V.—On the Foraminifera and Sponges of the Upper Greensand of Cambridge.[1]

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The Upper Greensand of Cambridge occurs as a thin but very important bed, covering the eroded surface of the Gault, and blending upwards into the overlying Chalk-marl. It consists essentially of Chalk-marl, saturated with green grains of Glauconite, and crowded with a variety of fossils. The fossils in great part derive their origin from the Gault, out of which they have been concentrated by a natural process of levigation. At the time when the Gault sea was shallowing to its close, its submarine shores became eroded by a cold current flowing from the north, which bore away its lighter sedimentary clay, and left its imbedded fossils behind, to be subsequently rolled into the sublittoral deposit of the Upper Greensand. Thus it happens that in our neighbourhood the uppermost beds of the Gault are not to be found, and their only representative is this mere pebble-bed at the base of the Chalk. The rich fauna in our formation thus collected ready to the hand of the Palæontologist has been well worked out in its higher developments by Mr. Barret, Mr. Seeley, and various other observers. Of the *Protista* and *Cœlenterata,* however, some departments have been left all but untouched; and it is to the Sponges of the latter and the Foraminifera of the former that my paper refers. The Foraminifera occur abundantly, and in a rich variety, which seems to anticipate their more luxuriant appearance in the succeeding Chalk. The *Vitrea perforata* are represented by large forms of *Bulimina, Textularia,* and *Orthocerina,* which mimic truly arenaceous foraminifera by imbedding the siliceous and volcanic sand of the formation in their tests. *Cristellaria, Flabellina,* and *Frondicularia* are numerous, and of very fine growth; the *Frondicularia* sometimes attaining a ¼″ in length.

Rotalina is an abundant genus, so also are *Globigerina* and *Lagena.* The occurrence of this latter genus is noteworthy, for with the exception of one species, *L. apiculata* found in the Gault on the Continent, it has not been met with before below the Maestricht Chalk; in the Greensand, however, are several species, both of *Ectosolenian* and *Entosolenian* forms, of which one at least appears to be identical with a living species (*L. squamosa*) of the British seas. The large and numerous *Trochammina* and *Lituola* constitute a marked feature of the deposit. Of the same size as the Foraminifera, and associated with them, occur those characteristic green grains, whose origin in this formation has so long remained a subject for the merest conjecture. It is well known that off the coast of America, in the Ægean, and in some fossil deposits, green grains have been met with, distinctly derived from casts of Foraminifera. It was denied, however, that this was the case with the green grains of the

[1] Read before the Cambridge Phil. Soc., March, 1873.

Upper Greensand formation.[1] Mr. Seeley[2] considered that they were mostly derived from wasted Volcanic rocks, and the numerous Volcanic erratics in the deposit seemed to lend some support to his conjecture. It was with the full conviction that this explanation was the true one, that I commenced an extended examination of these grains: it was not long, however, before I convinced myself to the contrary; and I now feel assured that the majority of the Glauconite granules are undoubtedly casts of Foraminifera. What one is at once struck with is the constancy in form of a number of these green grains, many of them constantly appearing as rounded tetrahedra, divided into projecting lobes by deep sulcations, which are generally lined at the bottom with white calcareous matter, serving well to define the limits of each lobe. While examining these forms, which roughly resemble *Bulimina*, one comes across others almost exactly similar to *Textularia*, *Globigerina*, or even delicate *Nodosariæ*. The grains resembling *Bulimina* in shape are similar also in size, and the same is the case with the Textularine, Nodosarine, and Globigerine forms. A section of one of the Bulimine forms frequently reveals the septa of its chambers, or something representing them, still extending to a greater or less extent inwards between their casts. The cracks and interstices of the coprolites of the Greensand are frequently injected with Glauconite, and this proves at least the possibility of a similar infiltration of the Foraminifera. Nothing, however, can be more conclusive than the occasional occurrence of a green grain which is still enveloped in the actual test of the Foraminifer whose chamber it has filled; here we have an undoubted case of a foraminiferal cast, and as regards the other green grains, their resemblance in size and shape to the Foraminifera accompanying them, and the appearance of many of them in section, lead us to the conclusion that they likewise owe their origin to Foraminifera.

