scandinavie par MM. Scheerer et Keilhau"*. He also mentions that at Laveline "le calcaire passe insensiblement au gneiss encaissant.'

The conclusion we have formed respecting the origin of these tongue-shaped masses of hemithrene will be obvious to the reader. Undoubtedly there is a decided difference between them and the enclosing gneiss; it cannot, however, have been caused by any mechanical break. Nor can the hemithrene be infolded masses due to a crumpling of the beds; for the gneiss is plainly seen passing into the hemithrene both vertically and horizontally, the change of colour (dark in the former and light in the latter) affording the clearest evidence of the transition, while the bedding is perfectly even and only slightly disturbed. Even hand specimens may be collected with the two rocks in such union as to make it impossible to detect any thing like a mechanical division between them.

With these evidences before us, and taking into consideration various others that have been adduced, including those revealed by the Cleggan dyke, proving rock-forming siliceous minerals to have had their calcium silicate changed into a carbonate, the conclusion becomes inevitable that the hemithrene of St. Philippe is a methylosed product after gneiss.

M. Rozel held the opinion that the hemithrene masses of the Vosges are veins of igneous origin†—thus agreeing with Emmons (1842), Mather and Von Leonhard (1833), with respect to corresponding cases made known by each as occurring in other regions. Delesse, on the contrary, conceives that the Vosgesian masses are genetically contemporaneous with the associated gneiss. Our view is that they are due to heated water holding carbonic acid or carbonate of lime in solution, which has penetrated the gneiss through joints and other openings, and converted it, where so affected, into dyke-like masses of calcareous marble‡.

Having shown the convertibility of mineral silicates into calcite and calcitic rocks, the question that next turns up for consideration is whether a similar change has taken place over a large area.

* Annales des Mines, 4e sér. vol. xx. p. 181.

† Bull. Soc. Géol. de France, vol. iii. pp. 215-235.

‡ It is said that the rock at Chippal resembles in its purity Paros marble. I was unfortunately prevented reaching this locality during my visit to the Vosges.—W. K.

It will not be denied, except perhaps by a few, that earthy sedimentary rocks have been mineralized over extensive regions into ordinary metamorphics; there is therefore no reason why chemical changes or methylosis may not have been effected on a regional scale. Bischof, according to the extract previously quoted from his 'Chemical and Physical Geology,' was evidently not averse to this view; nor would Heddle, we strongly suspect, be opposed to it.

Speaking of the euphotide at Portsoy, and the occurrence there of a "very siliceous limestone in immediate contact with it," Heddle proceeds—"Now the frequent association of thin beds of limestone with serpentine supplies very direct evidence of the conversion of hornblendic and augite rocks into serpentine. In that fact we have a ready answer to the question, 'What becomes of the carbonate of lime necessarily formed during such an alterative process as the above?' I will not say that limestone is always to be found in such association; we do not always find limestones even where we have indubitable evidence that they once existed; for here the very thing that makes can unmake or sweep away. The carbonate of lime thus fashioned out of the rock forms a belt beneath the residual serpentine, thicker or thinner in accordance with the original thickness of the stratum of transformed rock; also thicker or thinner according to whether that rock was augitic or hornblendic; for the former can supply considerably more lime than the latter. This calcareous belt must lie beneath the parent rock, sealed against any great amount of further change, unless or until upheaval or denudation expose it to meteoric influences. Then water, flowing either downwards or upwards, may—nay, in time must—sweep it away in solution, leaving lime-sink or collapsed void to evidence its former existence. But if the limestones, so frequently associated with serpentines, are thus to be assigned to the decomposition of the rock which yielded these serpentines, we have a crucial test of the soundness of the theory of the change, in the inquiry as to whether unchanged gabbro, or other such rocks, occur in contact with lime. That it never does, I will not say: but, in glancing at a sketch geological map which I have constructed of the district where these rocks occur, I find, as regards the great belt of diorite and diallagic rock which sweeps up Central Scotland, that where either the limestone appears in contact with it, or a "wash-out discloses its former existence, there the rock is serpentine; where it appears as unaltered rock there is no lime.

"I find, moreover, that wherever the association can be observed, the lime invariably is beneath the serpentine. So it is with the loch of Cliff lime and the serpentine of Unst, both of the lime and serpentine beds at Polmally, both of the lime and serpentine beds at Portsoy, at Limehillock, Tombreck, the Green Hill of Strathdon, and Beauty Hill; and in enumerating these I have named all the most important masses in the country"*.

We have only one objection to Professor Heddle's view. It would seem that he considers the calcareous matter, resulting from the changes he advocates, to be transferred to beneath the rock from which it was abstracted. But a difficulty strikes us as to what was in the place of the new "calcareous belt" before it was formed. This point seems to have been overlooked. We are quite ready to admit the important bearings of the fact stated by Heddle, that the lime "invariably is beneath the serpentine;" we cannot but suspect, however, that the lime has taken the place of a mass of transmuted serpentine or malacolite.

The notable shotted structure which frequently characterizes hemithrenes, and in many instances ophites, has an important bearing on the present question, inasmuch as this structure is due to the presence of crystalloids or portions of different minerals possessing a peculiar exterior.

As far as we have been able to ascertain, Macculloch appears to have been the first to bring the matter before the notice of geologists †. According to his description of the Tiree marbles (one mass of which is "an irregular rock—a nodule of limestone, improperly called a bed, lying among the gneiss without stratification or continuity"), they consist of amorphous or finely granular calcite in pink, white, and other colours, in which are imbedded crystalloids of sahlite, augite, and hornblende, termed in a general way coccolite, separately dispersed, or aggregated—in the latter state attaining the size of an orange or larger. Other minerals are present, as mica, serpentine, steatite, sphene, &c. The crystalloids are often either

* *Op. cit.* pp. 540, 541. Bischof mentions the occurrence of beds composed of limestone beneath others formed of mineral silicates. See 'Physical and Chemical Geology,' vol. iii. pp. 304, 305, 307, 308.

† Western Islands of Scotland, vol. i. pp. 48–56 (1819).

partially rounded or entirely shapeless—a peculiarity which Macculloch conceived to have resulted "from an incipient solution."

Naumann next drew attention to the rounded form of the crystalloids of augite and other minerals in calcitic rocks, particularly in that at Pargas, in Finland, and attributed it to partial fusion.

Emmons, in 1842, referred to the rounded outlines of crystals of certain minerals imbedded in the crystalline limestones of Rossie, New York, and suggested that they were due to a partial fusion *.

In 1863 Sterry Hunt briefly noticed the occurrence of rounded grains of various minerals in the Archæan rocks of Canada †.

Our attention having been drawn to the so-called "chamber-casts of Eozoon" in 1866, we identified them with the crystalloids in the hemithrenes of Pargas, Tiree, and New Jersey, also with the lobulated grains of serpentine common in the ophite of Connemara. It was likewise suggested by us that they had been shaped by chemical reactions aided by heated water, which, having affected them superficially, had removed their substance and replaced it by the calcite in which they are now imbedded ‡.

About the same time as ourselves Gümbel noticed similar rocks, also the peculiar form of the crystalloids contained therein; but he adopted the view, then pretty generally received, that the latter were of organic origin §.

In his report, addressed to Sir William E. Logan, and published in 1866, Sterry Hunt, again referring to the subject ||, drew attention to the fact that crystalloids with rounded forms, besides occurring in the bedded hemithrenes of Canada, are also present in "calcareous veins" (some being 150 feet thick) intersecting the latter and the associated gneisses, dolerites, &c. As this fact will have to be noticed again, its further consideration may for the present be deferred.

* Geology of the First District of New York, pp. 37–39. Delesse, we are aware, has noticed rounded crystals; but, unfortunately, our extract, stating the fact, from one of his memoirs has got mislaid.

† Report, Geological Survey of Canada, 1863, p. 592.

‡ Quart. Journ. Geol. Soc. vol. xxii. pp. 198, 199, 209 (Jan. 1866).

§ Sitzungsberichte d. Münchener Akad. d. Wissensch. (Jan. 1866).

|| We find no reference to the rounded crystalloids in S. Hunt's memoir "On the Mineralogy of certain Organic Remains from the Laurentian Rocks of Canada," published in the Quart. Journ. Geol. Soc. vol. xxi. (Nov. 1864).

In our paper of 1868 we also noticed the occurrence of crystalloids of malacolite in ophite from Connemara, which are not only more or less externally eroded and separated by calcite, but have gaping or chink-like cleavage-partings filled with the same substance. The mineralogist, it was asserted, knows full well that originally the cleavage-partings had individually their two planes in perfect contact; hence there is no other explanation open to him than the one which admits that some solution, charged with carbonic acid or a carbonate, has gained access into the cleavage-partings of the malacolite, and, necessarily reacting on some of its constituents (? calcium silicate), has generated the infilling of calcite.

Reverting to our account of the different minerals in the Tiree marble, it was stated that we had found in this rock "crystalloids of hornblende, others of sahlite, a few of quartz, and some apparently of serpentine; while an occasional one appears half composed of hornblende and the other half of sahlite"*.

Pretty much the same result has been lately obtained by Heddle, who mentions portions of sahlite in which "an incipient as well as a perfected passage into serpentine is seen"†.

Since the year 1869 we have described the microscopic structure of hemithrenes from the Isle of Skye, New Jersey‡, Aker, and Ceylon§. Zirkel, in 1870, noticed the "roundish, sharply-defined, serpentine grains" in Scandinavian hemithrenes, and assumed them to be pseudomorphs. In our papers it was shown that they contain not only rounded crystalloids of malacolite and white pargasite (or it may be wollastonite), singly and in aggregations, but the same things decreted and fashioned into slender shapes, corresponding with the remarkable configurations already described as occurring in Canadian ophite. A specimen from New Jersey contains numerous configurations associated with spinel, a well-developed example being actually imbedded in the calcite occupying a fissure-like opening in a large octahedral crystal of this mineral||. Specimens of the Skye rock, where it is ophitic¶,

* Proc. Roy. Irish Academy, July 12, 1869.

† *Op. cit.* p. 459. ‡ Proc. Roy. Irish Acad. n. s. vol. i. (1871).

§ Geological Magazine, vol. x. Jan. 1873.

|| Proc. Roy. Irish Acad. vol. x. p. 547 (Feb. 1870).

¶ This rock seems for the most part to be a carrarite; but the portions we have examined are in the state of ophite or hemithrene.

after being decalcified, showed separated grains or crystalloids of malacolite with a thin white crust enclosing their translucent substance; others were seen with a portion of the latter removed, but the crust remaining intact; while close by were hollow spheroidal cases identical in composition with the crusts: before decalcification the cases were filled with calcite. A few examples of the cases occur entirely riddled, reminding one of the perforated shell of a Polycystine *.

In our remarks on these things it was contended, considering the crystalloids of malacolite show themselves in every stage of decretion, that in numerous instances they must have disappeared altogether; also that it was equally to be inferred that the interstitial calcite separating the grains, even that forming the associated layers, had replaced a corresponding amount of malacolite.

From the various evidences just given, added to those previously adduced, all demonstrating that both minerals and rocks essentially silicates have been converted into calcite and calcareous masses, we feel it impossible to form any other conclusion, as regards the hemithrenes so far considered, than that they were originally silacid metamorphics, also that the associated marbles, "consisting of nearly pure carbonate of lime," are examples in which the mineral silicates have been completely extracted by the same methylotic process.

Professor Heddle, it may be said, takes a different view. Referring to the hemithrenes that have come under his own observation, such as occur in Tiree, Harris, Lewis, and some other localities in Scotland, and contending that the crystalloids they contain "are one and all pseudomorphs of preexisting crystals of augite, sparsely sprinkled throughout a great mass of lime, in an amount which is altogether quite trifling," he declares that "these trifling specks could never have been the origin of a lime stratum tens of feet in thickness" †.

Whatever may have been the origin of the other hemithrenes referred to by Heddle, we certainly must contend, with respect to the Tiree marbles, that their rounded crystalloids are not only pseudomorphs but also the residue of what was once an augitic rock, and that the portion which has been destroyed, or rather removed, has undergone replacement by calcareous

* Proc. Roy. Irish Acad. n. s. vol. i. p. 138 (1871). † *Op. cit.* p. 542.

matter*. Agreeing with Heddle that it was not the "sparsely sprinkled" pseudomorphosed crystals "which have been the origin of the lime stratum," we nevertheless ask why may not augitic rock-masses, by methylosis and decretion into the "trifling specks," have given rise to it? Considering also that the marbles of Harris and Lewis are Archæan, like those of Tiree, we have no hesitation in placing them in the same category.

Professor James D. Dana, as it seems to us, advocates the methylotic origin of hemithrenes; but he takes a different view from ours as to the *modus operandi* of the process. In his description of rocks of the kind common in Westchester County, New York, he argues that they have been originally limestones or dolomites, which, through the action of hot silicic solutions, have become silicated, their mineral carbonates (calcareous and magnesian) being thus converted into malacolite, tremolite, and other mineral silicates†. We have no objections to urge against changes of this kind having occasionally taken place. But in the rocks to which we refer the evidences are so palpable and prevalent of the calcite having replaced malacolite, that we feel assured, if Prof. Dana were to decalcify specimens of the Westchester rocks, he would at once see the force of our view in its application to his particular instances. Another objection lies against the idea that hemithrenes are silicated limestones, inasmuch as, if applied to the Archæan deposits of the kind, it would make the latter to have been even more calcitic than they are at present; and this would increase the difficulty in solving the problem (to be discussed in a subsequent Chapter) as to the source which supplied the calcite.

* The Tiree marble evidently contains much more augitic residue than is represented by the crystalloids, as there are frequently imbedded in it siliceous bodies of various sizes: the crystalloids are also often surrounded by a white, spongy, siliceous covering (corresponding to flocculite), to be seen after decalcification. Macculloch has noticed something of the kind (*op. cit.* vol. i. p. 53).

† American Journal of Science, 3rd ser. vol. xx. p. 28, &c. The origin of these rocks will be further noticed in Chapter XIII.

CHAPTER XI.

ON THE ORIGIN OF THE MINERALS CHARACTERISTIC OF OPHITES AND RELATED ROCKS, THE MINERAL PERIDOTE IN PARTICULAR.

THE object of this Chapter is to show that the minerals referred to in the heading are the direct products of hydrothermal reactions in methylosed and volcanic rocks, also of pseudomorphism in minerals characteristic of ordinary metamorphics and different kinds of igneous masses. If this object can be accomplished, it will necessarily follow that all the minerals under notice are, in a certain sense, secondary products. Several of these minerals, such as calcite and the different serpentines, are generally admitted to have had this origin; there are others, however, which, as far as we can ascertain, have never been considered any thing else than original in the same sense as the quartz, feldspar, and hornblende of granites are held to be so.

At first sight the occurrence of secondary minerals in volcanic rocks seems improbable. Still it is pretty generally considered that many of the minerals found in dolerites, trachytes, and ordinary lavas have been generated under circumstances, as to time and conditions, totally different from those under which the rocks in question were formed.

Even granite, generally assumed to consist of original minerals, occasionally contains zeolites, which all must admit to be secondary products. The same must be asserted of calcite and serpentine, already notified as present in the diorite and other rocks near Galway and in Jersey.

It is necessary to mention, in the next place, that numerous instances must occur of a rock that has undergone partial methylosis, having some of the minerals it contained in its previous or primary condition (whether such rock be igneous or ordinary metamorphic) retaining their original character, and others partially altered. Thus the hemithrene of St. Philippe carries hornblende and muscovite; but as these minerals lie immediately adjacent to the contact rock, viz. gneiss, there can be no doubt that they have escaped the changes which converted the same species accompanying them into malacolite and phlogopite.

It has been clearly shown that, besides other minerals, malacolite and serpentine—demonstratively secondary products—have themselves undergone chemical changes which, gradually removing certain of their constituents, especially the silacid, have terminated in calcitic or miemitic (dolomitic) replacements.

With respect to several other minerals characteristic of ophites and hemithrenes, such as spinel, idocrase, apatite, sphene, &c., it may be assumed that, although original in these cases (that is, formed independently of any other mineral), they are nevertheless of secondary origin, having resulted from the intervention of hydrothermal reactions.

Another mineral of importance in the subject under consideration is peridote, also known under the name of olivine*. It runs into several varieties, as limbilite, chrysolite, glinkite, boltonite, olivinoid, hyalosiderite, &c. Analyses make it to consist of magnesia from 32 to 50 per cent., protoxide of iron from 6 to 30 per cent., and silica from 31 to 44 per cent. Accessory ingredients, as alumina, oxide of nickel, oxide of manganese, titanic acid †, and silicate of lime, are not unfrequently present. The magnesia is often about 13 per cent., generally 10 per cent., and occasionally 2 or 3 per cent. in excess of the silica. Silicate of lime is present in specimens of peridote from the lava of Fogo (Cape-Verd Isles) to the extent of nearly 6 per cent. Monticellite is a highly calciferous peridote, containing 34 per cent. of calcium silicate.

The minerals nearest to peridote are humite (which contains, in addition to the essentials of peridote, between 2 and 3 per cent. or more of fluorine) and chondrodite, in which the fluorine is increased in some cases to more than 7 per cent. Leipervillite (bronzite according to Pisani) only differs from peridote in its magnesia reaching to 75 per cent. Forsterite, another related species, but containing only a few per cent. of protoxide of iron, carries us on to diaclasite, enstatite, and certain reputed diallages and hypersthenes: in these last the silica is in excess of the

* D'Argenville's name *peridote* (date 1755) has priority over that of Werner's *olivine* (1790); obviously, then, French mineralogists are right in adopting it. Pliny's name, chrysolite, it would appear, was not applied to the mineral now so called by mineralogists (see Dana's 'Mineralogy,' under "Olivine").

† A titaniferous peridote from Zermatt, according to M. A. Damour, contains 5·30 per cent. of titanic acid (Bull. de la Soc. Minéralogique, t. ii. pp. 15, 16).

magnesia. Fayalite is usually classed with peridote, though containing only a small quantity of magnesia.

Serpentine is another chemically related mineral, with the difference principally in being hydrous. It frequently contains iron protoxide, by which its relation to peridote is further sustained.

The frequent change of peridote into serpentine, which we have already noticed, has no doubt largely contributed to the prevailing idea that the former mineral is always an original product. Taking this view, some difficulty would be felt by conceiving that peridote itself could occur as a product of pseudomorphism. Hence it is, in the case of a rock containing peridote associated with augite or hornblende, that the idea of the first having been pseudomorphically generated out of either of the latter two does not seem to have been entertained.

Rocks containing peridote have been called peridolytes, the principal of which are lherzolyte, dunyte, and picryte.

Peridote is of somewhat common occurrence in many dolerites, trachytes, and lavas. Its presence is well known in what may be an igneous rock,—the hypersthenyte near Elfdalen in Sweden*; and it is said to occur in the granite or syenite between the Nile and the Red Sea. Delesse discovered a ferruginous variety of peridote in cavities of the pegmatite or granite of the Mourne Mountains†. The related species, fayalite, has been found in ordinary metamorphics (those simply mineralized) at Tunaberg in Sweden, forming, with augite &c., a bed, called eulysyte, in gneiss. A true peridote dominates in a rock, called olivenyte, associated with talc-schist, at Uddevalla, Sweden; a variety has been observed near Kyschtimsk, north of Miask, and near Synersk in the Ural in talcose rock: these cases show that the mineral is also present in methylosed metamorphics; while its frequent occurrence in serpentine, made known by Breithaupt, Bischof, Hunt, Otto Hahn, and others, leads to the same conclusion. As it is found in methylosed rocks, the presence of peridote in veins of calcite, presumably of secondary origin, traversing large blocks of talcose schist scattered over the southern moraine of the Findelen glacier near Zermatt, is not surprising to us, though it must be to those who subscribe

* This rock is said to consist of hypersthene, labradorite, and peridote.

