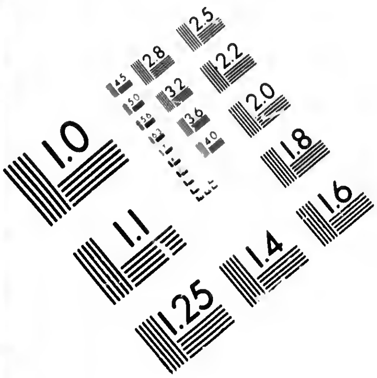

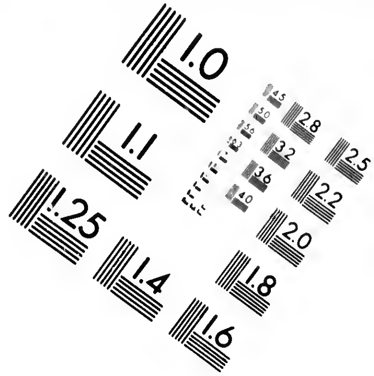

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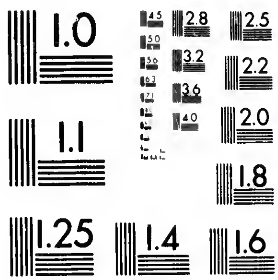

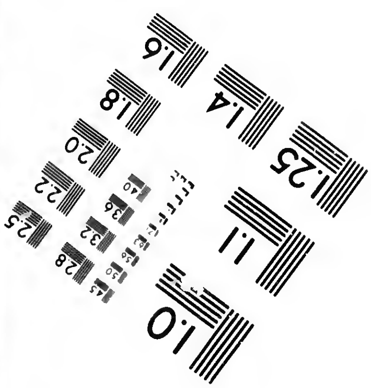

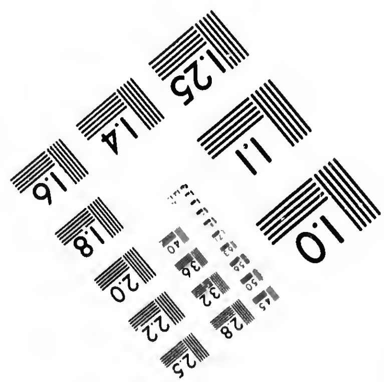

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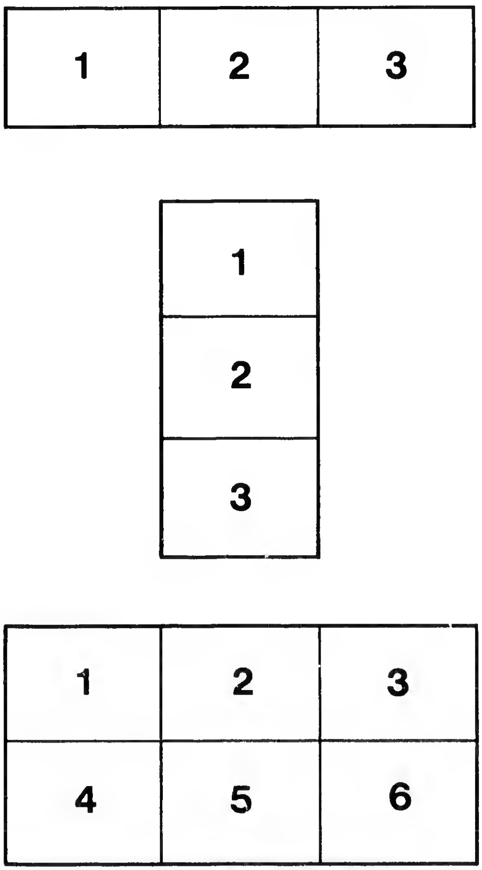

[*From the* QUARTERLY JOURNAL *of the* GEOLOGICAL SOCIETY *for August* 1876.]

NOTE *on the* PHOSPHATES *of the* LAURENTIAN *and* CAMBRIAN ROCKS *of* CANADA. By J. W. DAWSON, LL.D., F.R.S., F.G.S.