The fossils we have thus far touched upon are probably contemporaneous with the Greensand itself. We now approach forms which are almost to a certainty derived from the Gault. The Coprolites of our formation, since they first received their name from Prof. Henslow, have passed through a somewhat eventful career. It was soon seen that they were not what their name implies, but the conjectures hazarded concerning their real nature fell somewhat wide of the mark, till Mr. Bonney published his valuable suggestions, by which was indicated the first step towards the elucidation of their origin.

The first fact of importance to be noticed in reference to the Coprolites is their marked connexion with previously existing, highly decomposable, organic matter. The polished surfaces of the teeth of *Otodus*, and of the palates of *Pycnodus*, are seldom or never encrusted with Coprolite; while their attached surfaces, to which

[1] Mr. Bonney, however, expressed his belief that many of the green grains would be found to owe their origin to Foraminifera.—Proceedings Geol. Assoc., vol. iii., no. 1, p. 5.

[2] Geol. Mag. Vol. III., p. 305, 1866.

were adherent softer animal tissues, are often completely imbedded in it. So, also, the sternal surfaces of Crustacea are buried in Coprolite, while this is seldom the case with the exposed surfaces of their carapaces. Other examples might be adduced, and, indeed, instances of the same fact multiplied almost without end. An additional argument on this point is furnished to us by analyses, which prove as a general result that organic matter still exists in the Coprolites, and that sometimes to the extent of 5 per cent. This makes itself evident by a smell of burnt horn when the nodules are heated, and by an odour like petroleum when they are dissolved. Not only in the Greensand, but in various other formations, this connexion of Coprolite with animal matter has been observed. It is strikingly noticeable in the Coprolites of the Red Crag, which have been derived from the London Clay, as those of the Greensand from the Gault. The palates of *Myliobates* are found in the Crag with their biting surfaces exposed and bare, whilst their attached surfaces are deeply incrusted with the Coprolite. So, also, with the teeth of *Carcharodon*, *Otodus*, and their allies; great balls of Coprolite surround their bases, but leave their blades perfectly clean. The incrusted Crustacea of the Crag are sometimes, however, completely inclosed in Coprolite. Analyses here, as in the Greensand, indicate the presence of organic matter.

Various other deposits contain nodules, which present characters more or less in accordance with the foregoing; but most interesting are the forms of the Lower Silurian of Canada,[1] which offer striking illustration of the fact we have been adducing. Here the phosphatic matter incloses *Lingula*, and fills casts of *Pleurotomaria* and *Holopea*. When heated it evolves ammoniacal water, with an odour like burnt horn. It almost always contains fluorine, and is sometimes surrounded on the exterior by iron pyrites, as also are some of our Greensand forms, a fact of significance in relation to the formation of these bodies, and strictly paralleled by the similar incrustations sometimes found around certain flints. Analyses made of these Silurian Coprolites always yield a large per-centage of organic matter.

This connexion between Coprolites and organic matter, which derives support from almost every fact which an investigation of these forms brings to light, furnishes us with a basis for a scientific definition of the term. The original meaning of the word Coprolite has, in reference to our Upper Greensand forms, long ago been washed out, and has become replaced by a perfectly distinct signification indicating the phosphatic fossils of our formation, or more restrictedly such of them as are of obscure or uncertain origin. The word is not a good one, but in face of its almost universal adoption one cannot hope to exterminate it. Flints are scarcely likely to acquire a name after some long Greek derivative, and Coprolites could hardly do so a second time. As one is not at liberty to choose a new name for these bodies, I propose to limit the application of the old one, and to call those bodies Coprolites which are produced by the phosphatic

[1] Geological Survey of Canada, Edition 1863, p. 461.

fossilization of organic matter, or of the immediate products of its decomposition. This does no violence to the obvious meaning of the word, which may as correctly be derived from "manure-stone" as from "fossil-dung."