† Reference to the fact is unknown to us; but the occurrence of peridote in the Mourne granite is mentioned by Dr. Haughton in Quart. Journ. Geol. Soc. vol. xii. p. 191.

to the prevailing idea just stated. But it ought to be greatly embarrassing to the latter to find that it notably occurs (as boltonite) in the hemithrene of Massachusetts, also as "roundish sharply defined grains," more or less changed into serpentine, crowding the corresponding rock ("granular limestone") at Snarum, Aker, and Modum in Norway*.

To add to its remarkable indifference as to the nature of the material selected by peridote for its matrix, the fact may be mentioned that this mineral, or some of its varieties, besides being often in association with other substances, exists imbedded in the nickeliferous iron of meteoric amygdaloids that have fallen in Siberia, Atacama, and elsewhere†; and it is a common ingredient in meteoric stones.

We have shown that peridote is a variable mineral through the increase or decrease of the percentage of its magnesia and iron, also through the presence of accessory substances. Thus, let it be conceived, in the case of a rock like ophite, which has often resulted from hornblende and augite, that during the process of alteration the protoxide of iron belonging to either of these minerals were not removed, there seems to be no valid reason against the probability that this substance would become united, all things being favourable, with any available free silicate of magnesia, and thus form peridote or some variety of it.

The two minerals peridote and serpentine can be readily differentiated by the polariscope when they are associated as in ophite. Guided by the peridote in the hypersthenyte of Elfdalen (which is optically in agreement with the same mineral from Expailly, in Auvergne, and several other localities), and allowing for variations due to circumstances such as have been mentioned, it may be stated that this mineral exhibits a display of the richest colours by rotating the prisms, viz. yellowish green, sap-green, pink-rose, ruby, blue, &c.—being a greater variety and of more brilliancy than those displayed by chrysotile. On the contrary, serpentine only shows pale yellow (under parallel prisms), changing into dark grey (when the prisms are crossed), and back again into pale yellow.

The specimens of peridote which we are about to notice exhibit

* Neues Jahrbuch für Mineralogie, 1870, p. 828.

† As meteoric peridote is generally believed to be of extramundane origin, probably solar, obviously any endeavour to explain its origin may be properly avoided.

the beautiful green, ruby, and other colours that especially distinguish it. Rather often may be detected by polarized light septa and strings of this mineral loosely and confusedly interreticulated with serpentine. In fig. 4, Pl. III., we have represented a short plate ("chamber-cast" of "Eozoon") consisting of serpentine at one end and peridote with a strong oblique cleavage at the other. Fig. 5, Pl. III., exhibits peridote forming a portion of another "chamber-cast" and intersected by layers of calcite.

The interreticulation of peridote and serpentine in the first of the above cases is strongly suggestive of its being due to segregative chemical action; but in the two latter it would seem that the peridote is pseudomorphic after some mineral, partly retaining its crystalline form. The intersecting layers of calcite in the specimen under figure 5 may be accepted as strong presumptive evidence of chemical changes involving the pseudomorphic development of this carbonate.

The opinion is pretty general that peridote is in all cases an igneous product. A different view may be entertained by Sterry Hunt, who, considering the doctrine of chemical precipitation which he advocates with respect to the origin of the Archæan hemithrenes, ought to regard peridote, at least that form of it which is known to occur in these rocks, as having been formed in the humid or wet way; for it has come under his notice both in their bedded and "vein"-masses*.

It has seemingly never struck any one that the frequent intermixture of peridote and serpentine (the latter in bedded and dyke-shaped masses) is strong evidence at least of its being due to chemical alteration. Breithaupt, who had knowledge of masses of serpentine containing peridote, was evidently influenced by the prevailing idea, already noticed, in making the suggestion that they are altered examples of the latter mineral —that is, of a rock related to what is now called a peridolyte. But as to a rock of this kind being a methylosed dolerite, diorite, or any thing else, the idea to Breithaupt was apparently, as it is to several others of the present day, entirely out of the question.

The occurrence of peridote in talc-schists seems to have perplexed Bischof; for he, too, advocated its igneous origin: but being a thorough hydrothermalist as regards the agencies which developed rock-metamorphism, he was compelled to admit that the case "would seem to indicate that this mineral has

* Chemical and Geological Essays, pp. 31 and 210.

been formed in the wet way"*. Bischof, we are strongly inclined to think, would have felt no hesitation in taking this view had he been acquainted with peridotiferous ophites that were sediments originally.

Supported by numerous evidences which have come to light of late years through the study of ophites, we must declare ourselves on the side of the opinion that the presence of peridote in all such rocks is as much the result of hydrothermal and chemical changes as is the serpentine with which it may be associated. Besides, it is well known that lava contains water and steam for years after its eruption: jets of vapour are still given off from the lava of Jurolla, now nearly ninety years after its ejection.

The occurrence of peridote in granites, though countenancing the idea of this mineral having been formed by igneous action and in the dry way, cannot be accepted as proving any thing of the kind; for it is now well known that these rocks occasionally contain zeolites, serpentine, chlorite, and other hydrous minerals, which must have been formed in the wet way. Hence hydrothermal conditions, required by our theory for the production of secondary minerals, have not always been absent in granites.

Not long since we pointed out instances of peridote in the amorphous or colloidal form, where it is interreticulated with serpentine. It may also be mentioned that the former mineral occurs in the crystalloid and crystalline conditions, as at Snarum. Beautiful crystals have been found in the lavas of Vesuvius, in forms proper to itself, and not pseudomorphic after those belonging to another mineral: this may be regarded as proving that peridote is not of secondary origin. Any argument of the kind, however, is invalidated by the fact that other minerals are in the same predicament. Epidote, calcite, and talc occur crystalline, each as a secondary product and in forms proper to itself, also as pseudomorphic after garnet &c.

Again, the occurrence of crystals and crystalloids of peridote in true igneous dykes and beds of lava is held by some to prove that this mineral and the ejections containing it are of contemporaneous origin. But a formidable difficulty meets this view at the outset. As generally considered, peridote is one of the most refractory bodies known; and in agreement with this fact is the well-attested statement that peridote frequently occurs under circumstances showing that the heat of its matrix, when

* Chemical and Physical Geology, vol. ii. p. 358.

in a molten condition, was insufficient to fuse it. The opinion is therefore pretty general that the peridote in these cases has been thrown out of volcanoes in a solid condition (crystalline and amorphous), imbedded in the lava; in other terms, as expressed by Bischof, "all these facts are indications of its existence in a solid state in the melted lava, and are quite inconsistent with the opinion that it has originated from the lava." Moreover "the occurrence of peridote in a metamorphic rock renders it intelligible that lava penetrating through beds in such rocks might carry up with it lumps or crystals of this mineral" *. But we cannot admit that its presence in lava is to be explained in this way. The fact that it occurs abundantly in the old lavas of Vesuvius and rarely in those of historical eruptions may be held as supporting a contrary interpretation, in cases of this kind at least; for, admitting that this mineral has been derived from previously existing rock-masses lying at great depths, there is no reason against the subterranean sources yielding it at the present day.

Before closing this portion of our present argument we shall cite a passage from Bischof giving his view as to the origin of other minerals (augite, hornblende, leucite, &c.) common in dolerites and lavas, though it may not be unnecessary to remind the reader beforehand that, in agreement with passages already cited, our author must have inconsistently excluded peridote. "It is evident that, after the solidification and cooling of lava, crystals can no longer be formed by fusion. Therefore, when we find that the older lava contains crystals which either do not occur at all in the more recent lava, or which are at least much larger and better developed than in the latter, it is certain that these crystals have been formed in some other way than by fusion, and there is no other way than the wet way in which they can have been formed: .... there is no reason why this mode of formation should be considered impossible in the older lava, which has for long periods been exposed to the action of water." .... "We must therefore refrain from regarding crystalline minerals which occur in volcanic masses as products of fusion" †.

In view of the various points thus far brought forward, it seems most unreasonable to exclude peridote from the list of products of alteration. Therefore, until better evidences than have hitherto

* Chemical and Physical Geology, vol. ii. p. 358.

† Ibid. vol. ii. pp. 94, 95.

been adduced to the contrary are forthcoming, we shall continue to maintain that peridote, whatever kind of rock may be its matrix, or whether occurring in crystalline forms peculiar to itself or as amorphous masses, is as much a secondary product as other secondary minerals which may be its accompaniments.

Weighing the evidences and considerations hitherto adduced, it may be taken as clear that, although genetically a secondary mineral, peridote is of independent origin in the crystalline and crystalloidal examples last under notice.

Our next object is to show that peridote, or a mineral substance assumed to be the same, has originated through pseudomorphism after other minerals, and that therefore in cases of this kind it cannot be of independent origin.

That peridote occurs frequently changed into other minerals, as serpentine, is a well-established fact; but the proposition just laid down does not seem to have been entertained by mineralogists: it is one, however, which cannot be said to be gratuitous; for other minerals are known to be similarly polygenetic. As hexagonal crystals, quartz is in a form proper to itself and of independent origin; but as the same mineral substance is found in forms peculiar to calcite, such forms are pseudomorphs, and cannot have originated independently. Our illustration has its parallel in peridote.

Again, as we purpose to show that peridote is pseudomorphous after hornblende and augite, we may be allowed beforehand to ask the question—As serpentine frequently occurs pseudomorphosed after hornblende and augite, why cannot the latter species be pseudomorphosed into peridote, which is so closely related to serpentine? We shall endeavour to answer the question in the affirmative by the consideration of evidences pertaining to the crystalline form, cleavage, and polarization respectively characteristic of the three minerals concerned.

Peridote belongs to the trimetric crystalline system; and it necessarily has for its primary a right rectangular prism, which in this particular mineral rarely occurs otherwise than under somewhat complex prismatic and basal modifications. Its simplest prismatic modifications, by removal of the lateral edges to the complete effacement of all the primary faces, would be rhombic, with acute and obtuse angles respectively

86° and 94°; but it seldom, if ever, occurs in this form. In the annexed woodcut, fig. 1, the outside dotted lines represent a cross section of the primary rectangular prism of peridote; the thick continuous lines within represent the secondary rhombic modification; the broken lines represent the cleavage. Usually the prism has eight, ten, or twelve lateral faces; a cross section, being thus many-sided, has a somewhat rounded or rather elliptical outline. Cross sections of peridote are figured in Zirkel's work with six sides*.

The cleavage of peridote consists of three dissimilar sets, two being parallel with the prismatic faces of the rectangular primary, and one conformable with the basal faces; consequently their mutual intersections are at right angles to one another (see inner broken lines in fig. 1), as may be observed in the cleavage-solids which occasionally occur in masses of this mineral common at Unkel and elsewhere.

Turning to augite and hornblende, both belong to the monoclinic crystalline system; their respective crystals, which often occur as six- or eight-sided prisms, are usually less modified than those of peridote; and moreover, on account of their inclination, they are further differentiated from crystals of the last mineral. The simplest modification of the primary of hornblende, when it obliterates, as stated of peridote, all the original faces, gives rise to an oblique rhombic prism, whose acute and obtuse angles are respectively 55° 30′ and 124° 30′ (see fig. 3). The corresponding modification of augite yields angles 87° 5′ and 92° 55′, as in fig. 2. It will thus be seen that the cross section of a rhombic prism of augite differs extremely little in its angular measurements from a similar section of peridote, and that both are nearly a square. The decidedly rhombic form of the cross section of hornblende need not be mentioned in this comparison.

The basal modifications in each of these three minerals render it difficult to determine the form of their respective longitudinal sections, depending, as the question does, as to whether such section be a true one or not, on its parallelism with the vertical crystalline axis.

* Die mikroskopische Berschaffenheit der Mineralien und Gesteine, pp. 99, 216. None of Zirkel's figures represents a true cross section of peridote, as they are too rhombic; they must be somewhat oblique to the vertical axis instead of at a right angle.

[*To face* p. 68.

Fig. 1.

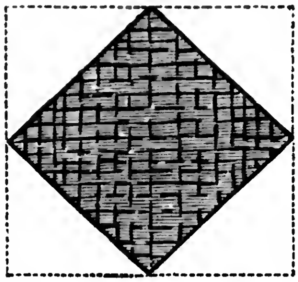


Fig. 2.

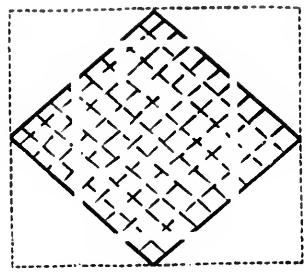


Fig. 3.

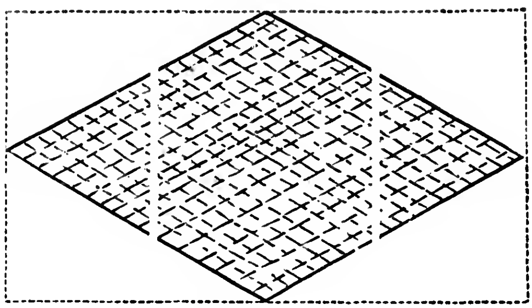


Fig. 1. Diagrammatic transverse sections of a prismatic crystal of peridote. Obtuse angles 94°; acute angles 86°. The outer dotted lines represent the form of its primary; the inner continuous lines angular measurements of its simplest modification; the broken lines its rectangular cleavage. The prism is upright.

Fig. 2. Diagrammatic transverse sections of a prismatic crystal of augite. Obtuse angles 92° 55′; acute angles 87° 5′.

Fig. 3. Diagrammatic transverse sections of a prismatic crystal of hornblende. Obtuse angles 124° 30′; acute angles 55° 30′.

The augite and hornblende prisms (Figs. 2 & 3) are inclined (monoclinic). Their inclination to be assumed as from bottom to top of the page. When their angles are truncated down to the white lines, the resulting section is that of the usual prism.

The outer dotted lines represent the form of the primary; the continuous lines a secondary form, or that of the cleavage-solid; the broken lines the cleavage, which is rhombic.

The cleavage of hornblende and augite is prismatic and basal: the two prismatic sets are parallel with the faces of the secondary rhombic prism; while the basal set, which is parallel with the basal faces of the inclined primaries, necessarily intersects the prismatic cleavage-planes obliquely *.

Obviously, whatever difficulty attaches to crystalline form, cleavage is of great assistance in enabling the investigator to distinguish peridote from either augite or hornblende; for while there are only right-angled sets of cleavage in the first, there are nothing but oblique sets in the two last. Still there are difficulties to be encountered in connexion with this point, depending on whether or not the section which may be under examination is in its correct, or approximately correct, position of intersection relatively to the vertical axis of the prism: but their consideration may be advantageously passed over as involving niceties of calculation unnecessary in this work; and we feel ourselves bound to argue out our conclusions suitably for geological students in general.

Let us next examine the sections of crystals of "peridote," as represented by two of our fellow labourers, to see how far they are in conformity with the cleavage-characters of this mineral.

Unfortunately the figures of "peridote" given by Allport" †, although representing each a cross section, do not exhibit any cleavage. Professor Hull's figures are not in this predicament ‡.

Allport, who has carefully examined a number of British dolerites, has represented in his figures 25 and 27 cross sections of what he takes to be peridote; but, from their form, it may be equally assumed that they represent augite. He has also given another section, four-sided, in fig. 26; but exception may be taken to it as being too simple in form for peridote, and having its angles approaching too closely to those characteristic of the acute rhombic modification peculiar to hornblende in its simplest secondary form, and as equally represented by its clea-

* The basal cleavage of these minerals, it will be understood, could not be represented in figures of cross sections.

† Quart. Journ. Geol. Soc. vol. xxx. pl. 34. figs. 25–27.

‡ Trans. Royal Irish Academy, vol. xxv. pl. xi. figs. 25–30, "Report on the Chemical, Mineralogical, and Microscopic Characters of the Lavas of Vesuvius from 1631 to 1868," by the Rev. Prof. Haughton and Prof. Hull.

vage-solid : compare Allport's figure with our fig. 2. We therefore cannot accept this case, any more than the others, as an example of peridote, unless in the condition of a pseudomorph.

We have been obligingly favoured by Mr. John Young, of the Hunterian Museum of Glasgow, with a number of specimens of trap rocks from the Clyde district—the same rocks which supplied Mr. Allport with several of his specimens. From the specimens which Mr. Young sent us we have had prepared several microscopic sections; but in none do we observe any thing opposing the above conclusion. Many of the crystals contained in them (showing peridotic colours) exhibit irregular rhomboidal sections, which, we consider, prove that the longitudinal or vertical axis of the sections is inclined; moreover several of them exhibit prismatic rhombic cleavage. The mineral we must therefore consider to have been originally augite or hornblende *.

In our present investigations we have been materially assisted by Professor Hull, who, though aware that we were disposed to take a view different from his, has kindly allowed us to examine the sections represented in the "Report" with which his name is connected. In the figures to which allusion is now made, attention has been paid not only to angular measurements, but to cleavage-peculiarities.

We have not been able to form any satisfactory opinion on any of the sections referred to (being unsymmetrical forms), except the one under fig. 20; fortunately this is sufficiently decisive for our purpose. The section given in fig. 7, Plate I., is from a drawing made by ourselves, which, it will be seen, closely agrees with Dr. Hull's representation, except that the cleavage is shown a little more in detail.

It is stated that this is a "section of olivine crystal from the lava of 1794." The mineral or chemical nature of the section we do not dispute; for it exhibits under polarized light the colours characteristic of peridote, excepting that they are slightly

* A crystal of augite described by Sandberger has, disseminated through its entire mass, a substance which he considered to be peridote (Bischof, op. cit. vol. ii. p. 307). We should like to draw Mr. Allport's attention to this case. Moreover the presence of calcite associated with serpentine in Mr. Allport's examples is a noteworthy evidence in favour of our view as to the origin of the "calcareous skeleton" and the calcitic interpolations in the "nummuline wall" of "*Eozoon Canadense.*"

duller, and their variation is somewhat different *. These differences, however, are no more than what may be observed in most minerals assumed to be peridote. It may also be mentioned that, considering the approximate agreement between peridote and augite (woocut fig. 2) in their cross sections, Dr. Hull was justified in assuming the crystal to be peridote: for the same reason we see no impropriety in taking it to be augite; but the sectional difference they exhibit is not to be overlooked.

Still, although so much can be said in favour of the identification made by Hull, it is extremely doubtful to us that it is a correct one, inasmuch as the prismatic cleavage, so well displayed in the crystal under notice, instead of being right-angled in its intersections or parallel with the sides of a rectangular prism, as required for peridote, is rhombic, precisely like that of augite. We are therefore inclined to the conviction that this example was originally a crystal of augite, which has undergone a chemical change into a substance resembling that of peridote, or, as we prefer to say, which has become peridotized.

The presence of peridote in certain rocks may be satisfactorily explained in accordance with the views that have been advanced; for, admitting that crystals of hornblende and augite can be pseudomorphosed into peridote, there is no reason why a crystalline rock, whether xerothermal, methylosed, or volcanic, which contains these minerals, may not become more or less peridotized. It is in this light that we regard dunyte, picryte, lherzolyte, ossipyte, olivenyte, and others of their class, also many of the doleritic dykes described by Allport †. We are therefore opposed to accepting the presence of peridote in any one of the above-named examples as evidence that a rock of the kind is in its original condition, but rather as proving that it is more or less a methylotic product.