THE extent and distribution of the deposits of apatite contained in the Laurentian of Canada and in the succeeding Palæozoic formations, have not escaped the notice of our Geological Survey, and have been referred to in some detail in Reports of Mr. Vennor, Mr. Richardson, and others, as well as in the General Report prepared by Sir W. E. Logan in 1863. Some attention has also been given, more especially by Dr. Sterry Hunt, to the question of the probable origin of these deposits*. My own attention has been directed to the subject by its close connexion with the discussions concerning *Eozoon*; and I have therefore embraced such opportunities as offered to visit the localities in which phosphates occur, and to examine their relations and structure. I would now present some facts and conclusions respecting these minerals, more especially in their relation to the life of the Laurentian period, but which may also be of interest to British geologists in connexion with the facts recently published in the 'Journal' of this Society in relation to the similar deposits found in the Cambrian and Silurian of Wales†.

In the Lower Silurian and Cambrian rocks of Canada phosphatic deposits occur in many localities, though apparently not of sufficient extent to compete successfully for commercial purposes with the rich Laurentian beds and veins of crystalline apatite.

In the Chazy formation, at Alumette Island, and also at Grenville, Hawkesbury, and Lochiel, dark-coloured phosphatic nodules abound. They hold fragments of *Lingulæ*, which also occur in the containing beds. They also contain grains of sand, and, when heated, emit an ammoniacal odour. They are regarded by Sir W. Logan and Dr. Hunt as coprolitic, and are said to consist of "a paste of comminuted fragments of *Lingulæ*, evidently the food of the animals from which the coprolites were derived"‡. It has also been suggested that these animals may have been some of the larger species of Trilobites. In the same formation, at some of the above places, phosphatic matter is seen to fill the moulds of shells of *Pleurotomaria* and *Holopea*.

In the Graptolite shales of the Quebec group, at Point Levis, similar nodules occur; and they are found at Rivière Ouelle, Kamouraska, and elsewhere on the Lower St. Lawrence, in limestones and limestone conglomerates of the Lower Potsdam group which is probably only a little above the horizon of the Menevian or Acadian series. In these beds there are also small phosphatic tubes with thick walls, which have been compared to the supposed worm-tubes of the genus *Serpulites*§.

* Geology of Canada, 1863; Chemical and Geological Essays, 1875.
† Davies & Hicks in Quart. Journ. Geol. Soc. August 1875.
‡ Geology of Canada, p. 125.
§ Geology of Canada, p. 259; Richardson's Report, 1869.

The Acadian or Menevian group, as developed near St. John, New Brunswick, contains layers of calcareous sandstone blackened with phosphatic matter, which can be seen, under the lens, to consist entirely of shells of *Lingulæ*, often entire, and lying close together in the plane of the deposit, of which in some thin layers they appear to constitute the principal part*. Mr. Matthew informs me that these layers belong to the upper part of the formation, and that the layers crowded with *Lingulæ* are thin, none of them exceeding two inches in thickness; but he thinks that the dark colour of some of the associated sandstones and shales is due to comminuted *Lingulæ*.

At Kamouraska, where I have studied these deposits, the ordinary phosphatic nodules are of a black colour, appearing brown with blue spots when examined in thin slices with transmitted light. They are of rounded forms, having a glazed but somewhat pitted surface—and are very hard and compact, breaking with glistening surfaces. They occur in thin bands of compact or brecciated limestone, which are very sparingly fossiliferous, holding only a few shells of *Hyolithes* and certain *Scolithus*-like cylindrical markings. In some of these beds siliceous pebbles occur with the nodules, rendering it possible that the latter may have been derived from the disintegration of older beds; but their forms show that they are not themselves pebbles. Phosphatic nodules also occur sparingly in the thick beds of limestone conglomerate which are characteristic of this formation; they are found both in the included fragments of limestone and in the paste. The conglomerates contain large slabs and boulders of limestone rich in Trilobites and *Hyolithes*; but in these I have not observed phosphatic nodules.

In some of the limestones the phosphatic bodies present a very different appearance, first noticed by Richardson at Rivière Ouelle, and of which I have found numerous examples at Kamouraska. A specimen now before me is a portion of a band of grey limestone, about four inches in thickness, and imbedded in dark red or purple shale. It is filled with irregular, black, thick-walled, cylindrical tubes, and fragments of such tubes, along with phosphatic nodules—the whole crushed together confusedly, and constituting half of the mass of the rock. The tubes are of various diameters, from a quarter of an inch downward; and the colour and texture of their walls are similar to those of the ordinary phosphatic nodules.