* When the prisms are parallel the colour is pale yellow, at 45° pale purple, at 90° (cross prisms) deep purple, at 135° pale pink, returning to pale yellow: there is no brilliant sap-green, nor ruby. The structure is granular.

† The remarkable doleritic rock at Carmoney Hill, co. Antrim (the matrix of the new mineral, hullite, Hardman), is so charged with peridote, as first made known by Prof. Hull (Proc. Royal Irish Acad. 2nd ser. vol. iii. (Science), pp. 166, 167), that we are disposed to consider it another example of the kind.

CHAPTER XII.

ON THE ORIGIN OF THE ARCHÆAN "CRYSTALLINE LIMESTONES" OF CANADA.

The Canadian Archæans are for the most part mineralized metamorphics, the methylosed members (usually silo-carbacid) being a subordinate group. In general highly crystalline, the former consist of bedded masses of granitoid gneisses, quartzites, diorites, dolerites, various crystalline schists, &c., and the latter of calci-hornblendic gneisses, ophites, "crystalline limestones," and other related kinds. The "crystalline limestones" having been proved to be chemically, mineralogically, and structurally identical with hemithrenes, we shall assume them to be rocks of the latter kind.

The "crystalline limestones" or hemithrenes, which are often interstratified with the mineralized metamorphics, vary much in their mineral composition: calcite, or miemite (either of which is usually present) generally serves as a matrix for the mineral silicates—chondrodite, augite, hornblende, phlogopite, orthoclase, labradorite, serpentine, quartz, idocrase, &c.; which, with apatite, graphite, and other non-silicates, occur as crystals, or as irregularly-shaped grains (crystalloids) varying much in size, "either alone or variously associated, and sometimes in such quantities as to make up a large proportion of the rock, to the exclusion of carbonate of lime;" so that beds are often seen to graduate completely into diorites, gneisses, and other silacid metamorphics*.

The beds are often greatly contorted; and their component layers are frequently and independently crumpled in the most extraordinary manner. At the Ragged Chute on the Madawaska (Canada) there is a bed, according to Logan, "three feet

* Report of the Geological Survey of Canada for 1866, p. 185; and Chemical and Geological Essays, p. 206.

thick, which consists of alternating layers of limestone and gneiss singularly corrugated, lying between masses of *evenly laminated* hornblendic gneiss"*. The latter, from its structure, may be regarded as due to sedimentation; but the corrugation of the enclosed "layers of limestone and gneiss" is totally inconsistent with its being of similar origin. Obviously the phenomenon is an example of segregated lamination, whose corrugation is the effect of internal movements, in individual beds, produced by chemical forces.

The latest estimate of the thickness of the entire group of Archæan rocks has been made by Mr. Henry G. Vennor, who, from very careful and laborious observations carried on during a number of years, is entitled to the highest confidence, and "from whose views" Mr. Alfred R. C. Selwyn, Director of the Canadian Survey, says "he has no reason to dissent." "It would appear that the whole volume is not less than between 50,000 and 60,000 feet; and this estimate does not include the great fundamental unstratified or obscurely stratified gneisso-syenitic series, but commences only with the first strata of clearly stratified gneiss." As to the great fundamental series, it is at present impossible to suggest even its approximate thickness; but, forming the backbone of Eastern Ontario, as well as thousands of square miles in the region to the northward of the Ottawa river, it "is apparently a distinct formation, though the separation between it and the first strata of the overlying stratified gneiss is not always clear"†.

It is well known that the late Sir William Logan designated the great metamorphic group under consideration by the name Laurentian, also adding thereto, with a distinctive title, another metamorphic group, on the whole mineralogically different, which he regarded as an unconformably overlying one. But the investigations of Vennor have thrown some doubt on the alleged unconformity; the latter geologist is nevertheless disposed to

* Geology of Canada, 1863, p. 27. Dr. Bigsby, speaking of the bands of Canadian crystalline limestone, states "they are tortuous, and often, by bending round, sharply return by a parallel course to within a short distance from their visible point of departure. Corrugated seams of gneiss are sometimes enclosed in the limestones" (Geological Magazine, vol. i. p. 156).

† Report of the Geological Survey of Canada for 1876 and 1877, pp. 280, 299, 300.

adopt a twofold division, but to make the separation on a different horizon to that adopted by Sir William.

If we have not misunderstood the proposed subdivisions, the lowest one, which includes most of the Laurentian system of Logan, is essentially composed of silacid rocks, only a thin zone of crystalline limestone being included in it; the next one embraces, in addition to the silacid members, a massive zone of hemithrenes ("crystalline limestones"), in which are included stratified dolerites, ophites, and other related rocks. According to Vennor, who had favourable opportunities for taking measurements, the zone has "an average thickness of 5600 feet" *.

Mr. Selwyn proposes to make a system for the last group of rocks, retaining for it Logan's name, Huronian †, but to add thereto some other groups (certain members being slightly altered). Respecting the correctness of this proposal there may be some disagreement among American geologists.

It has been remarked by Sir William E. Logan 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 still older laminated sand-rock; and the formation of these beds leads us still further into the past" ‡.

Cordially agreeing with these remarks, we are prevented accepting Sterry Hunt's belief that in "pre-Cambrian times there prevailed chemical activities dependent upon greater subterranean temperature, different atmospheric conditions, and abundance of thermal water, and that under these circumstances

* Ibid. p. 264. This is Mr. Vennor's estimate for the "Hastings limestone zone." His estimate for what is considered to be a corresponding zone in Lanark township is not "less than from 5600 to 6000 feet thick" (Report, 1874-75, p. 143).

† Canadian Naturalist, vol. ix. p. 30.

‡ Quart. Journ. Geol. Soc. vol. xxi. pp. 46, 47.

were deposited the materials of the great crystalline rocks"*, —that is, as chemical precipitates.

There are no more reasons for ascribing the 60,000 feet of Laurentian sands, argills, and other deposits (that is, in their original condition as sediments) to Dr. Hunt's "chemical activities" than there are for attributing the 30,000 feet of similar deposits forming the Longmynds to the same agencies.

At the Dublin meeting of the British Association, 1878, Dr. Sorby referred to the presence of certain crystalline substances, in the "red clay" and other deposits, which the 'Challenger' expedition brought up from the bottom of the Pacific and Atlantic Oceans, in such a way as to make it appear that he is not opposed to the notion that they are the products of chemical precipitation. The nature of these crystalline substances and the deposits enclosing them is engaging the attention of Rénard and Murray. The full result of their investigations has not yet been published; but some of their conclusions are stated in the British-Association Report of the Sheffield Meeting in 1879, pp. 340, 341. There is nothing in their statements to countenance the idea that any thing in or belonging to the red clay, or the deposit itself, is a chemical precipitate from ocean water, but on the contrary, that it is for the most part a volcanic ash, which through decomposition or disintegration has become converted into red clay. The crystalline substances it contains, viz. plagioclase, augite, peridote, sanidine, magnetite, zeolites, sideromelane, &c., are more probably non-disintegrated portions of mineral aggregations contained in the volcanic ash, than the result of chemical reactions. Prof. A. Geikie (seemingly referring to some of the above), in stating that "these silicates (there may be several of them) have certainly been formed directly on the sea-bottom,"† commits himself to what we expect will turn out to be an erroneous conclusion.

Dismissing the silacid metamorphics for the present, Sterry Hunt's theory of the origin of the Canadian Archæans in their totality necessarily makes the interbedded "crystalline limestones" a "chemical deposit; and there is no doubt that a part of these limestones, like those of more recent formations, have been directly precipitated by chemical reactions from the waters

* Nature, August 22, 1878, p. 444.

† Article "Geology," in 'Encyclopædia Britannica,' vol. x. p. 288.

of the ocean." . . . . to "reactions, which are still going on in the ocean's waters, and which have, in past times, given rise directly to limestone strata, in which the occurrence of shells and corals is only accidental" *. That the latter deposits are in the main of organic origin is doubtless the opinion of most geologists; but a difficulty in connexion with this point has arisen as regards the Archæan hemithrenes.

To those who believe in "Eozoon," with the exception of Sterry Hunt, the organic origin of the Canadian hemithrenes, it may be assumed, is a settled matter. But it must be admitted, even by those to whom we refer, that there are others who totally dissent from this belief, and who, besides, reject the theory of chemical precipitation. Obviously, then, the *onus* lies with them to suggest or propose a different solution of the problem.

It would be rash on our part to deny that organisms of any kind were in existence during the Archæan periods; but our researches having afforded no proper evidence in support of the affirmative, we are induced to make the attempt to solve the question, as to the origin of the Canadian hemithrenes, otherwise than by the doctrine either of organic intervention, or chemical precipitation.

Reverting for a moment to the Laurentian *silacid rocks*, our view as to *their* origin is based on a full recognition of existing operations pertaining to physical geography: it involves the intervention of mechanical and chemical agencies in effecting the disintegration of rocks already in existence; also the removal and dispersion of the materials derived therefrom, and their consequent deposition in other and distant areas. It will therefore not be unreasonable to regard the Ontarion funda-

* 'Geology of Canada,' 1866, pp. 200, 201. The author further declares "the often repeated assertion that organic life has built up all the great limestone formations, is based upon a fallacy; for animals have no power to generate carbonate of lime." It may therefore be presumed that mollusks, crustacea, &c. have no power to convert the sulphate of lime, or chloride of calcium (the principal lime constituents of the ocean), into the carbonate of lime of their shells. But as we hold the contrary opinion, we may be allowed to maintain that the shells and corals contained in the limestone are the essential contributors to its formation, and consequently, that "organic life has built up all the great limestone formations."

mental "unstratified gneisso-syenitic series" as the rocks which yielded the silicates of alumina, magnesia, and lime, the alkaline silicates, and the oxides of iron, that gave rise to the sands, muds, and agglomerates of the overlying Laurentians. While the assumed mechanical actions were going on the carbonic acid of the water and atmosphere would doubtless act on the calcic, magnesian, and alkaline silicates; next would necessarily follow the conversion of the latter into soluble carbonates.

Besides other resultants, bicarbonate of lime would be generated, and forthwith conveyed by rivers into lakes and seas. Having never denied the existence of plants or animals during the Archæan periods, we see no reason why some of the lime salt, as above generated, may not have contributed to the formation of organic skeletons; but this yet remains to be proved. We must also admit the probability that in shallow seas and lagoons, also along shores, carbonate of lime would be thrown down by the evaporation of their water; and it may be equally admitted that the water under certain conditions would otherwise part with it. In this way may have been formed deposits of limestone, but comparatively insignificant in quantity, while carbonate of lime may have become intermixed with the components of other shallow-water deposits. The calcareous base of the conglomerates near the Coulonge river, Co. Ottawa, strikes us as being probably a littoral formation.

But with respect to the 6000 feet of "crystalline limestones" —the silo-carbacid members of the Laurentians—we must hold to a different explanation of their origin.

Without availing ourselves of heat emanating from contiguous masses of molten rocks, we shall simply assume that before the Laurentian deposits were thrown out of their original position, a considerable portion (being buried at great depths and under enormous pressure, and retaining their original water) became affected by the elevated temperatures prevailing at such depths; and thus they passed into the mineralized condition characteristic of ordinary metamorphic rocks. Afterwards, through the introduction of extraneous water containing a carbacid solution, these mineralized metamorphics became chemically changed into hemithrenes and other related rocks.

In support of this view we might appeal to evidences, already described, of the most conclusive kind—those yielded by the

Mont St. Philippe and the Glassillaun dyke at Cleggan; but we have others at hand.

It has already been stated that Sterry Hunt has shown that the Laurentian rocks of Canada are intersected by two classes of veins, distinguished as "granitic" and "calcareous." "Most of their characteristic minerals are common to the two classes; and it is easy to trace a gradual change from the typical granitic veins to those in which carbonate of lime is the predominant mineral" *; hence "it is impossible to draw any definite line between" them. The fact is, the one passes by "insensible degrees" into the other through the gradual decrease of mineral silicates and the increase of carbonate of lime.

The same authority has also shown that there are certain Laurentian beds, "generally granitoid or gneissoid in structure, which may be described as pyroxenites, from the prevailing mineral," pyroxene (augite): this mineral is "sometimes nearly pure, and at other times mingled with mica, or with quartz, and orthoclase, and often associated with hornblende, epidote, &c." The beds are occasionally of great thickness, and are "then often interstratified with beds of granitoid orthoclase gneiss, into which the quartzo-feldspathic pyroxenites pass, by a gradual disappearance of the pyroxene." "These peculiar strata, which contain at the same time the minerals of the associated gneiss and of the limestones," also "gradually pass, by an admixture of carbonate of lime, into the adjacent crystalline limestones" †—those whose origin is under consideration: it is noteworthy that, besides serpentine, they, too, contain the mineral species of the granitoid gneiss and the pyroxenites. Thus the opposite extremes of the Laurentian series of rocks, from the essentially silacid to the highly calcareous members, are linked together by intermediate gradations.

Another remarkable point remains to be noticed. It is stated by Sterry Hunt that "in their mineral character the calcareous veins so closely resemble the stratified limestone that the different geographical relations of the two alone enable us in some examples to distinguish between them," and that "the observer will often find it difficult to determine whether a detached mass, or an imperfectly displayed outcrop of crystalline limestone, belongs to a bed or a vein" ‡.

* Geology of Canada, 1866 (Dr. Sterry Hunt's Report, p. 191).
† Ibid. p. 185. ‡ Ibid. p. 188.

In a former Chapter mention was made of many of the minerals, both in the limestone beds and the calcareous veins, having more or less rounded or corroded surfaces. It would appear that this phenomenon is more common in the beds than in the veins. Referring to the corroded minerals belonging to the veins, Sterry Hunt avers that "this rounding of the angles of certain crystals appears to me to be nothing more than a result of the solvent action of heated watery solutions." But he holds a different view respecting these bodies in the crystalline limestones: they "sometimes occur in small distinct crystals, but more generally in rounded irregular grains, which present a marked contrast to the same minerals occurring in the veins. This rounded form of the minerals in the beds of limestone, is to be carefully distinguished from the rounding of the crystals in the veins. In the latter case the rounding is by no means constant, and is confined to a few species, while in the limestone beds it will be found that a rounded form characterizes alike apatite, and quartz, and such silicates as pyroxene (augite), hornblende, serpentine, and chondrodite"*. In accordance with his view, maintaining the organic origin of "*Eozoon Canadense*," he declares that the "rounded form" which characterizes such silicates, occurring in the beds, has been "demonstrated, in many cases at least, to be due to no such subsequent action, but has been given by the calcareous organic structure, in whose chambers these silicates were originally deposited"†.

It will not be expected that we can accept this so-called demonstration after having shown, with other evidences to which the merest allusion is only necessary at the present moment, that the "chamber-casts" of "*Eozoon Canadense*," when they are not bordered by the "nummuline wall," are usually coated with flocculite, resulting from the disintegration and waste of their component serpentine, just as the same part in its typical state is the product of corresponding changes in chrysotile—and more especially since "we now know," as stated by Sterry Hunt, "that water, aided in some cases by heat, pressure, and the presence of certain widely distributed substances, such as carbonic acid, alkaline carbonates, and sulphides, will dissolve the most insoluble bodies." And considering that watery solutions of the kind are ever present,

* Geology of Canada, 1866, p. 190. † Ibid. p. 191.

and all-pervading, in deep-seated rocks, as repeatedly contended for by the author, the fact may be taken as positive evidence that the "granitic veins" and the peculiar pyroxenic beds were alike penetrated by such solutions, whose solvent powers were exerted on the mineral silicates, whether belonging to the beds or the veins. As to the "marked contrast" which it is endeavoured to make out between the "rounded irregular grains" of the former and the "rounded crystals" of the latter, it seems extremely doubtful that the difference is more than one of degree: it is not, however, beyond an explanation on our view. As the veins are clearly posterior to the beds, the latter have an important factor in their favour: *time* would enable the corroding agents to act more decidedly and more generally on the "grains" in the beds than on the "crystals" in the veins. Moreover the "contrast" may also be due to a difference in solvent power between the penetrating water in the two cases.

Again, the action of solvents, by rounding the "grains" or "crystals," involves removal and displacement, whether it takes place in beds or veins; and as there are no openings surrounding either the grains or "crystals," but on the contrary an environment of calcite, obviously the latter is the replacement substance. And it may be equally affirmed that *all* the calcite which occupies the interspaces between the grains and crystals is in the same predicament, as in certain pseudomorphs w mineral silicates have been replaced by a mineral carbonate.

Applying this reasoning to the solution of the problem in regard to the origin of the Canadian bedded "crystalline limestones" or hemithrenes, it will be understood that we have simply to enlarge the field of solvent action. We may take a region occupied by contorted granitoid, labradoritic, hornblendic, and other gneisses, permeated by thermal water charged with a carbacid solution—the water having gained admission into the rocks either directly or indirectly from an overlying ocean, along zones of outcrops, jointing, or porous beds, the direction of such zones corresponding to the strike of the rocks: by this means the gneisses would become regionally converted into hemithrenes, the quartzo-feldspathic diorites, with their admixtures of calcite and serpentine, being "beds of passage between the two rocks."

We may now summarize the evidences and considerations which have been brought forward by way of substantiating our view as to the origin of the Archæan "crystalline limestones" of Canada—that they were silacid metamorphics which have become chemically and otherwise changed or methylosed into calcitic masses (hemithrenes), it having been shown:—

That the calcite of the calcareous structures of "*Eozoon*" in the ophite of the Canadian Laurentians is a replacement of serpentine and other mineral silicates;

That the mineral silicates, augite, hornblende, &c. (characteristic of hemithrenes), are often pseudomorphosed into calcite;

That only under extremely limited conditions are chemically precipitated limestones formed;

That no reliable evidences have yet been adduced proving the existence, during the Archæan periods, of lime-elaborating organisms (the only other kind of agency admissible on our part), through whose intervention the "crystalline limestones" could have been formed;

That the peculiar convoluted or tortuous lamination which distinguishes many of the "crystalline limestones" is only explicable, in the absence of cases to the contrary, on the idea of its being a superinduced phenomenon;

That the "crystalline limestones," also the associated ophites, are most abundant where they are interbedded with silacid rocks ("pyroxenytes"), whose essential minerals contain a large percentage of calcium (and magnesium) silicate;

That the gneissose rocks of St.-Philippe (Vosges) and of Glassillaun (Cleggan Bay) have been converted into hemithrenes by chemical action; finally,

That the great Archæan limestone formation of Canada consists of silacid gneisses which "pass insensibly" into hemithrenes through decrease of mineral silicates and increase of carbonate of lime,—that this formation is intersected by "granitic" and "calcareous veins," between which "it is easy to trace a gradual change,"—that the "pyroxenytes" and beds of limestone, also the "granitic" and "calcareous veins," include in a general sense identical crystalline siliceous minerals, with their surfaces more or less corroded by the dissolving action of heated water containing carbacid solutions, ever present in deeply-seated rocks,—and that, under the influences stated, the "granitic veins" and the bedded "pyroxenytes" have gradually undergone changes, which eventually converted them respectively into "calcareous veins" and beds of "crystalline limestone."

If any extensive beds of really pure limestone, resembling carrarite, are included in the great Archæan class of rocks, we should, rather than ascribe them to simple mineralization as we do the marble named, prefer the suggestion that they have been deprived of mineral silicates through the latter having been washed out by dissolving waters.

CHAPTER XIII.

WHY ARE LIMESTONES COMPARATIVELY RARE IN THE FORMATIONS IMMEDIATELY SUCCEEDING THE ARCHÆANS?

It has long been a matter of surprise that the Cambrians (the great series of rocks from the base of the Longmynds to the top of the Tremadocs), exceeding by far 40,000 feet in thickness, contain very few limestones; and the surprise is heightened when the paucity of the latter formations is compared with the vast masses of calcareous members belonging to the Archæans. We are referring to the Cambrians as they occur in Wales, Scotland, and Ireland, where their calcareous matter, comparatively a mere fractional constituent, is generally in a diffused state, or forming only thin layers.

Even by including Hicks's Dimetian series (which, however, he regards as Archæan), the "limestone beds" it contains at Porthlisky would form no valid exception to our statement, particularly as there are strong grounds for the opinion that they, and the ophite associated with them, do not retain their original composition*.

* Dr. Hicks has kindly favoured us with two small specimens taken from the "impure limestone bands" (from 1 to 3 feet in thickness) of Porthlisky, and belonging to his Dimetian series. This is separated by unconformity from his Pebidian series. He is inclined to consider both as Archæan, the Pebidians being overlain unconformably by unaltered Harlech grits. We find the specimens to be principally composed of white augite or malacolite, in short well-cleaved crystalloids confusedly aggregated. After decalcification they present themselves separated by interstices, cavities, and continuous passages, which before had been filled with calcite. In many instances the crystalloids of malacolite are translucent, and their angles are sharp; but often they are opaque, rounded, and incrusted with white flocculent matter. Every thing observed in connexion with the malacolite and calcite convinces us that the former is in course of replacement by the latter. The calcite is more abundant where the crystalloids of malacolite are eroded

It is not until the Lower Silurians are reached that limestones are found to occur to any extent; and these are either very impure, as in the Llandeilo flags, or they form thin beds, *e. g.* those in the Bala limestone of the Caradocs. The Durnes limestone in Sutherlandshire (a partly mineralized rock, older than our Llandeilo flags, and probably the equivalent of the Stiperstones, the bottom of the Lower Silurians) and the Coniston limestones may be regarded as improvements on their Welsh equivalents.

During the Upper Silurian period a marked change took place: limestones were developed on the grandest scale; and since then the formation of the same class of rocks to the like extent has continued throughout every succeeding period.

On the continent of Europe a similar scarcity of limestones characterizes the Cambrians, while a fair increase in their amount marks the Lower Silurians.

In North America the Cambrian limestones offer no very marked exception to contemporaneous formations in the British Isles or on the Continent.

Of the Acadian and Potsdam groups, which have been bracketed with the Welsh Llongmynds, Harlech Grits, and some other Lower Cambrians, the first contains no recorded non-crystalline limestones*; while the second only comprises some of inconsiderable thickness and occupying but small areas: such are the red sandy dolomites and other calciferous formations of Troy (N. B.), North-western Vermont, the Straits of Belle Isle (Newfoundland), and a few more places.

---

and covered with flocculite (which substance can only be their residue) than where they are sharp and translucent. The crystalloids of malacolite in a few cases were observed to be so far decreted as to assume rude branching forms. In one instance of this kind the form closely resembled typical imitative configurations. Intermixed with the calcite and malacolite we found a pale greenish-yellow granular substance resembling serpentine, bundles of prismatic epidote or actinolite, magnetite in octahedral crystals, a triclinic feldspar showing striping, and galena. This case strikingly resembles the one at Cleggan. If these specimens are characteristic of the limestone beds at Porthlisky, there can be no question about the latter being methylosed products.

* For reasons which will be understood after a perusal of the last paragraph of the present Chapter, we confine our remarks on the question under consideration to unaltered limestones.

In the Canadian group, presumed to correspond with our Upper Cambrians, we have evidence that a further increase of limestones took place, while the Chazy limestone (considered to be the youngest member of this group) and the Trenton limestones of the Lower Silurian system afford ample evidence of an abundant increase of the calcareous element.

With reference to the large increase of limestones in the last-named formations, the fact must be taken as showing that in North America the increase took place earlier than in the European areas.

Connected with this is the remarkable fact, already stated, that the earliest Palæozoic formations (those constituting the two Cambrians) contain few fossils with ordinary calcareous skeletons. Besides some others (fucoids) of no importance to the question at issue, the Cambrians yield the remains of Protozoans, Crustaceans, Cœlenterates, Mollusks, and Echinoderms, occasionally in abundance, and some of them (*Paradoxides*) of gigantic proportions; instead, however, of the skeleton of these organisms being ordinarily thick and composed of lime, as is general in certain of their classes respectively, they are (admitting a few apparent exceptions) thin, and for the most part horny, with comparatively a small quantity of phosphate of lime, and a much smaller of the carbonate—a circumstance which may be taken as favouring the idea that the Cambrian stages of organic development were not much beyond that of the larval evolution of the invertebrates whose remains have been noticed*.

The absence of calcareous fossils, and the rarity of limestones in the Cambrians, it may therefore be assumed, are correlative phenomena. It would seem that the seas of the very earliest Palæozoic periods were poorly charged with calcic constituents, and that they were thinly tenanted by lime-elaborating organisms. Was the latter consequent on the former?

The Cambrian rocks, whether occurring in North America, on the continent of Europe, or in the British Islands, consist of

* Mollusks and other invertebrates in their larval condition have horny shells. It seems extremely doubtful that there was much calcic matter of any kind in the Cambrian trilobites. Stony corals have not yet been found in the Cambrians. *Archæocyathus Atlanticus* (presumed to be a sponge), from the Potsdam of the Straits of Belle Isle, Newfoundland, may be calcareous. Stems of crinoids occur in the Potsdams.

materials precisely such as would result from the mechanical degradation of the gneisses, syenites, and other silacid members of the Archæans. The abundance of argillytes, sandstones, and other mechanically produced deposits, the rare accompaniment therewith of limestones, and the contemporaneous presence of non-calcareous fossils admit of no difficult explanation; but when viewed in connexion with the occurrence of 6000 feet of crystalline limestones in the preceding Archæans, the problem becomes inexplicable.

It must strike every geologist that, if such an enormous thickness of calcareous rocks was available during the Lower Cambrian period (that is, when these sandstones and argillytes were in course of derivation, through disintegration and denudation, from the Archæan gneisses &c.), we ought to expect that the great lime-bearing series referred to yielded, through organic intervention, a considerable amount of limestones. But where are they? Certainly not in the diffused quantities, or the "belts" and "bands," that are known, particularly as it is questionable that the lime in these cases is much in excess of the amount which could have been generated by the contemporary action of the carbonic acid, then pervading the atmosphere and different waters, on the calcium silicate in the labradoritic, hornblendic, and augitic débris produced by the disintegration and denudation of the Archæans during the Cambrian periods.

With respect to the period when the Archæan crystalline limestones were completely elaborated (for our hypothesis involves slow processes requiring immensity of time), we can offer no decided opinion. It would appear improbable that their denudation, operating throughout a vast chronological term that embraced the two Cambrian periods, and producing miles in thickness of débris, would give rise to no more than the small quantity of limestones that were deposited during these periods. On the other hand, however, there seems to be great probability that the crystalline limestones constituted the great factors which so vastly increased the number of organisms with calcareous skeletons, and the consequent calcareous deposits, during the Silurian periods.

To account for the paucity of early post-Archæan limestones, we offer the suggestion that, during the Lower Cambrian period there was no great series of crystalline limestones included among the Archæan rocks, that the hemithrenes and ophites constituting this series were only in process of elaboration when the Lower Cambrians were in course of formation.

It would be of importance to learn if any specimens of hemithrene or ophite occur in the Archæan conglomerate of the Coulonge river and other places. The circumstance would have to be accepted as proving that the methylosis which had developed the crystalline limestones had set in antecedent to the formation of the conglomerate.

The explanation involved in the above suggestion embraces all the facts of a problem which is unresolvable by either of the doctrines we are opposed to, as regards the origin of the Archæan hemithrenes and ophites; for if one were true, its advocates would be able to point to something less vulnerable than sparingly-developed limestones of the Cambrians; or if the other were a fact, its supporters would be able to refer to other than the little better than corneous fossils characteristic of the same rocks. Again, why chemical calcareous precipitates should cease, or why the presumed "*Eozoon Canadense*" should precede others only furnished with skeletons of a larval type, while it never puts in an appearance subsequent to the Archæan periods, except in the like methylosed and crystalline rocks, as the ophites or hemithrenes of Connemara, Ceylon, Aker, Mt. St.-Philippe, the Isle of Skye, and other places (most of them considered to be Postarchæan, the last-named one being Jurassic), are also questions which require to be satisfactorily answered.

In the meantime we must continue to put faith in our suggestion that the rarity of limestones in the Lower Cambrian system is due to the absence of preexisting calcareous rocks from which they could be derived—that the great series of Archæan crystalline limestones, which would represent such preexisting rocks, was only imperfectly elaborated during the Lower Cambrian period. This we beg to be accepted as our answer to the question, Why are limestones comparatively rare in the formations immediately succeeding the Archæans?

The preceding observations, we wish it to be understood, refer to Cambrian calcareous deposits that have undergone neither mineral nor chemical changes: we are thus particular because it is well known there are certain metamorphosed groups which comprise crystalline limestones and ophites, in Canada, the State of

New York, and New Brunswick, considered by many geologists to be of post-Archæan age, as the altered Quebecs, Emmons's "primary limestones," &c. A corresponding formation (the limestone of Essex and adjacent counties) is considered by Professor James Hall to belong to a "period subsequent to the deposition, metamorphism, and disturbance of the rocks of authentic Laurentian age," and to apparently hold a place in the series between the Laurentian and the "Potsdam periods; but whether of Huronian age or otherwise" he does "not pretend to say; and it may even prove of later date than this"*.

Contending for the existence of true Archæans or Laurentians in the highland region of Northern New York, and that these rocks are unconformably overlain by a younger and well-developed series of gneisses, mica- and hornblende-schists (including *crystalline limestones* and ophites) in Westchester and other adjoining counties, Prof. Dana has of late endeavoured to prove, by their relations to certain fossiliferous deposits occurring in neighbouring places, that the younger metamorphics are of Upper Cambrian and Lower Silurian ("Calciferous," "Quebec," "Chazy," and "Trenton") ages†. Should this prove to be correct, there will be no need of trying to make out that the crystalline limestones they contain were ever otherwise than calcareous; for as such they may have been simply mineralized. Nevertheless it does not seem improbable that some of the Westchester crystalline limestones may be methylotic products, particularly as there is no reason to exclude from the series containing them two or more older groups, the Acadian and Potsdam, whose remarkable deficiency of calcareous matter in their unaltered condition would render it highly probable, should they in their metamorphosed state contain well-devoloped crystalline limestones and ophites, that metamorphosing agencies had generated such limestones.

* 'American Journal of Science and Arts,' 3rd series, vol. xii. p. 300.

† American Journal of Science and Arts,' 3rd series, vols. xix. and xx., "Geological Relations of the Limestone Belts of Westchester Co., N. Y." The reader is referred, in this connexion, to Selwyn in 'Canadian Naturalist,' new series, vol. ix. pp. 17–31.

CHAPTER XIV.

SOME CRYSTALLINE LIMESTONES ARE SIMPLY MINERALIZED.

It will be recollected that we have made an exception to certain crystallized calcareous rocks related to hemithrenes being of purely methylotic origin. It seems probable that this exception may apply to the marbles of Dalnein in Strathdon, Glen Elg, Glen Tilt, and the neighbouring localities: still we cannot altogether reject the idea that there are no methylosed examples amongst these marbles, even should they be of post-Archæan age, just as it may be doubted that *all* the Westchester crystalline limestones are simply mineralized products. The fact mentioned by Dana that "green hornblende in minute rounded crystals is occasionally found disseminated through the limestone of Westchester," and the similar well-known fact of the Scotch marbles being shotted with decreted crystalloids of augite &c., involve the action of corroding or dissolving solutions—the prime agents in methylosis—which marbles, according to Heddle, contain trifling specks or remains of augite, and are of post-Archæan age; and for this reason doubts may be entertained of their belonging to the group treated of in Chapter X.

But we see no improbability of an impure limestone belonging to the Cambrian, Silurian, or later systems *, through mineralization, changing into a rock which it would be difficult to distinguish from a hemithrene †. Therefore, until further light has been gained respecting the geological position of the marbles of Glen Elg and other places referred to by Heddle, and generally considered to be Upper Cambrian or Lower Silurian in age, we consider it safest to admit that some of them may have been calcareous in their original condition, especially as the Durness limestones are proved to be early Palæozoic by their fossils.

* Some of the Scandinavian "primary limestones," described by B. Cotta (Zeitschrift der deutsch. geol. Gesellschaft, 1852, Band iv. pp. 47–53), are undoubtedly of this class; but we strongly suspect that many others he has noticed (Aker &c.) are methylotic.

† Excluding its ophitic portions, much of the Isle-of-Skye "white marble" may be an example of mineralized limestone.

Many of the bedded crystalline calcitic rocks of Connemara appear to be simply mineralized metamorphics. There are calcareo-siliceous bands, more or less crystalline, commencing at Lough Bofin, a little north of Oughterard, and skirting, apparently continuously, the mail-road on to Ballinahinch, thence across the mountains to Letterfrac*. There are good reasons for believing that they were also originally impure limestones. Still we entertain a suspicion that the "crystalline limestones" which have been noticed, by Mr. R. Glascott Symes, occurring in what appear to be corresponding metamorphic schists in Mayo, will turn out to be methylosed hemithrenes. They are "seldom following the foliation of the beds, but occur along lines of great fault." "From such evidence," according to Mr. Symes, "it may be assumed that this crystallized limestone has been formed by infiltration or percolation of bicarbonate of lime, from the once overlying Carboniferous rocks, into joints or cracks in the now metamorphic series." Prof. Hull, however, expresses his aversion to this view, and considers these limestones "to belong to the group of strata in which they are found, just as similar limestones do in the West Galway district"†.

It is highly probable that the pure marbles (carrarite) of the Apuan Alps are simply mineralized. But it rarely happens that the Irish cases to which we have referred are unassociated with methylosed rocks—that is, beds chemically changed into dolomites, ophites, and even into true hemithrenes. Moreover the limestones in the north-east of Donegal are undoubtedly no more than mineralized, and probably of Lower Silurian age; while the calcitic rocks occurring further west, filled with idocrase and other mineral silicates, and interbedded or intimately associated with granites &c., may be of methylotic origin and represent a much earlier geological period.

* We are not sufficiently acquainted with the stratigraphy of the calcareous marbles and ophites of the Barna-Oran district, east of Ballinahinch, to offer a decided opinion as to whether the former are methylosed or mineralized—though, from their being associated with the latter, the probability seems strong to us that they were originally silacid rocks.

† Explan. Mem. of Sheets 41, 53, and 64, Geological Survey of Ireland, p. 12. Mr. Symes mentions other cases of the kind occurring in Mayo—beds of micaceous limestone in mica-schist, in some places traversing the latter at right angles, at others following the direction of its folia. See Expl. Mem. of Sheet 75, p. 12, and Expl. Mem. Sheets 63 and 74, p. 11.

CHAPTER XV.

DOLOMITES AND DOLOMITIC ROCKS HAVE UNDERGONE METHYLOSIS.

Dolomites, in our opinion, are in all cases products of methylosis; but the phenomena have been effected in two different ways —one by substitution of their original basic and acidic components, as in the dolomitic hemithrenes of the Canadian Archæans, and the other by replacement, more or less, of only their original basic carbonate of lime. Although the rocks we propose to consider in the present Chapter are of sedimentary origin, it must be understood that we do not deny the probability of certain igneous and silacid masses (veins and dykes in the Canadian Archæans), through methylosis, having been dolomitized.

But the rocks we are more directly engaged with are the magnesian limestones which, chiefly belonging to various systems of the primary and secondary groups, are spread over extensive areas of Europe and North America, and beneath or associated with which nothing is present except sedimentary deposits in an *unaltered* condition. Our typical example is the Permian magnesian limestone of the north of England.

Various opinions have been propounded as to the origin of the magnesian carbonate present in this limestone and others analogous to it. There are some, as Apjohn, T. Richardson, Hunt, and Ramsay, who believe that this compound is an original constituent; while others, as Virlet, Scouler, Haidinger, Von Morlet, Bischof, Johnston, Sorby, and Hardman, make it to be a superadded ingredient: the last opinion is methylotic. But let the different opinions of both classes be examined, and it will be found that all are at variance as to the *modus operandi* which has developed the magnesian constituent.

Von Buch's celebrated theory of dolomitization (applied, however, to rocks we have excluded) advocates that the limestones forming the dolomite mountains of the Tyrol have been impregnated with magnesia sublimed from the adjacent diorites.

Reverting to the magnesian limestones to which we have restricted ourselves, our view, as already made known in one of our memoirs*, is methylotic; but as it differs in some important particulars from others that have been published, we proceed to give a description of it. Our objection to the opposite hypothesis involving simultaneous precipitation of carbonates of magnesia and lime is based on the absence of any recent deposits of the kind.

The magnesian limestones of the north of England are plentifully fossiliferous; and from the general facies of their organisms, also their wide distribution, it seems far from improbable that they have been formed in deepish water of a wide-spread ocean†. There are beds, as the Durham marl-slate and the Manchester marls (the one underlying and the other overlying the magnesian limestones), which are largely characterized by carbonate of magnesia.

To explain the methylosis of these different rocks the following hypothesis is suggested. It is based on the assumption, which has gained many adherents of late years, that during the Triassic period, particularly towards its close, the widely-spread ocean which had thrown down the Permian deposits became reduced to mere inland seas resembling the Caspian and Lake Aral.

Our hypothesis assumes that, under these altered circumstances, the water of the Triassic seas, besides much of it disappearing through evaporation, sank into the subjacent rocks, and that the salts of this water, under the force of chemical reactions generated by new conditions, became variously combined with the materials of these rocks. The abundance of chlorides of sodium, magnesium, and calcium, and of sulphates of magnesia and lime in sea-water readily explains the origin of the rock-salt and gypsum in the lower members (red shales of Cheshire and Lancashire) of the Keuper ‡. We are more especially concerned, however, with the other deposits, resulting from the magnesium

* Quart. Journ. Geol. Soc. vol. xxii. pp. 211, 212.

† See 'Monograph of the Permian Fossils of England,' Palæontographical Society, Introduction, pp. xvii, xviii; also Appendix in present work.

‡ The thick beds of rock-salt at Nantwich, Cheshire, appear to be of

chloride and sulphate. As both are highly soluble compounds, and have no particular affinity for the basic substances of ordinary Triassic rocks (chiefly sandstones), they would penetrate the latter without being precipitated or producing reactions. But on coming into contact with the underlying calcareous marls and limestones of the Permian system, mutual decomposition would ensue. A portion of the lime of these rocks would be taken up by the chlorine or sulphuric acid (originally in combination with the magnesium of the Triassic sea-water) and carried off in solution; while the base that had been in union with these acids would combine with the liberated carbonic acid to form carbonate of magnesia *.

The latter compound, by virtue of its affinities, would become combined or incorporated with the remainder of the base of the marl or limestone †; and thus these rocks would become dolomitic or converted into dolomite ‡.