Under the microscope the nodules and the walls of the tubes show no organic structure or lamination, but appear to consist of a finely granular paste holding a few grains of sand, a few small fragments of shells without apparent structure, and some small spicular bodies or minute setæ. The general colour by transmitted light is brown; but irregular spots show a bright blue colour, due probably to the presence of phosphate of iron (vivianite). The enclosing limestone and the filling of the tubes present a coarser texture, and appear made up of fragments of limestone and broken shells, with some dark-coloured fibres, probably portions of Zoophytes. Scattered

* Bailey and Matthew, "Geology of New Brunswick," Geol. Survey Reports.

through the matrix there are also small fragments, invisible to the naked eye, of brown and blue phosphatic matter.

One of the nodules from Alumette gave to Dr. Hunt 36·38 of calcic phosphate; one from Hawkesbury 44·70; another from Rivière Ouelle 40·34; and a tube from the same place 67·53*. A specimen from Kamouraska, analyzed by Dr. Harrington, gave 55·65 per cent. One of the richest pieces of the linguliferous sandstone from St. John yielded to the same chemist 30·82 of calcic phosphate and 32·44 of insoluble siliceous sand, the remainder being chiefly carbonate of lime.

Various opinions may be entertained as to the origin of these phosphatic bodies; but the weight of evidence inclines to the view originally put forward by Dr. Hunt †, that the nodules are coprolitic; and I would extend this conclusion with some little modification to the tubes as well. The forms, both of the tubes and nodules, and the nature of the matrix, seem to exclude the idea that they are simply concretionary, though they may in some cases have been modified by concretionary action. There are in the same beds little piles of worm-castings of much smaller diameter than the tubes, and less phosphatic; and there are also *Scolithus*-like burrows penetrating some of the limestones, and lined with thin coatings of phosphatic matter similar to that of the tubes. Further, the association of similar nodules in the Chazy limestone with comminuted *Lingulæ*, as already stated, is a strongly confirmatory fact.

The tubes are of unusual form when regarded as coprolitic; but they may have been moulded on the sides of the burrows of marine worms; or these creatures may have constructed their tubes of this material, either consisting of their own excreta or of that of other animals lying on the sea-bottom. In any case, the food of the animals producing such excreta must have been very rich in solid phosphates, and these animals must have abounded on the sea-bottoms on which the remains have accumulated. It is also evident that such phosphatic dejections might either retain their original forms, or be aggregated into nodular masses, or shaped into tubes or burrows of Annelids, or, if accumulated in mass, might form more or less continuous beds.

The food of the animals producing such coprolites can scarcely have been vegetable; for though marine plants collect and contain phosphates, the quantity in these is very minute, and usually not more than that required by the animals feeding on them.

We must therefore look to the animal kingdom for such highly phosphatic food. Here we find that a large proportion of the animals inhabiting the primordial seas employed calcic phosphate in the construction of their hard parts. Dr. Hunt has shown that the shells of *Lingula* and some of its allies are composed of calcic phosphate; and he has found the same to be the case with certain Pteropods, as *Conularia*, and with the supposed worm-tubes called *Serpulites*, which, however, are very different in structure from the tubes above referred to.