Another kind of methylosis, however, supervened in some localities. The Permian magnesian limestones in the north of England are for the most part compact, earthy, or microcrystalline; but in the neighbourhood of Sunderland they are singularly characterized by imbedded coralloidal, globose, mamillated, and other forms, whose secondary or superinduced origin, though first proved by Sedgwick, cannot be said to be generally admitted. Consisting for the most part of carbonate of lime in a crystalloidal condition, and containing only a few per cent. of carbonate of magnesia, it is a fair inference that these varied forms are a local development, caused by some demagnesiating agent which penetrated the depositional partings and

---

subaerial origin, in which case they may have resulted from the evaporation of the salt water of lagoons.

* It may be admitted that carbonic acid would also be present in the water, and thus assist in the reaction.

† Owing to the varying percentage of carbonate of magnesia in these rocks, it is not an undisputed point that this compound is in chemical combination with the carbonate of lime.

‡ The paste of the Bristol dolomitic conglomerate may have been derived from a mechanically abraded Permian magnesian limestone; but the pebbles contained in it have clearly been detached from adjacent beds of Carboniferous limestone &c. The drift of Galway is essentially a calcareous deposit derived, by glacial degradation, from the carboniferous limestone of the district, and has consequently been *mechanically* formed.

well-developed joints of the rock*; for it is a fact that they (coralloidal forms) are present on the grandest scale in immediate connexion with these divisional structures, shooting off from their planes, and appearing as if they were globose nullipores, stromatoporal sponges, branching corals, and other organisms †.

This view of the demagnesiation of the coralloidal limestone seems to be perfectly warranted, since it is paralleled in the known cases of calcite occurring as a pseudomorph after miemite.

According to our hypothesis of the dolomitization of the north-of-England Permian rocks, the magnesiated water has descended from overlying or subaerial sea-basins. But possibly in other cases, as in Ireland and the north of England, where local examples are common of ordinary Carboniferous limestone suddenly becoming changed into dolomite, the water may have ascended, through jointings and deposition-partings, from subterranean sources. We entertain no doubt, however, that the water was originally derived from the sea.

There remains to be noticed another methylotic hypothesis, which has been suggested by Apjohn ‡ and Grandjean. Mr. Hardman adopts it in explanation of the Irish local examples referred to in the last paragraph §. He assumes that the limestone in these cases originally contained carbonate of magnesia, derived from corals and other organisms, a few per cent. (rarely 7) having been found in some living species. In limestones of the kind, when penetrated by water charged with carbonic acid, this solvent, it is suggested, would act on their calcareous

* There are beds containing fossils at "Byers's Quarry," on the coast a few miles north of Sunderland, which have been demagnesiated, but without development of coralloidal structures; they, however, are highly crystalline.

† At the time of writing my Monograph of the Permian Fossils (see Introduction, pp. xiv–xxi) I was of opinion that the Permian limestones of Durham were originally dolomitic, but that in certain localities, as near Sunderland, they had undergone methylosis, the remarkable configurations being the result. A fine collection of these configurations, formed by myself during a period of several years, is contained in the Geological Museum of the Queen's College, Galway. An inspection of them will fully bear out the description of their similarity to certain organisms.—W. K.

‡ "Analysis of some Irish Dolomites," Journal of the Geological Society of Dublin, vol. i. pp. 368–381 (1838). Apjohn, however, is more in favour of the rocks he noticed having been originally dolomitic.

§ Proc. R. Irish Academy, no. 7, pp. 705–730 (1876).

portion, carrying it off as a bicarbonate in solution without removing the magnesian constituent. According to Dr. Apjohn, "it is not improbable that this removal of the carbonate of lime may proceed until what remains behind contains the two carbonates in the ratio of atom to atom," or in the proportion they are presumed to be in dolomite. This decalcifying process, it is conceivable, ought in many cases to be consummated by the removal of all the calcareous matter, and the consequent conversion of what was once a dolomitic limestone into a residual mass of magnesite. But it is extremely doubtful that any thing of the kind on a commensurate scale is known.

CHAPTER XVI.

THE CHRONO-GEOLOGICAL RANGE OF OPHITES AND RELATED ROCKS, AND THE AGE OF THEIR METHYLOSIS.

As, with certain exceptions already noticed, methylosis is consecutive to mineralization, it may be taken as granted that, where both phenomena have prevailed, the former is of subsequent elaboration to the latter.

Our remarks on this subject, however, must be brief, as it is beset with no common difficulties, especially, as will have been seen, in respect to the oldest or Archæan rocks. Indeed, amongst later systems insurmountable difficulties are encountered, as in the case of the ophites and hemithrenes of Ireland and Scotland, which render it impossible to determine, with any but the most distant approach to certainty, the geological age in which these rocks passed through their last phase of metamorphism. And to refer to post-Archæans of the kind in North America, enough has been mentioned to show that not only the period of their methylosis, but the age of their deposition is at present involved in the greatest obscurity.

Another difficulty attaches to rocks of a later age. In Northern Italy, methylosis has been developed in formations ranging from an early period to the Jurassic; and there are strong grounds for believing that in this region the formations of one system have undergone a change of the kind before those of a later system had been deposited. The only certainty in connexion with these rocks is that the latest change is of post-Jurassic age.

The ophitic marble of the Isle of Skye, which is Liassic, it seems highly probable, has been mineralized and methylosed in much later ages; possibly the latest is synchronous with the volcanic upbursts that have ravaged the western borders of

Scotland, and which, according to Prof. Judd, took place during an early Tertiary period.

In Eastern Europe serpentine masses are common in association with Upper Secondary formations. The euphotides and other igneous rocks of Central Italy, there can be no doubt, have broken through Cretaceous "*alberese*" limestone and Eocene sandstones and schists during a late Tertiary period, thereby producing the beautiful ophicalcite (*oficalce*), ophieuphotide, and gabbro verde for which Liguria is so renowned.

It would even appear, from the discoveries of Achiardi, that the methylosis of rocks into serpentine is in process of elaboration at the present day in Tuscany. That the same process is still in operation amongst deep-seated rocks permeated by heated mineral waters, may be inferred with perfect confidence.

APPENDIX.

THALASSA AND XERA IN THE PERMIAN PERIOD.

By Professor WILLIAM KING, Sc.D. &c.

In my 'Monograph of the Permian Fossils of England'* (1850) I expressed the opinion, based on the general character of their respective groups of fossils, that the formations of the Permian system had been deposited, some in shallow seas, and others in a deep ocean. In using these expressions it was meant to limit the application of the last one to depths known to long-line fishermen, and ranging from 50 to 100 fathoms or more†; for when this opinion was stated very little had been published respecting the existence of living things in the abysses of the great ocean.

Further, in consideration of the fact that the Permian formations occupy widely separated areas, I inferred that the ocean (or seas) in which they were deposited was of considerable extent, encompassing, at least, a great portion of the European quarter of the globe.

Investigations on Permian geology made during the last thirty years have in no way invalidated these conclusions; yet Dr. Ramsay, in his 'Physical Geology and Geography of Great Britain,' and certain of his memoirs, has been induced to interpret the evidences I relied on in a totally opposite sense.

From the "dwarfed aspect" of the Permian shells, and their "poverty in number," it is Dr. Ramsay's "belief" that the waters they lived in "were of an inland unhealthy nature," comparable to those of "brackish lakes" like the Caspian.

Before discussing these points, it is necessary for me to mention that I have lately (June 18, 1880) advanced the hypothesis that the regions over which the different rock-systems formulated by geologists are spread have each undergone,

* Introduction, pp. xiii, xiv.

† Several years ago I named a characteristic form of *Buccinum undatum*, var. *pelagicum*, on account of its living at depths ranging from 55 to 80 fathoms (Ann. & Mag. Nat. Hist. 1846, vol. xviii. p. 249).

during the period of formation of any one system, a cycle of vertical movements, upward and downward, which alternated with those of another cycle in an adjacent region*. Thus, assuming a given region to be affected by an upward movement, it would be in alternating correlation with an adjacent region, where the opposite or downward movement would be going on. These movements would necessarily cause a region to be occupied by land, say in the beginning and ending of a given systemal period†, and by water in the middle division of the same chronological term.

It will also be understood that the maximum of the downward movement of any one period would submerge a region to its greatest depth beneath the level of the sea; while the maximum of the upward movement would place it, as land, at its greatest altitude.

Taking the vertical movements of a single cycle, the region affected by them would present a succession of land- and sea-features representing their different stages of development. Thus, in a region which has attained its maximum elevation, and which it may be assumed is in the 1*st stage,* land interspersed with lakes, rivers, and bordered by estuaries would predominate, producing lacustrine and estuarine marls, clays, and sands; also other deposits, often terrestrial or conglomeratic, all more or less charged with the remains of a fauna and flora bespeaking the prevalence of widely-spread terrestrial conditions. In the 2*nd stage,* the movement being downward, and the sea necessarily encroaching on the lowlands, marine, littoral, and shallow-water deposits—argillaceous, sandy, marly, and calcareous—would be thrown down. In the 3*rd stage*—that in which the downward movement reached its maximum, and when the sea (Thalassa)

* An abstract of a paper containing this hypothesis appears in the 'Proceedings of the Royal Irish Academy,' ser. 2, vol. iii. (Science), No. 5, Dec. 1880. A region is assumed to be of continental extent. See Supplementary Note A.

† By a "systemal period" I mean a division of geological time, during which a rock-system was in process of formation: it may be said to correspond to a single cycle of vertical movements. Taking the masses of deposit constituting a rock-system, the mutations of its life-features, and the successive physical phenomena it witnessed, the conviction is strong in me that a systemal period is so vast as to be utterly beyond approximately calculating.

dominated over the region—pelagic deposits, eminently calcareous and containing the remains of a deep-sea fauna, would be widely spread. Next, in the *4th stage*, opposite vertical movements supervening, the previously developed shallow-water phenomena would be repeated. Further elevation would bring on the last and *5th stage*, in which, again, "the dry land (Xera) appeared" (ὤφθη ἡ ξηρά. Septuagint, Gen. i. 9).

The following table will illustrate this hypothesis in its main points, at the same time affording evidence of its soundness by showing that one of the type rock-systems is constituted in accordance with its principles * :—

		Permian conglomerates, &c.
5th Stage. Lacustrine, estuarine, and terrestrial deposits	Carboniferous System.	Grits. Coal-measures of Durham and other places. Kilkenny coal-beds.
4th Stage. Estuarine and shallow-sea sediments		Yorkshire Ganister coal series. Northumberland Millstone-grits. Malbay flags.
3rd Stage. Deepish-water and pelagic formations		Yoredale rocks. Scar Limestones, in many places alternating with shales.
2nd Stage. Shallow-sea and estuarine deposits..............		Tweedian beds. Lower Limestone shales. Lower coal-beds (? estuarine).
1st Stage. Estuarine, lacustrine, and terrestrial dejections ..		Knocktopher *Palæopteris*-sandstones. Conglomerates.
		Devonian.

If facts could be reconciled with Dr. Ramsay's belief, I should have no hesitation in discarding the Permian group of rocks as a system, and transferring it to the Carboniferous. Feeling

* A few notes are necessary in this place. The recognized rock-systems afford ample evidence that the various sedimentary developments involved in this hypothesis have often deviated in a marked manner from regularity; they have been irregularly recurrent, and have varied in horizontal and vertical extent, in time-limitation, and in force, as evidenced by the sudden and repeated changes (from freshwater to marine conditions) in rocks of a formation, the presence of a well-developed formation over a certain area and its absence in another and contiguous area, the dissimilarity between syn-

satisfied, however, that the group contains formations referable in the main to the different stages of a cycle of vertical movements, I cannot but regard it as of systemal rank, though I admit that it cannot be equalled in comprehensiveness with certain other rock-systems.

The following table exhibits a series of formations representing the different stages, as successively developed in the course of a cycle of vertical movements which took place during the Permian period :—

	Lancashire Triassic Bunter sandstones.
5th Stage.	St.-Bees (Whitehaven) red sandstones.
4th Stage.	Manchester marls and thin-bedded limestones. Yorkshire and Barrowmouth (Cumberland) *Schizodus*-limstones and gypseous marls. Sunderland coralloidal limestones. Hartlepool and Marsden limestones. Ardtrea (co. Tyrone) magnesian limestone.
3rd Stage.	Humbleton (Durham) fossiliferous limestones.
2nd Stage.	Midderidge (Durham) compact limestones. Durham marl-slate.
1st Stage.	Pontefract sandstones. Solway red-sandstones. Westoe (Durham) *Sigillaria*-sandstones.
	Coal-measures of the Carboniferous system.

chronous formations in separated areas of one and the same region, and the vast difference in thickness of the rocks severally constituting the different systems.

Rock-systems are often deficient in formations representing the 1st and 5th stages: such are usually tripartite, as the Triassic; though in some instances of the kind the missing formations have doubtless been removed by denudation, which, as will be readily understood, must be energetic during these two subaerial stages. The *Carboniferous system* may be taken as an example in which all the stages, especially the 1st and 5th, are well represented. The *Triassic system*, which on the continent comprises three formations corresponding with the 2nd, 3rd, and 4th stages, is in the British Isles devoid of any representative of the middle one (3rd) of these stages. On the other hand, this stage is well developed in the *Cretaceous system* of the south of England and other countries; but the 5th stage is poorly represented in most regions, except, seemingly, in the Rocky Mountains and the more western ranges, where occur intercalated formations containing *Ammonites*, *Baculites*, &c., and Tertiary plants, which indicate the missing time-link between the Cretaceous and Eocene periods. (See Prof. J. Stevenson, American Philosophical Society, June 18, 1875.)

To accept Dr. Ramsay's belief, it would be necessary to overlook altogether the middle (or 3rd) and much of the 2nd formations of the Permian system.

Reverting to Dr. Ramsay's grounds for assigning a brackish-lacustrine origin to the Permian rocks in general, I propose, in the next place, to notice the one founded on the "poverty in number of the fossils" they contain.

Conclusions on this point are not to be influenced by considerations arising from the study of individual characteristics, but of general facts. Evidently Dr. Ramsay has been influenced in his belief by the fact that brackish lakes, compared with sea-basins, are sparsely inhabited by molluscs; but he overlooks another fact of importance, that depths exceeding 100 fathoms are not so prolific in animals of the kind as shallower bottoms. "Poverty in number" as a feature of deep-sea life affords a more satisfactory explanation of the point in question than the corresponding feature in its brackish-water relations.

The same argument attaches to the "dwarfed aspect" of the Permian invertebrates; for the term "dwarfed" is equally applicable to a deep-sea fauna, which usually consists of small and delicate species. Such forms as *Productus horridus*, with its long projecting hinge-spines, and *Fenestella retiformis*, with fragile fronds six to eight inches in spread, and several other tender organisms could only live at considerable depths, where still water prevailed. But it cannot be said that the Permian fossils are particularly dwarfed; the Bryozoon just referred to is a strong fact against any statement of the kind. *Spirifer alatus* does not compare unfavourably with most of its Carboniferous congeneric species; and *Camarophoria multiplicata* is a match for the largest of its allies, *C. Kingii* (Davidson), of the Carboniferous limestones. Several other Permian fossils could be mentioned in this comparison. It is quite true that, so far, the Permian rocks have not yielded any thing equal to *Productus giganteus* and *P. ponderosus* and other heavy fossils, especially corals; but these may be safely consigned to shallow seas.

It is necessary to mention that the Permian palliobranchs were denizens of deep water; for in fossiliferous beds which bear all the marks of having been formed in shallow water these shells are absent. Certain beds of coralloidal limestone on the shore at Sunderland which came under my notice have their surfaces distinctly rippled; but they contain no fossils of the kind—merely bivalves (*Schizodus* &c.). These beds, however, do not belong to the deep-water stage; for they overlie the limestone (fossiliferous *par excellence*) which crops out at Humbleton and other inland localities. Other beds occurring in Lancashire, Yorkshire, and Cumberland, which possess similar palæontological characteristics, are referable to the same stage.

Another fact of importance, which also seems to have been overlooked by Dr. Ramsay, is that the Permian invertebrates, which he assumes to have lived in "brackish water" of an "inland unhealthy nature," are, as a rule, well-developed species, and bear the stamp of having inhabited an open sea. How can it be conceived that palliobranchs, only known as denizens of the sea, could exist in brackish-water lakes?

As to why an exuberant variety of invertebrate marine life is not a characteristic of the Permians, it must be borne in mind that information on the distribution of these rocks is still very limited. In the face of certain deposits in North America and Central Asia, doubtfully referred to the Carboniferous, or Permian Triassic system, it seems preferable to wait until they have received fuller attention. In the Austrian Alps and in Northern India there occur fossils (*Ammonitidæ, Goniatidæ,* &c.) of types indicating that the rocks containing them may be of Permian age.

Now, as my theory of regional cyclical vertical movements admits of different conditions prevailing at the same time in separated regions, it is not at all improbable that the marine formations referred to may belong to the pelagic stage, and nevertheless be synchronous with those which in Western Europe gave birth to the shallow-water and estuarine (2nd or 4th) deposits of the Permian system. I would suggest the application of this argument by way of explaining the difference between the rock-systems of Europe and their presumed equivalents in extra-European regions.

Dr. Ramsay has introduced into his remarks on the Physical Geography of the Permian Period * another matter, which he

* Op. cit. pp. 149, 150.

evidently thinks supports his belief, but which, as will be learnt from a perusal of Chapter XV., I am totally opposed to. To quote his words:—"I repeat that the Permian magnesian limestone was not, as used to be supposed, formed in the sea, but in an inland salt lake, under such circumstances that carbonates of lime and magnesia were deposited simultaneously, probably by concentration of solutions due to evaporation. In an open sea lime and magnesia only exist in solution in very small quantities; and limestone rocks there are formed (as in coral reefs) by organic agency." If, as seems to be meant by the last sentence, lime and magnesia are unlikely to be precipitated in an open sea (a view I quite agree with—not, however, because salts formed of these bases are in small quantities, which statement is a slip of some kind), it is to be apprehended that there is little chance of their being deposited in an inland salt lake, considering that Dr. Ramsay has not been able to point out a single instance of the kind.

"In some of the lower strata of the magnesian limestone, when weathered, it is observable that they consist of many curious thin layers, bent into a number of very small convolutions, approximately fitting into each other, like sheets of paper crumpled together. These dolomitic layers convey the impression that they are somewhat tufaceous in character, as if the layers, which are unfossiliferous, had been deposited from solutions. In other parts of the district, along the coast of Durham, large tracts of the limestone consist of vast numbers of ball-shaped agglutinated masses, large and small; and I have observed in limestone caverns, in pools of water surcharged with bicarbonate of lime, that sometimes precipitation takes place on a small scale, producing similar nodular bodies. It is notable also that, when broken in two, many of the balls are seen to have a radiated structure; that is to say, from the centre rudely crystalline-looking bodies, all united, radiate to the circumference. In other places we find numerous bodies radiating in a series of rays that gradually widen from the centre, and are unconnected at their outer ends, which reminds the spectator of radiating corals. There is, however, nothing organic about them; and I do not doubt that they owe their growth to some kind of crystalline action going on at the time that the limestone was being formed."

The facts on which the above description is based I must regard as affording no more support to Dr. Ramsay's belief than the fossils that have been under consideration. It appears to me that the coralloidal and other bodies described in the foregoing extract, besides having been examined with insufficient deliberation, have not been considered in connexion with the evidence adduced by Sedgwick and myself, proving them to be of superinduced origin. I pointed out upwards of thirty years ago their relation to well-developed rock-jointing*, a fact which may be unhesitatingly accepted as disproving the idea "that they owe their growth to some kind of crystalline action going on at the time the limestone was being formed." And with respect to the presumed identity between the "ball-shaped agglutinated masses" of the Permian limestones and the "nodular bodies precipitated in pools of water of caverns," the two phenomena are not to be compared,—the one (taking ordinary stalagmitic deposits into consideration) being a simple product, and the other a complex development—the "balls" of the "masses" essentially consisting of carbonate of lime, and their matrix of carbonates of lime and magnesia.

In conclusion I would respectfully urge on Dr. Ramsay to consider the various points that have been adduced against his belief; at the same time I must express myself as indulging in the hope that the next edition of his valuable work will contain views on the physical geography of the Permian period more in harmony with the general evidences of the case.

* See Supplementary Note B.

SUPPLEMENTARY NOTE A.

In the abstract referred to in a previous page I first broached the hypothesis of cyclical vertical movements on a regional scale in connexion with "Rock-jointing in its relation to Phenomena in Physical Geography and Physical Geology;" and as the subjects it treats of are of general importance, and exciting much attention just now, I may be excused introducing them into the present note.

In my Report on Jointing and Slaty Cleavage, which appears in the 'Transactions of the Royal Irish Academy,' vol. xxv. (1875), reasons are given in favour of the doctrine that jointing is a *physical* phenomenon, which, constituting lines or zones of weakness in the earth's crust, has permitted subterranean disturbances, often accompanied by igneous upbursts, to follow the courses of these zones *.

With respect to slaty cleavage, in consideration of various evidences adduced in the Report, I have for several years past maintained that it is the result of pressure consequent on subterranean disturbances exerted against planes of jointing (Bangor slates), or depositional partings (Delabole slates),—thus bringing them into approximate or immediate contact.

Since the Report appeared, Daubrée has given a description of some experiments which he regards as proving the mechanical origin of jointing. By means of torsional pressure applied to plates of ice, he has developed, in the latter, groups of "approximately parallel" lines of fracture, crossed by other lines nearly at right angles. But I cannot regard these experiments otherwise than as simply illustrating the well-known truth that similar effects are produced by dissimilar causes; and it may be strongly contested that ice, *crystalline* in its origin—in which it is doubtful that structural planes, original or superinduced, are ever absent—is a suitable substance on which to experiment by way

* This doctrine suggested itself to me on my becoming acquainted with an early speculation in dynamical geology of Phillips's. See op. cit. pp. 637 and 638, and Phillips's Report Brit. Assoc. 1834, p. 657.

of illustrating a phenomenon abundantly characteristic of *mechanically* deposited rocks.

I do not deny that pressure, under certain conditions, has produced parallel fractures in rocks; and examples could be cited of a mechanically developed parallel divisional structure such as some geologists have taken for jointing. Still, as jointing is common in its *indisputably typical* or *normal condition, without a tittle of evidence of mechanical pressure* having been in any way concerned in its development, obviously a physical causation must be ascribed for the phenomenon. As stated in my Report, there are miles and miles of Carboniferous limestone, in *nearly horizontal* beds, forming the bare surface of many parts of counties Clare and Galway, in which jointing is wonderfully developed; but nowhere is it accompanied by evidences of crush or stratal disturbance involving a mechanical causation. On the contrary, the phenomenon so closely simulates mineral cleavage in fineness, and it is so completely divested of all indications of supervened compression, that the view of its mechanical origin, advocated by Daubrée and others, must be regarded as completely at fault.

M. Daubrée, however, by way of adducing some evidence of the required pressure in rocks, has brought forward a case notified by Harkness and examined by myself*. It is an instance in Carboniferous limestone near Cork, which not only comprises typical jointing, but shows indisputable evidence of the rock having undergone powerful compression. This case, however, is altogether valueless with reference to the mechanical hypothesis; for it can readily be proved that the jointing (which is meridional) has been developed *after* the rock had become compressed. Clearly the divisional structure in this instance is altogether *independent* of compression. The fact is, the Cork limestone (as well as its associated rocks) has been flexured into east-and-west rolls, corresponding in direction with an *old* equatorial jointing, traces of which are still to be seen in the roughened and dislocated divisional planes everywhere present. On the contrary, the jointing referred to by Daubrée cuts cleanly through the disturbed rocks, north and south, and holds on for miles in the same way as the meridional jointing of Ireland generally.

* Op. cit. pp. 638 & 639.

In the matter of slaty cleavage, Sorby (who, it is well known, ably supported the view originally brought out by Daniel Sharpe many years before my Report was published) has of late returned to the subject. In his Anniversary Address, as President of the Geological Society, he makes known some microscopic observations in connexion with the development of slaty cleavage. It would appear "that, though in some cases" his "original explanation of very perfect cleavage may be true" (that is, due to pressure alone, aad independent of any preexisting divisional structure), he now recognizes "*fine lamination in the plane of deposition*," and "*very close joints*," as noteworthy agents, and affording an "explanation which removes a very serious difficulty in completely explaining the mechanical origin of slaty cleavage in rocks which have yielded to pressure as imperfectly plastic substances"*.

Do not these observations manifest a decided leaning in the direction of the theory which, for several years, I have been advocating?—viz. that slaty cleavage, instead of being simply the result of pressure, is the outcome of pressure exerted against preexisting divisional planes of jointing and bedding.

Reverting to the disturbances and accompanying igneous upbursts which have followed zones of jointing, the least reflection will make it clear that they would powerfully affect rocks possessed of this divisional structure, assumably compressing them at right angles to the course of an axis of disturbance, and bringing the joint-planes into immediate contact, thus developing slaty cleavage. The same agencies, besides producing enormous dislocations or faults, must have, by their transgressive action, flexured rocks into mountain chains and intervening valleys, also into parallelism with an axis of disturbance.

Although agencies of the kind must have often obliterated jointing, I assume that cleavage-planes represent it—also that the strike of these planes indicates the course or direction pursued by the obliterated jointing, and consequently the system to which this divisional structure belonged.

There are two systems of the kind—one *meridional*, and the other *equatorial*—depending on the maximum frequency of the joints within certain points of the compass. The first, especially,

* Quart. Journ. Geol. Soc. vol. xxxvi. pp. 72–74 (1880).

is divisible into two sections—east-of-north, and west-of-north; a third section, not so strongly developed, remains to be added, which, running north and south (that is, between the others), may be called medio-meridional. The equatorial system, in general not so well developed, may also be divided into two or more sections. As the earth's continents and great peninsulas (India &c.) have their chief coast-lines running in directions corresponding to the two principal meridional sections (which is also the case with the main trends of the islands of the Pacific and other oceans), my contention is that their east coast-line belongs to, and has been aligned by, the east-of-north meridional jointing—also that their west coast-line stands in corresponding relation to the west-of-north section. Thus I look upon the coast-lines of continents as a correlated phenomenon, taking these features to be defined by the edges of the great submarine plateaux which, stretching out for 200 miles or more, abruptly terminate in a succession of bench-like terraces, suddenly descending into the abysses of the oceans.

Respecting another prominent feature of our continents, I offer the suggestion that the east-of-north and the west-of-north sections of meridional jointing have primarily marked out the sides of the triangle under the form of which these great land-masses are for the most part presented; while the base of the triangle is ascribed to equatorial jointing. But as it is not yet clear to me why the base of the triangle faces the north and its apex points to the south, I am inclined to think the solution lies in the fact that the greatest elevated land-masses characterize the northern hemisphere and equatorial regions—a disposition which would cause a greater width of elevated land to lie within the basal area of the triangle than at the apex.

This last point requires to be considered in connexion with the theory originally advanced by Dana*, that the earth's continents have always been continents, or, as I prefer to put it, that the present continents, in the main, have been from the earliest geological periods greatly elevated regions separated by enormously deep depressions. Dana, however, contends that the great land-features of the globe have been produced by regional up-bendings and down-bendings of its crust, the former having given rise to continental masses, and the latter to vast ocean-basins; whereas, although accepting the pre-

* 'American Journal of Science,' 1846, and 'Manual of Geology.'

Cambrian antiquity of the main surface-features of the *earth's crust*, it is my opinion that our continental coast-lines are in correlation with enormous faults, which have thrown down the rocks on one side of a dislocation thousands of feet below their corresponding masses on the other side, and, furthermore, that the general direction of any given continental coast-line has been determined by some system or section of jointing.

In contending that jointing, slaty cleavage, great lines of faulting, continental coast-lines, and mountain-chains are correlative phenomena, I feel myself powerfully sustained, not only by the parallelism between the United-States coast and the Appalachian ridges, but equally by the corresponding parallelism of the enormous faults (some with a downthrow of thousands of feet) which characterize this mountain-system. One of the faults is known to stretch from Quebec to New Jersey!

The disturbances which developed the "great feature-lines" of our globe seem to have been in operation in pre-Cambrian periods. Evidences have been discovered in the Wahsatch range (Rocky Mountains), by Clarence King, of an elevated mass, defined in one tract by a nearly vertical cliff, which, with an altitude of 30,000 feet, was presumably in existence before the earliest palæozoic deposits were formed; and there are the strongest evidences for the conclusion that, before the adjacent Cambrian rocks were deposited, the Archæans of North America had been violently flexured, and thrown up into ridges—belonging to two divergent systems conformable with the zones of weakness which determined the east-of-north and the west-of-north outlines of this great continent; the ridges forming in its central region a mountain-mass in pre-Cambrian times.

The agent which gave an east-of-north trend to the west coast of Europe similarly affected much of the north-west coast of Africa: seemingly it struck obliquely across the equatorial section of the Atlantic, reappearing at Cape St. Roque, and proceeding onward along the mountainous sea-board of Brazil to the La Plata. Enormous as undoubtedly is this extent of coast-line formation, it is surpassed by what is presented on the west coast of the two Americas and the east coast of Asia: obviously the former, with its parallel mountain-ranges, is in genetic relation with the west-of-north and median sections of meridional jointing, and the latter with the east-of-north section.

Attention may next be directed to the great inland ranges constituting the Alps and the Himalayas. Both mountain-masses have been more or less affected by forces exerted in directions corresponding with the two principal sections of meridional jointing; but in both cases the phenomenon has been greatly swayed by movements presumably acting under the influence of the equatorial system.

The disturbances which developed High Asia—a vast continental mass within a continent stretching from India to the tundras of the Taimyr peninsula in Asiatic Siberia—have ridged it up transversely into mountain-chains, with intervening desert platforms. Its southern extremity is formed by the Himalayan and other ridges, whose general level (20,000 feet or more in altitude) culminates in still loftier peaks, some not far short of 30,000 fee All the transverse ridges, in a great (or the middle) portion of their length, have an east-and-west course.

The development of High Asia is a vastly complex phenomenon, presumably resulting from disturbances which have been directed along different zones of weakness. The zone in correlation with equatorial jointing seems to have been the medium through which the transverse ridges and their respective igneous axis were upheaved; while those referable to the two principal sections of meridional jointing may have similarly influenced the terminations of the ridges on both sides of this huge plateau, especially in the region east of it, where mountain-ranges, coast-lines, and off-lying islands all coincide in their strike with the east-of-north meridional jointing. The lofty parallel ridges east of Burmah, in being medio-meridional, are so far in conformity with the last-mentioned features. This brief notice will scarcely permit of any reference being made to the equatorial extensions from the Pamir through Western Asia, &c.

The question next suggests itself, arising from a consideration of all the phenomena that have been noticed—If the great pre-Cambrian plateaux have always existed as masses, having an elevation far above the bottom of the great intervening depressions (ocean-basins), how have they become covered up with marine sediments thousands of feet in thickness, and representing successive geological periods? In this connexion it may be argued that elevations of rock-masses are of two kinds;—one due to stratal disturbances, which for the most part have been exerted horizontally, or approximately so, and the other to vertical movements extending over wide geographical areas. More than thirty years ago my attention was called to the latter class of movements by the beautifully developed series of terraces in the Burren of Clare, reaching to the height of nearly 1200 feet. This particular instance I have ascribed to a slow upheaval of the district above the sea, the surface of each terrace representing the bottom of a coast-shore—a plane of marine denudation—and an intermittent stoppage in the upheaval*. An examination which I made in 1870 of the terraces of Lochaber resulted in my becoming convinced that they are ancient sea-margins: 1495 feet is the height usually stated of these terraces; but I detected on the flanks of Ben Nevis, and of the opposite mountains, the like features, which must reach to an altitude of between 2000 and 3000 feet. Besides the raised shell-beaches standing at a comparatively low level on the coasts of Norway, terraces have been lately observed and described by Daykins, which occur on the Dovrefjeld, at heights of from 2000 to 3100 feet. Darwin's account of the remarkable examples that occur in Patagonia, up to the height of 1300 feet, leaves no doubt on my mind that they have been formed by the action of the sea. Hector has described vast terraces on both the eastern and Pacific slopes of the Rocky Mountains, stretching from the Athabasca river to Mexico, and rising one above another to heights ranging from 3500 to 4500 feet above the level of the sea. Well marked parallel terraces are striking features in other parts of North America. A series of "horizontal benches," twenty in number, deeply cut into the mountain-slopes, and situated at heights between 1100 and 2580 feet above the sea-level, extend over an area of 10,000 square miles both east and west of the Alleghanies of Pennsylvania, Virginia, and Maryland. As properly remarked by Prof. Stevenson, who has lately described them, "they can be no other than sea-beaches marking stages in the withdrawal of the ocean"†. The late Daniel Sharpe made known the occurrence of lines of erosion on the inner and outer flanks of the Swiss Alps, at about 4300, 7500, and 9000 feet above the sea. And, to finish what could be made a much longer list, Rudolph Griesbach has described terraces in Natal lying at heights

* See 'The Geologist,' vol. vi. pp. 172, 173 (1863).

† American Philosophical Society, August 15, 1879.

of about 1000, 2300, and 5000 feet: it would also appear that these correspond with the main plateaus of Cape-colony. In short, it may be safely stated that marine terraces are to be seen in every region of the globe.

In the deep valleys of the lofty southern buttress (Gangri range) of Thibet, terraces ascend to the height of 16,000 feet; but as these may have been formed along the shores of elevated lakes, such as are now in Ladak and adjacent countries, it would be unsafe to classify them with the marine representatives that have been noticed.

It may nevertheless be maintained that a number of geological evidences afforded by the area last noticed, combined with the proofs already brought forward, establish the conclusion that vertical movements of vast regional extent have affected not only High Asia but the entirety of the earth's surface—elevating continents, including mountains and plateaus, at the same time uplifting the bed of the intervening oceans thousands of feet above their present level relatively to that of the sea, or plunging them as deeply in the opposite direction.

Without denying that the level of the sea may have undergone great fluctuations at intervals during past geological time, caused by æonic flows and ebbs of the ocean, and that such changes may have participated, to an extent far beyond what physicists and hydrographers are at present disposed to admit, in developing phenomena which, for convenience' sake, I have collectively ascribed to vertical movements of the earth's crust—or without offering any opinion respecting the hypotheses suggested by Babbage, Herschel, and others as to the cause of phenomena of elevation and subsidence—it does not appear improbable that cyclical or periodically recurrent vertical movements, each one representing a vast chronological term, have by slow degrees alternately elevated and depressed opposite areas, corresponding in extent with a continental or even a hemispherical division of the globe.

To illustrate this view, let it be assumed that one of our continents, having attained its maximum elevation, is next to undergo subsidence. During this elevated period the *land-surfaces* of moderate height would be in what may be termed the *first* stage of depositional action, viz. the formation of subaërial, freshwater, and estuarine deposits; in the *second* stage the same areas would be subjected to marine actions, producing littoral and deepish-water conglomeratic, arenaceous, argillaceous, and calcareous beds; in the *third* stage, in which maximum depth had been reached, they would be under pelagic conditions, developing limestones, argillytes, and siliceous rocks. Next, elevation having again come on, the *fourth* stage would be a repetition of the second, yielding comparatively shallow-water marine deposits; and this would terminate by passing into the *fifth* stage, which corresponds to the first one. Thus would our continents, notwithstanding their being at present at an average height of a few thousand feet above the sea-level, become overlaid in every systemal period with vast deposits of all kinds—those of any given stage representing one of the formations (assumably five) which constitute a geological rock-system, and, moreover, the whole agreeing with the formations of a system in their successive order of superposition.

A few points may be briefly added. It is not assumed that all such vertical movements have proceeded in the invariable course and to the extent, vertical or areal, above illustrated, or that they were unaccompanied by minor ups and downs. The region opposite to the one given as an illustration would be undergoing a cycle of counter vertical movements. As to the deposits which were thrown down over the abysses of the oceans (Atlantic and Pacific) when the continents were under pelagic conditions, it is admitted they involve some questions difficult to answer, whether considered in connexion with Dana's hypothesis, or the one just stated.

Obviously great recurrent climatal changes would result from these elevations and depressions—severe glacial conditions accompanying the one, and the replacement of the latter by genial ameliorations arising from the other.

The consideration of these points gives rise to the question, often debated, How has it happened that after the Pliocene period climatal conditions prevailed which converted a great portion of Europe and North America (there are grounds for excepting Northern Asia) into ice-covered regions, and that during the Miocene (or probably some portion of the Pliocene) period areas lying within from 10° to 20° of the North Pole have enjoyed, as it appears to some geologists, a climate approaching in genialness that of the south of Europe at the present day?

Influenced by objections to all the hypotheses that have been offered in explanation of these climatal interchanges, I find a much more tenable one in that which attributes them mainly to the aforementioned vertical movements.

Confining myself to the climatal conditions which characterized Grinnell Land, Spitzbergen, and other Arctic areas during the Miocene period, as indicated by their plant-remains, I make the suggestion that these and adjacent areas stood at a somewhat lower level relatively to the sea than at present, and formed an archipelago, freely permitting currents with a temperature slightly more elevated than that of the gulf-stream where it now strikes the west coast of Ireland to bathe the coasts of its islands. Climatal amenities now prevail in Arctic Scandinavia, the Kara Sea, and on the western border of the Taimyr peninsula in Asiatic Russia: the last place, the most northern continental land of the globe, now supports an exuberant forest vegetation in a much higher parallel than anywhere else within the Arctic circle, and only about 16° or 17° short of the North Pole—the fact being seemingly due to the presence of warm water, carried by ocean-currents and by rivers (as the Yenissei) from the south. Boreal Siberia, in direct communication with southern lakes, inland seas, and ocean-streams charged with warm water, and in the condition of an archipelago,—why may not its great forest belt be extended up to Spitzbergen and Franz-Joseph Land—to parallels corresponding with those in Grinnell Land, which formerly supported the growth of a vegetation approximately similar in some respects to that now characteristic of Northern Italy and the Southern States of North America?

As to the long winter-night of darkness and the long summer-day of sunlight, I feel satisfied from adducible evidences that, other things being favourable, such conditions would rather favour than impede vegetable growth. Areas favourably situated as to shelter, meteoric influences, soil, proximity to warm currents, &c., and especially where a thick covering of snow prevailed during the severe months of winter, would, in my opinion, become genial oases supporting an exceptional vegetation: such I look upon were the places in Grinnell Land and Spitzbergen where, during the Miocene or early portion of the Pliocene period, flourished guelder roses, waterlilies, sequoias, swamp-cypresses (*Taxodium*), &c. of extinct species, and *varieties* of known species now living in temperate latitudes, and doubtless *acclimated* to arctic conditions. The *adaptive constitution* of plants has not been sufficiently considered in connexion with this question.