* Geology of Canada, p. 461. † Ibid

It has long been known that the crusts of modern Crustaceans contain a notable percentage of calcic phosphate; and Hicks and Hudleston have shown that this is the case also with the Cambrian Trilobites. Dr. Harrington has kindly verified this for me by analyzing a specimen of highly trilobitic limestone from the Lower Potsdam formation at St. Simon, in which the crusts of these animals are so well preserved that they show their minutely tubulated structure in great perfection under the microscope. He finds the percentage of calcic phosphate due to these crusts to be 1·49 per cent. of the whole mass. It is to be observed, however, that the crusts of Trilobites must have consisted very largely of chitinous matter, which, in some cases, still exists in them in a carbonized state. A crust of the modern *Limulus*, or King Crab, which I had supposed might resemble in this respect that of the Trilobites, was analyzed also by Dr. Harrington. It belonged to a half-grown individual, measuring 5·25 inches across, and was found to contain only 1·845 per cent. of ashes, and of this only 1·51 per cent. of calcic phosphate. The crusts of some Trilobites may have contained as large a proportion of organic matter; but they would seem to have been richer in phosphates. Next to *Lingulæ* and Trilobites, the most abundant fossils in the formations containing the phosphatic nodules are the shells of the genus *Hyolithes*, of which several species have been described by Mr. Billings*. Dr. Harrington has ascertained that these shells also contain calcic phosphate in considerable proportion. The proportion of this substance in a shell not quite freed from matrix was 2·09 per cent. These shells have usually been regarded as Pteropods; but I find that the Canadian primordial species show a structure very different from that of this group. They are much thicker than the shells of proper Pteropods; and the outer layer of shell is perforated with round pores, which in one species are arranged in vertical rows. The inner layer, which is usually very thin, is imperforate. In one species (I believe, the *H. americanus* of Billings) the perforations resemble in size and appearance those in the shells of *Terebratulæ*. In another species (*H. micans* probably) they are very fine and close together, as in some shells of tubicolous worms. I am therefore disposed to regard the claim of these shells to the rank of Pteropods as very doubtful. They may be tubicolous worms, or even some peculiar and abnormal type of Brachiopod. In connexion with this last view, it may be remarked that the operculum of some of the species much resembles a valve of a Brachiopod, and that the conical tube is in some of them not a much greater exaggeration of the ventral valve of one of these shells than the peculiar *Calceola* of the Upper Silurian and Devonian, which has been regarded by some palæontologists as a true Brachiopod. I have not, however, had any opportunity of comparing the intimate structure of *Calceola* with that of these shells. Shells of *Hyolithes* occur in the Lower Potsdam in the same beds with the phosphatic nodules: and in one of these Mr. Weston has found a series of conical shells

* Canadian Naturalist, Dec. 1871.

of *Hyolithes* pressed one within another, as if they had passed in an entire state through the intestine of the animal which produced the coprolite.

Inasmuch, then, as some of the most common invertebrates of the Cambrian seas secreted phosphatic shells, it is not more incredible that carnivorous animals feeding on them should produce phosphatic coprolites than that this should occur in the case of more modern animals feeding on fishes and other vertebrates.

We may now turn to the question as to the source of the abundant apatite of the Laurentian rocks. Were this diffused uniformly through the beds of this great system, or collected merely in fissure or segregation veins, it might be regarded as having no connexion with other than merely mineral causes of deposit. It appears, however, from the careful stratigraphical explorations of the Canadian Survey, in the districts of Burgess and Elmsley, which are especially rich in apatite, that the mineral occurs largely in beds interstratified with the other members of the series, though deposits of the nature of veins likewise occur. It also appears that the principal beds are confined to certain horizons in the upper part of the Lower Laurentian, above the limestones containing *Eozoon*, though some less important deposits occur in lower positions*.

The principal apatite-bearing band of the Laurentian consists of beds of gneiss, limestone, and pyroxene-rock, and has a thickness of from 2600 to 3600 feet. It has been traced over a great extent of country west of the Ottawa river, and has also been recognized on the east side of that river as well. The mineral often forms compact beds with little foreign intermixture; and these sometimes attain a thickness of several feet, though it has been observed that their thickness is variable in tracing them along their outcrops. Several beds often lie near to each other in the same member of the series. Thin layers of apatite also occur in the lines of bedding of the pyroxene-rock. In other cases disseminated crystals are found throughout thick beds of limestone, sometimes, according to Dr. Hunt, amounting to two or three per cent. of the whole mass. Disseminated crystals also occur in some of the beds of magnetite, a mode of occurrence which, according to Dr. Hunt, has also been observed in Sweden and in New York in the Laurentian magnetites of those regions.

The veins of apatite fill narrow and usually irregular fissures; and the mineral is associated in these veins with calcite and with large crystals of mica. In one instance, at Ticonderoga, in New York, the apatite, instead of its usual crystalline condition, assumes the form of radiating and botryoidal masses, constituting the Eupyrchroite of Emmons. Since these veins are found principally in the same members of the series in which the beds occur, it is a fair inference that the former are a secondary formation, dependent on the original deposition of apatite in the latter, which must belong to the time when the gneisses and limestones were laid down as sediments and organic accumulations.

* Vennor's Reports, 1872–73 & 1873–74.