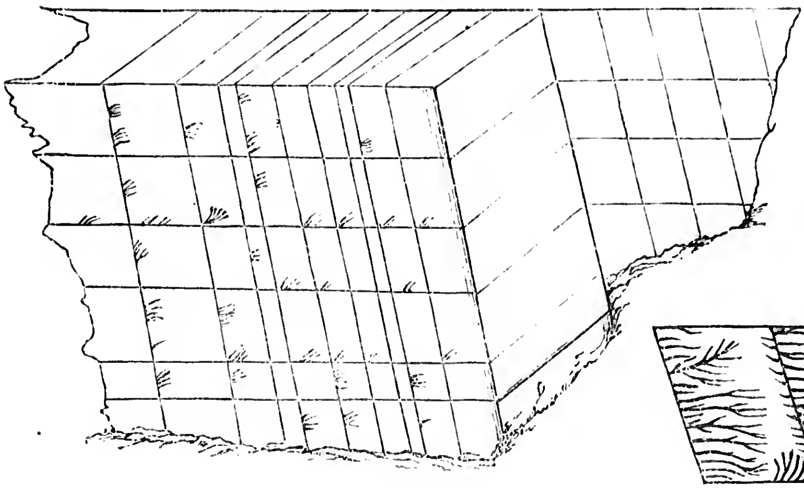
I shall conclude with a few brief remarks on linear igneous disturbances. Admitting the existence of a number which may be included in the equatorial system of jointing, disturbances of the kind are for the most part limited to the meridional zones of weakness. As is well known, a most important series of volcanoes characterizes the western borders of the two Americas; and a similar series lies off the east coasts of Asia, belonging, in my opinion, one to the west-of-north and the other to the east-of-north section of meridional jointing: both series become united in Behring's Sea. Other writers, by connecting the equatorial series of volcanoes north of Australia with the above two, have constructed a "circle of fire;" but with far too limited a range. The two meridional series (by pursuing a direct course, so as to embrace the Cocos Islands, St. Paul's, Kerguelen's Land, Enderby's Land, thence curving to Trinity Land, passing on to the South Shetlands, and through Fuegia into the Patagonian Andes) form but one a great volcanic girdle, which may be said to stretch without interruption round the world, traversing the Arctic regions a few degrees east of the North Pole, and intersecting the Antarctic circle at a corresponding distance west of the South Pole—thus dividing the crust of the globe along its greatest zones of weakness into two nearly equal halves, and at the same time separating its superficies into a water- and a land-hemisphere.

As to reflections which may naturally arise in connexion with the last subject, I avow myself to be, scientifically, too much of a teleoptimist, too extravagant a timist, and too little of a catastrophist to entertain any that involve serious or disquieting apprehensions.

SUPPLEMENTARY NOTE B.

ON THE CRYSTALLINE BODIES OF THE SUNDERLAND PERMIAN MAGNESIAN LIMESTONE.

Fig. 1.



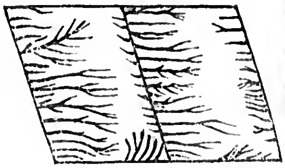


Fig. 2.

Fig. 1 represents a section of Permian limestone, exposed in a railway-cutting between Sunderland and Ryhope, as displayed when I made a sketch of it about the year 1846. The beds exhibit well-developed jointing, running in two directions. The front or face of the section is a joint-plane (as is also the one further in) belonging apparently to the equatorial system; the oblique lines, also the end-surface parallel with them, belong to the west-of-north meridional set. The horizontal lines and the corresponding surface at top represent bedding. The interest which attaches to this section is the fact, well displayed, that the coralloidal bodies spring from the planes of both bedding and jointing. I have repeatedly observed the same thing at other places in the neighbourhood of Sunderland; on one occasion a coralloid with a stem as thick as a man's arm, came under my notice. It is also a common occurrence, where semi-globular bodies are developed, for them to be integrally connected with the surface-portion (usually upper) of a bed.

Fig. 2 represents a portion (about a foot square) taken from a bed at Building Hill. The oblique lines represent west-of-north joints, and the horizontal bounding lines bedding-planes. The specimen, with several others of the kind, was collected about the year 1839, on an occasion when the quarrymen had exposed a singularly beautiful development of such forms. In this example, as in the section fig. 1, the coralloids branch off from the planes of bedding and jointing; but one of its features is worth special notice: the coralloids, according to a note I made at the time, are best developed where branching from the west bounding-plane of the meridional joints. These examples are amply sufficient to disprove the idea that they were formed at the same time as that in which the limestone was deposited; also that, howsoever they may have originated, the agent which produced them must have penetrated the partings of both jointing and bedding. It cannot be too strongly impressed on the mind of the reader that the coralloids, also the other configuration to which Dr. Ramsay has referred, are more or less crystalline internally, and consist of carbonate of lime, adding a few per cent. of carbonate of magnesia; while their matrix, or the body of the rock, is structureless and essentially dolomite.

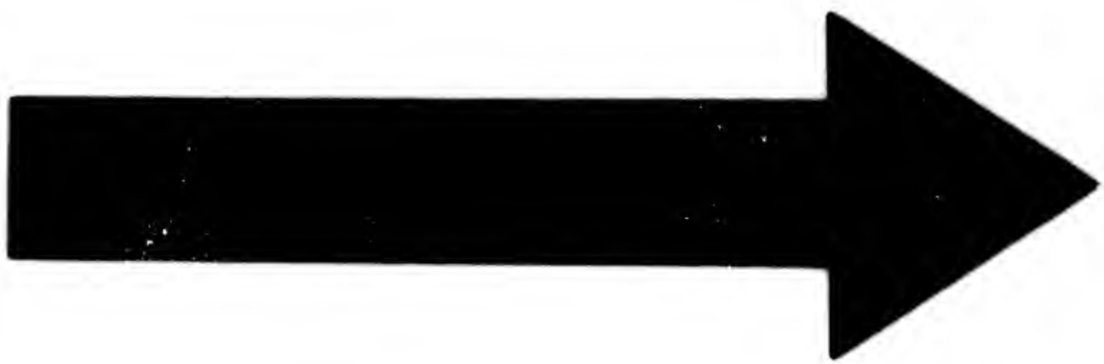
SUPPLEMENTARY NOTE C.

CERTAIN LIMESTONES ARE OF MECHANICAL ORIGIN.

It is well known that Dr. Sterry Hunt, in advocating the purely chemical origin of limestones, places himself in opposition to the opinion generally prevailing on this subject, viz. that while some rocks of the kind are chemical products, such as freshwater and marine travertines, by far the greater portion are of organic origin, that is, the skeletal exuviæ of shells, corals, foraminifers, and other animals. Excluding the methylosed crystalline limestones, I quite agree with this view; but I have now to bring under notice another class of calcareous deposits, whose origin, it is assumable, was altogether different; though they may have been primarily of organic, chemical, or methylotic development.

The calcareous nature of the erratic drift, so well developed near the "Citie" of Galway (to which reference has been previously made, footnote, p. 93), can only be due to this deposit having been derived from the Carboniferous limestone of the surrounding district by the abrading action of glaciers. From what has lately come under my notice I see no reason why certain calcareous deposits, obviously of littoral origin, cannot be the débris of mechanically abraded limestones. Lately, availing myself of an occasion when Lough Corrib was in a muddy condition, caused by heavy rains, I put aside a couple of quarts of the water to stand for a few days. Testing the sediment which had settled at the bottom of the vessel with hydrochloric acid, a brisk effervescence took place, denoting it to contain a notable quantity of carbonate of lime. The remaining clear water, on being tested with oxalate of ammonia, exhibited decided evidence of its containing bicarbonate of lime in solution. These facts prove that the water of rivers in limestone districts contains calcareous matter both mechanically suspended and in a chemically dissolved state; so that, while the latter may be carried out into the open sea, to be appropriated by shells, corals, &c. for their skeletons, and the débris of these converted into limestones, the former may be mechanically deposited in estuaries and along shores. I have often thought over the fact that many limestones are so greatly deficient of calcareous fossils as to render their organic origin doubtful: the lithographic limestones of Bavaria are cases in point, also the Permian marl-slates of Durham and Germany. I am therefore now strongly inclined to assume that these and other calcareous deposits are of mechanical origin.

When writing the footnote above referred to, I thought it not improbable that the dolomitic conglomerate of the Bristol district was a Triassic glacial deposit, its paste having been derived from a Permian magnesian limestone now entirely removed. But from information I have liberally received from Prof. Sollas (whose short note in the 'Geological Magazine' of February last led me to put a few questions to him) I feel persuaded his opinion is correct, that both the paste and the pebbles it contains have been dolomitized since they were accumulated, and that the paste had not been derived from a Permian limestone. Prof. Sollas and Mr. Margetson, I understand, are preparing for publication an account of the Bristol rocks.



DESCRIPTION OF THE PLATES.

PLATE I.

Fig. 1. Chrysotile interlamellated with serpentine. Colafirth, Shetland.

Fig. 2. Lamellated ophite ("*Eozoon Canadense*"), consisting of layers of serpentine and calcite in parallelism with one another. Canada.

Fig. 3. Peridote (olivine) enclosing fibrous or striated laminæ. Elfdalen in Dalecarlia.

Fig. 4. Feldspar enclosing fibrous or striated laminæ.

Fig. 5. Graphic granite, consisting of layers of feldspar (*a*) alternating with others composed of quartz (*b*). The former are transversely intersected by striated fibrous and striped laminæ. Harris, Hebrides.—Specimens of the kind have been taken for a fossil related to "*Eozoon Canadense*"!

Fig. 6. Specimen in which there is a definite and parallel alternation of reddish quartz and red feldspar, rivalling that of the lamellated variety of "*Eozoon Canadense*." Astracan.

Fig. 7. Transverse section of a crystal, presumed, from its cleavage, to be augite; an optical examination, however, shows that its substance is peridotized. Vesuvius.

PLATE II.

Fig. 1. Chrysotile changing into the acicular varieties; also the same replaced by calcite (*a*): the variety *c* answers to the "proper wall," and the calcite to the "intermediate skeleton" of "*Eozoon Canadense*." Reichenstein.

Fig. 2. Portion of specimen of "*Eozoon Canadense*." Layer of chrysotile (*a*) in parallel alternation with serpentine (*b*) on one side and calcite (*c*) on the other. In the latter case the fibres at the upper surface of the layer of chrysotile are broken and pressed obliquely out of position, thereby forming a thin lamina; these fibres are more or less separated by films of calcite integrally connected with the overlying calcitic layer. Thus the lamina corresponds to the "proper wall," and the latter part to the "intermediate skeleton." (N.B. The layers of chrysotile and serpentine are in such position to each other as to prove their genetic correlation: it is also noteworthy that on the margin where the chrysotile is in immediate contact with the serpentine there is no fibrous lamina with its fibres separated by calcitic interpolations.) Canada.

PLATE II. (*continued*).

Fig. 3. Portion of a specimen of "*Eozoon Canadense*," showing a fissure or crack (several more are present in the specimen, see 'Proc. Roy. Irish Acad.' vol. x. pl. xli. fig. 4) obliquely intersecting a lobulated layer of serpentine ("chamber-cast;" other layers of the kind are similarly intersected). This fissure, as in other cases, is characterized by "intermediate skeleton" (*a*), bounded at top and bottom by "proper wall" (*d*). A layer of chrysotile (*e*), in its incipient stage of development (see Pl. IX. fig. 1, *a*), lies above and in parallelism with the fissure, proving the genetic correlation of the two parts. Observe that the fibres of the chrysotile in the fissure pass continuously lengthwise into the separated aciculæ.

PLATE III.

Fig. 1. Decalcified specimen, magnified, of saccharoid marble (hemithrene), containing crystalloids of malacolite (*a*) decreted or etched into branching configurations (*a**), identical with "canal system" of "*Eozoon*;" also crystalloids of pyrosclerite (*b*), some of which have their surfaces coated with aciculæ. Mt. St. Philippe, near Marie aux Mines, Vosges.

Figs. 2 & 3. Crystalloids, highly magnified, of pyrosclerite invested with a fibrous lamina (*b*), portions of which are pectinated (d), as in the variety of chrysotile corresponding with the "proper wall" of "*Eozoon*." Mt. St. Philippe, Vosges.

Fig. 4. Section of a crystal of (?) peridote (polarized), associated with serpentine. "*Eozoon Canadense*," Canada.

Fig. 5. Section of a crystal of (?) peridote (polarized), divided by laminæ of calcite corresponding with the cleavage-divisions. The calcite is obviously a replacement product (pseudomorphism). Same as section fig. 4. Canada.

PLATE IV.

Ground-plan of a trap-dyke (*a*) intersecting gneiss (b) in a cove (A) at Glassillaun (B), on the north shore of Cleggan Bay, Connemara. The gneiss is converted into hemithrene (*c*) in places on both sides of, and adjacent to, the dyke. The dyke is calcitized.

PLATE V.

Natural vertical section of the last case (letters the same), showing gneiss converted into hemithrene by action of trap-dyke.

PLATE VI.

Fig. 1. Vertical section (being face of a quarry at Mt. St. Philippe) of gneiss (red colour) intersected by irregular masses of hemithrene (green).

Given as affording evidences that the gneiss has been methylosed into the hemithrene (pp. 51, 52). The specimens represented under figs. 1, 2, and 3, Pl. III., are from this quarry.

Fig. 2. "*Eozoon Canadense.*" A layer of chrysotile in its different stages of development:—*a*, incipient stage; *b*, typical chrysotile; *c*, closely acicular ("velvet pile") condition of "proper wall." Canada.

Fig. 3. "*Eozoon Canadense.*" "Proper wall" in two separate laminæ, and in different stages of modification. One of the laminæ is pectinated, and thus assumes the form typical of the "proper wall." Canada.

PLATE VII.

Specimen of a serpentine rock, pseudomorphic after tremolite (natural size). Cannaver, Lough Corrib, Connaught.

PLATE VIII.

Specimen of tremolite (natural size), for comparison with that represented in Plate VII., the crystalline structure of both being identical. St. Gothard.

PLATE IX. (*Frontispiece.*)

Fig. 1. Diagrammatic sketch, showing serpentine (a) changing into chrysotile (b); also the latter in its various modifications or stages of development. Under *a* the chrysotile is in the (*first*) incipient stage, being striated serpentine (that is, the variety marked with *separated* thread-like lines or cuts); *b*, (*second*) fibrous stage, which is typical chrysotile; *c*, (*third*) close-acicular stage, in which the fibres are changed into definite aciculæ; *d*, (*fourth*) pectinated stage, in which the aciculæ are separated by films of calcite—thus constituting the "proper wall" of "*Eozoon Canadense.*"

Fig. 2. Portion, highly magnified, of an accredited specimen of "*Eozoon Canadense*," showing the different features of the presumed fossil originating from chemical and structural changes in the minerals entering into its composition (pp. 18, 19). The layer a consists of ordinary serpentine changed into the striated variety or incipient chrysotile (*a*) (other layers consist entirely of structureless serpentine). At b is chrysotile in its typical condition. This layer at top, under *c*, is changed into the close-acicular variety, and under *d* into the separate-acicular or pectinated variety, the aciculæ in which are separated by calcite: it is thus converted into the "proper wall" of "*Eozoon Canadense.*" The aciculæ in the last stage are considered to be "casts of tubuli," such as characterize the nummuline layer ("proper wall") of certain recent foraminifers. The letter c denotes flocculite, a white (flocculent) variety of serpentine, which usually occurs as layers, or clotules: it is often decreted or etched out by solvent action into arborescent configurations (c*), forming the "canal system" of "*Eozoon.*" (N.B. The last feature is not in its original place: it occurs in another part of the specimen; but its relations to other eozoonal features are correctly represented.) The layers d ("in-

PLATE IX. (*continued*).

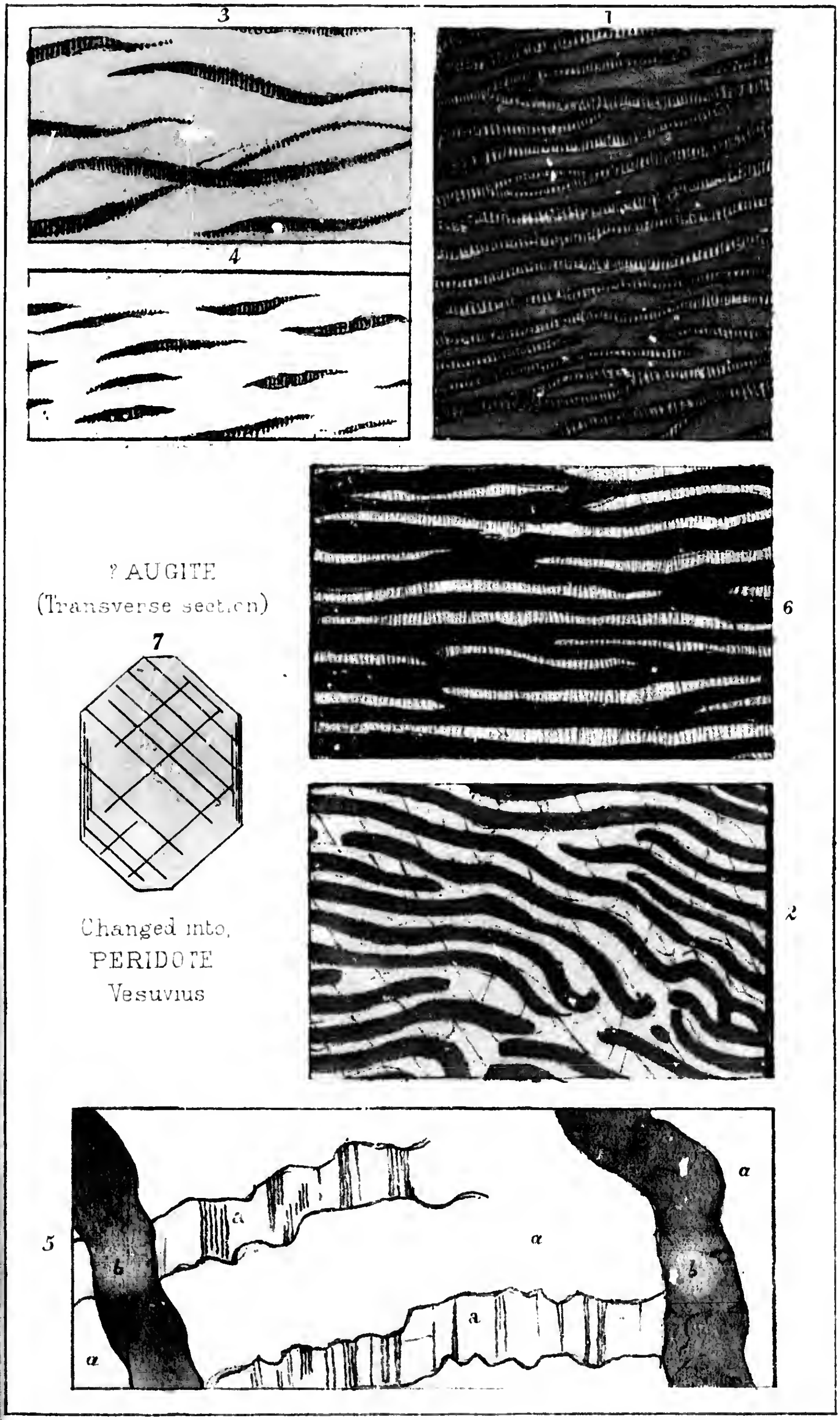
termediate skeleton") are in calcite, resulting directly from a chemical change in flocculite, also indirectly from serpentine: it forms the "intermediate skeleton" of "*Eozoon.*" (N.B. The films of calcite between the aciculæ of the pectinated variety of chrysotile are a similar pseudomorphic replacement.) Canada.