In all the localities in which I have been able to examine the Laurentian apatite, it presents a perfectly crystalline texture, while the containing strata are highly metamorphosed; and this appears to be its general condition wherever it has been examined. Numerous slices of the more compact apatite of the beds have been prepared by Mr. Weston, of the Geological Survey; but, as might be expected, they show no trace of organic structure. All direct evidence for the organic origin of this substance is therefore still wanting. There are, however, certain considerations, based on its mode of occurrence, which may be considered to afford some indirect testimony.

If, with Hunt, we regard the iron ores of the Laurentian as organic in origin, the apatite which occurs in them may reasonably be supposed to be of the same character with the phosphatic matter which contaminates the fossiliferous iron ores of the Silurian and Devonian, and which is manifestly derived from the included organic remains.

If we consider the evidence of *Eozoon* sufficient to establish the organic origin, in part at least, of the Laurentian limestones, we may suppose the disseminated crystals of apatite to represent coprolitic masses or the débris of phosphatic shells and crusts, the structure of which may have been obliterated by concretionary action and metamorphism.

Such Silurian beds of compact and concretionary apatite (without structure, yet manifestly of organic origin) as that described by Mr. Davies in the 'Journal' of this Society, may be taken as fair representatives of the bedded apatite of the Laurentian. Further, the presence of graphite in association with the apatite in both cases may not be an accidental circumstance, but may depend in both on the association of carbonaceous organisms, whether vegetable or animal.

Again, the linguliferous sandstone of the Acadian group is a material which, by metamorphism, might readily afford a pyroxenite with layers of apatite like those which occur in the Laurentian.

The probability of the animal origin of the Laurentian apatite is perhaps further strengthened by the prevalence of animals with phosphatic crusts and skeletons in the Primordial age, giving a presumption that in the still earlier Laurentian a similar preference for phosphatic matter may have existed, and, perhaps, may have extended to still lower forms of life, just as the appropriation in more modern times of phosphate of lime by the higher animals for their bones seems to have been accompanied by a diminution of its use in animals of lower grade.

The Laurentian apatite pretty constantly contains a small percentage of calcium fluoride; and this salt also occurs in bones, more especially in certain fossil bones. This may in both cases be a chemical accident; but it supplies an additional coincidence.

In the lowest portions of the Lower Laurentian no organic remains have yet been detected; and these beds are also poor in phosphates. The horizon of special prevalence of *Eozoon* is the Grenville band of limestone, which, according to Sir William Logan's sections, is about 11,500 feet above the fundamental gneiss. It appears, from recent observations of Mr. Vennor and Mr. W. T. Morris, that the bed holding the Burgess *Eozoon* is on the same horizon with the limestone of Grenville. The phosphates are most abundant in the beds overlying this band. This gives a further presumption that the collection and separation of the apatite is due to some organic agency, and may indicate that animals having phosphatic skeletons first became abundant after the sea-bottom had been largely occupied by *Eozoon*.

I would not attach too great value to the above considerations; but, taken together, and in connexion with the occurrence of apatite in the Cambrian and Silurian, they seem to afford at least a probability that the separation of the Laurentian phosphate from the sea-water, and its accumulation in particular beds, may have been due to the agency of marine life. Positive proof of this can be obtained only by the recognition of organic form and structure; and for this we can scarcely hope, unless we should be so fortunate as to find some portion of the Lower Laurentian series in a less altered condition than that in which it occurs in the apatite districts of Canada. Should such structures be found, however, it is not improbable that they may belong to forms of life almost as much lower than the *Lingulæ* and Trilobites of the Cambrian as these are inferior to the fishes and reptiles of the Mesozoic.

Discussion.

Mr. Hicks said that the author had traced the existence of these phosphatic nodules considerably lower in America than had been done in England. He was inclined to accept the view of their organic origin, seeing that in England certainly the abundance of phosphates depends on that of organic life. The phosphate was due chiefly to the shell and to the decomposition of the substance of the body of the animals.

Mr. Keeping remarked that the presence of graphite in these rocks had been ascribed to plants; if so, the deposit was formed not far from shore, and consequently we should not get that freedom from sediment which is necessary for the production of an extensive deposit of animal origin. It seemed to him that attributing to these deposits an animal origin was like going round to the back door when the front door was open; for there was plenty of apatite in the igneous rocks. He believed that even in later ages, when life was more abundant, no workable deposits of coprolite nodules had been formed where now found, but they had been sifted out by the action of water from older deposits; for example, those of Cambridge from the Gault, and those of the Red Crag from the London Clay.