Fig. 3. Portion (natural size) of a specimen of a lamellar graphic granite, consisting of layers of feldspar (? moonstone) definitely alternating in parallelism with others of quartz. The layers of feldspar are obliquely intersected by fibrous or striated laminæ. Tarbert, Harris.—Specimens of the kind are considered by eozoonists to be of organic origin. The striæ ("striation") were taken by Dr. Carpenter to be a "vertical tubular structure," corresponding with that of the "proper wall" of "*Eozoon Canadense*"!

y from a chemical
t forms the "inter-
ralcite between the
ilar pseudomorphic

lar graphic granite,
lternating in paral-
bliquely intersected
ens of the kind are
striæ ("striation")
ture," corresponding

Pl. I



Pinx W K

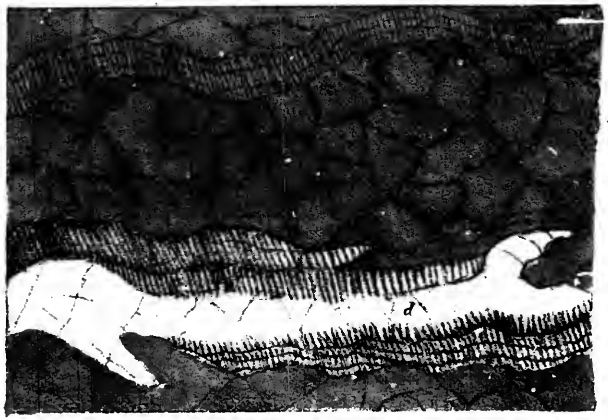
Hanhart lith

CHRYSOTILE from REICHENSTEIN
changed into "nummuline wall"

c

b

a

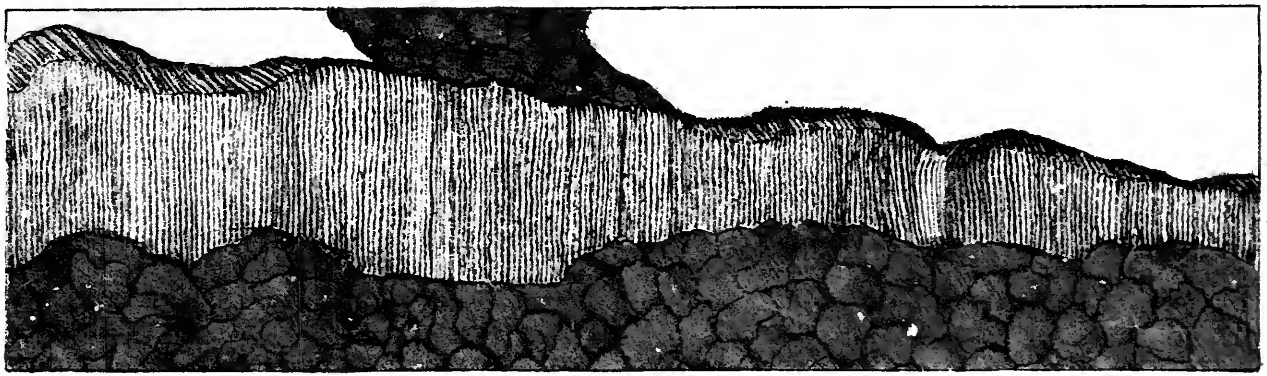


3

c d b

1

a



c

2

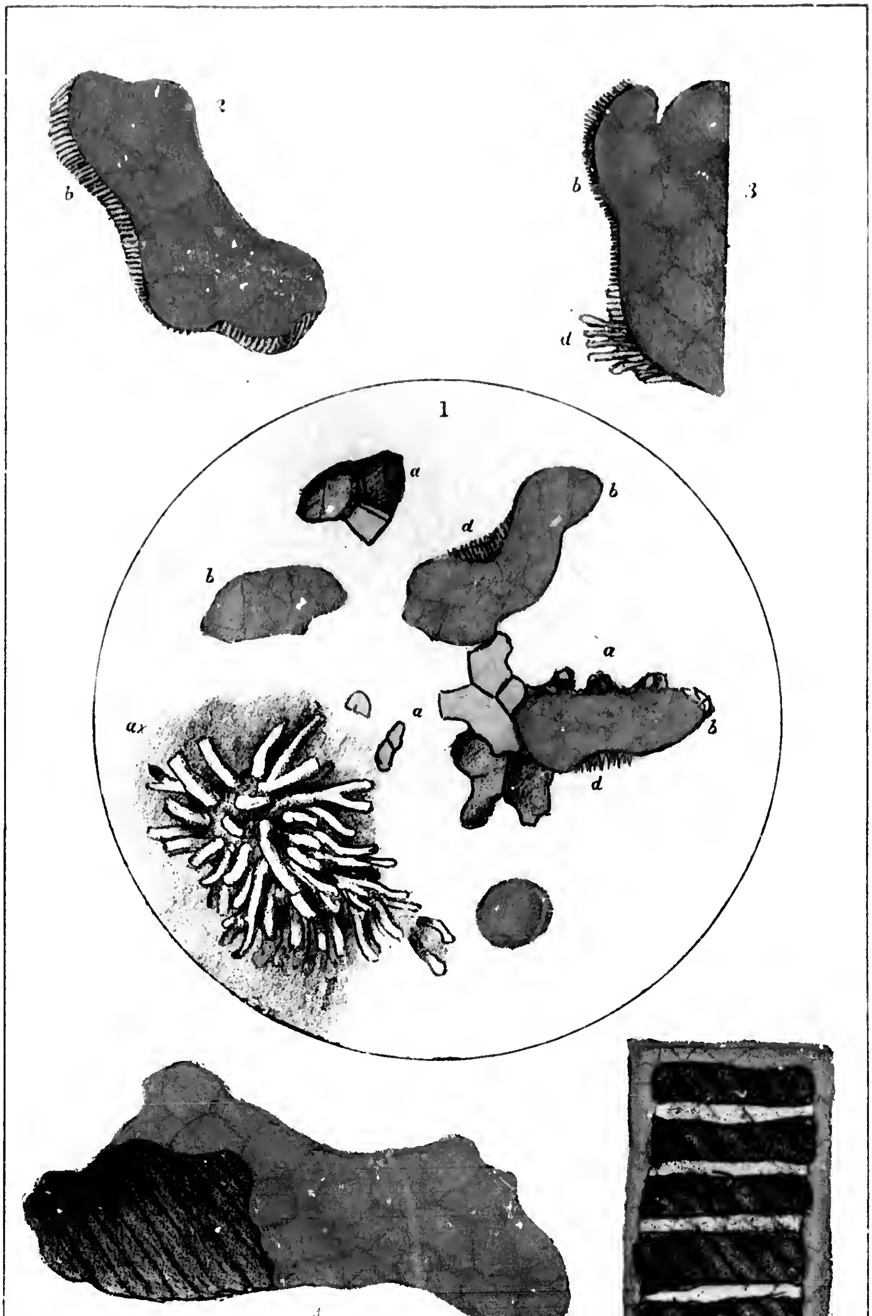
a

b

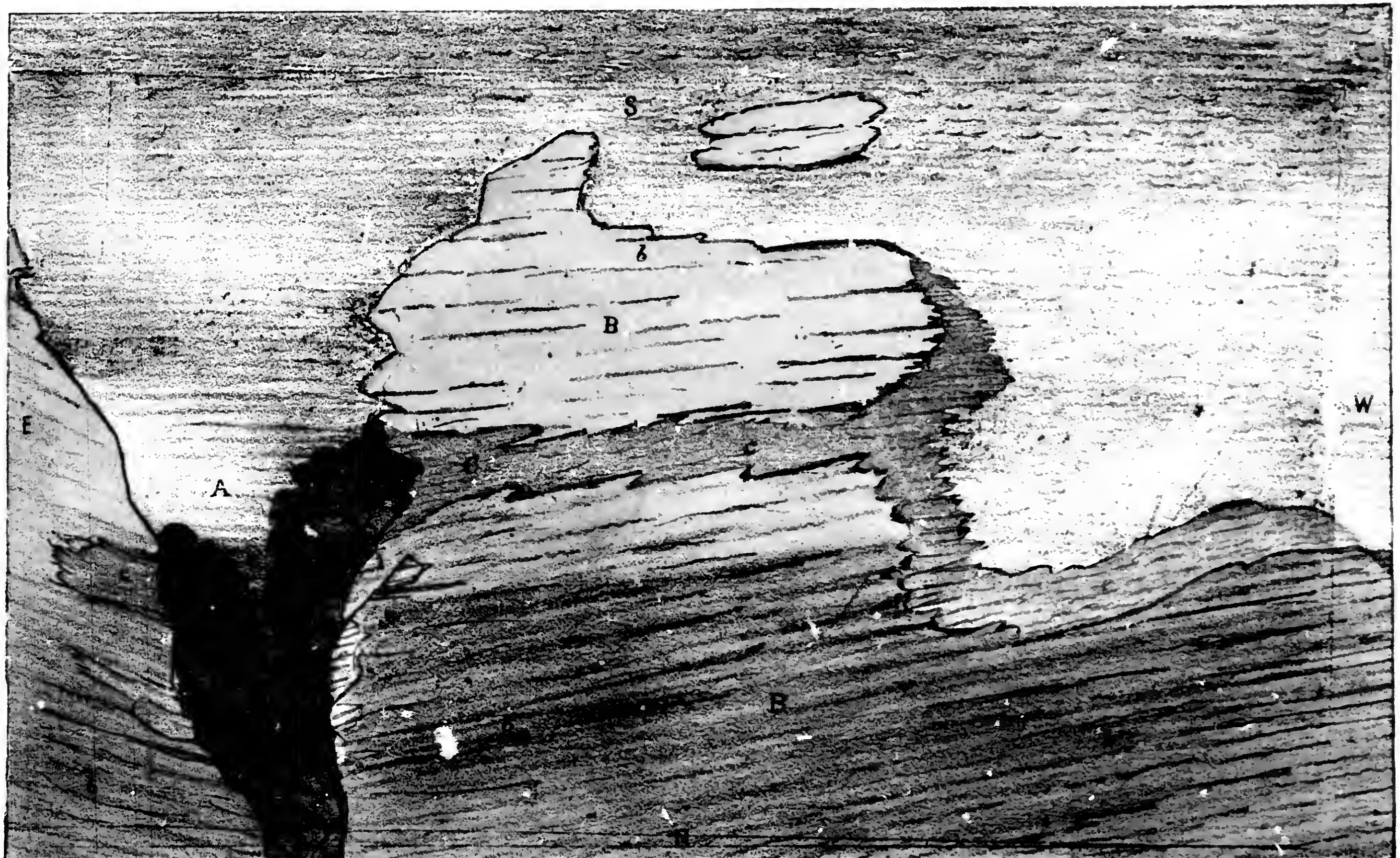
Figures 2 & 3 "Eozoon Canadense"

Pinx. W.K

Hannart lith.

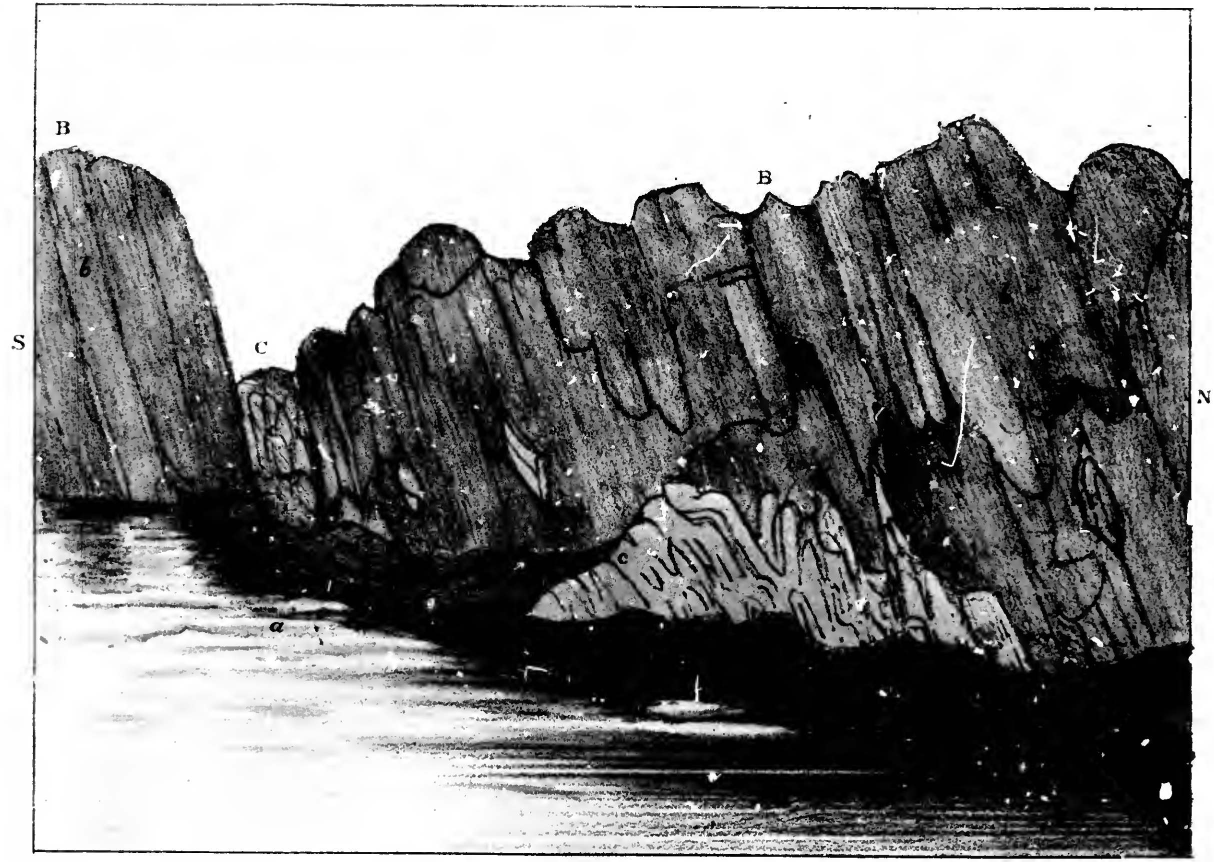


Pinx W K Hannart lith



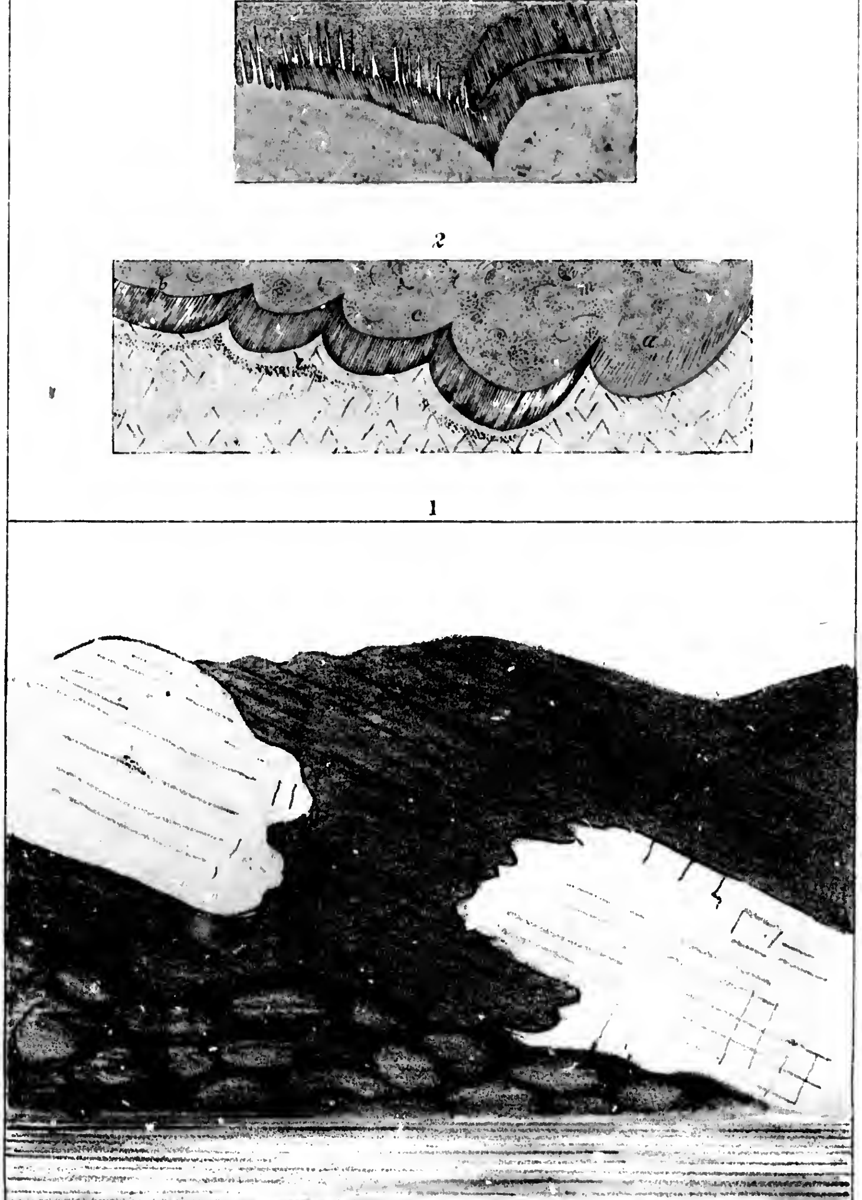
Pinx. W.K. Hanhart lith.

Pl V



Hanhart imp

Pl V.

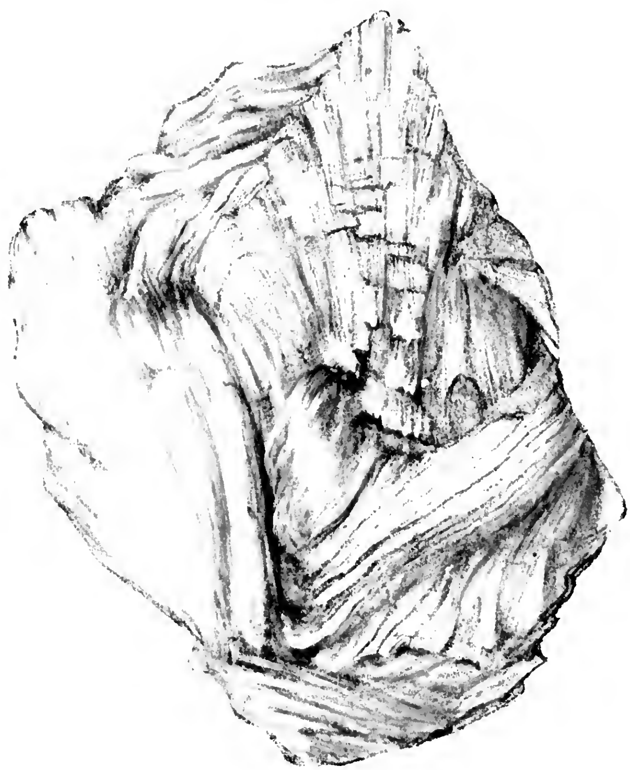


Pinx W.K. Hanhart imp

GNEISS (RED) CHANGED INTO HEMITHRENE (GREEN)
MONT S^T PHILIPPE VOSGES

Serpentine pseudomorphic after
Tremolite Lough Corrib, Galway

Hanhart imp.



Hanhart imp

TREMOLITE. St GOTHARD.

INDEX.

E.

Q.

R.

T.

Printed by Taylor and Francis, Red Lion Court, Fleet Street.

Museum of
70.

62.
ed rocks, 7.
led crystal-
vi.

xlix.