A Coprolite thus serves as an index of pre-existing organic matter, and the task of the Palæontologist lies in definitely determining from what particular form this organic matter has in each particular instance been derived. With the fossil remains of Reptiles, Crustacea, Molluscs, or of Ventriculites, the question could never have presented more than a passing difficulty, but in certain other cases it has proved so far problematical that no satisfactory solution has been received up till very recently. I now propose to suggest an explanation which has lately been worked out, and which to my mind seems thoroughly to meet the case.[1]

The ordinary nodules impress one with their resemblance to sponge forms at first sight, some are rod-like, solid throughout, and attached at one end (*Rhabdospongia*), others cylindrical, with a central cloaca (*Bonneyia*), some again are cup-shaped (*Hylospongia*), others massive and lobose (*Acanthophora*), while some are branching, and others, finally, are incrusting. On closer examination of these nodules, one is frequently rewarded by finding, on the exterior surface, little pits of most definite characters. They are oval or circular in shape, and from $\frac{1}{8}''$ to $\frac{1}{20}''$ in diameter. Their circumference is often depressed into a concave border, across which pass regular striations, frilling it like the milled edge of a coin; sometimes these groovelets cease at the outer border of the little pit, at others they pass across it and wander for a long way until they are lost in the surrounding surface. The general character of these pits is strikingly suggestive of sponge oscules; still more so is their arrangement. Frequently they are grouped in sieve-like patches, sometimes they occur on one side only of the nodule, and occasionally they are terminal; in all these respects they find close parallels among existing sponges.

Besides these osculiform pits are numerous minute punctæ, which, in the Gault Coprolites, are seen to be the distinctly open terminations of fine canals. In the Greensand forms, however, these canals have become filled up since the nodules were washed out from the Gault, and their openings consequently appear as mere specks of a lighter colour than the surrounding substance. In other fossil sponges minute openings similar to these would be called "pores" by Palæontologists. These are all the observations one can make without the aid of instruments, but all the characters we have so far noted agree essentially with those of sponges, and not with anything else.

It now becomes necessary to examine the Coprolites more in detail—in sections and solutions under the microscope. When I came to do this, the necessity for preparing an extensive series of sections at once presented itself as a difficulty. Mr. Bonney, how-

[1] Quart. Journ. Geol. Soc. Lond., Rev. O. Fisher, vol. xxix., p. 52; and W. J. Sollas, vol. xxviii., p. 397, and vol. xxix., p. 76.

ever, with his uniform kindness, placed at my disposal a large number of slides, on which are founded my succeeding observations.

The parts of a sponge which are most likely to be preserved are its siliceous spicules, and in most of the Coprolites of the formation spicules of one kind or another are to be found in greater or less abundance; a few simple needle-shaped spicules may generally be met with in any ordinary nodule, but in some particular forms they are especially numerous. *Rhabdospongia* has furnished some very fine examples; but, in the number and variety of their contained spicules *Polyacantha Etheridgii* and *Acanthophora Hartogii* far surpass all the rest. In both of these species hexradiate, quadriradiate, triradiate, and sinuous spicules are to be met with, and one of them is characterized especially by its porrecto- and recurvo-ternate forms. It is important to notice that the spicules are not only of indisputable sponge *forms*, but are sometimes also arranged in a manner which seems to indicate that they occur *in situ*, and were not washed in during fossilization.

Various other bodies accompany the spicules in these sections, and in solution. Little spherules $\frac{1}{400}''$ $\frac{1}{200}''$ are not uncommon, and unless they are spicular in origin, it is difficult to conceive what else they can be but sponge gemmules. In some sections *Xanthidia* may be observed of the same species as those of the Chalk—*X. hirsutum, X. ramosum, X. tubiferum. Polycystina* of various genera also occur, and will shortly be described; forms resembling *Haliomma* may be noticed of somewhat common occurrence.

It is important to notice, as deciding the siliceous nature of the included spicules, that on dissolving the Coprolites in concentrated hydrochloric acid, an insoluble residue remains, which contains the spiculæ of the organism, together with its included *Polycystinæ* and the *Xanthidia* just enumerated. These may easily be observed under the microscope by suspending the residue that contains them in a little water, and placing a drop of this on an ordinary glass slide. The *Xanthidia* that may be present are really beautiful objects; floating in the water on the slide, they swim about freelyin its currents, and catch with their claw-like processes at every little obstacle in their way, as though they were really alive.

Mr. Carter[1] has observed that in certain subspherous sponges the contractility succeeding death is often so great as almost to obliterate all their canals. That the organisms which furnished the Coprolites underwent great contraction after death is shown by the deep creases with which they are generally marked, while their contraction after *fossilization* is exhibited in quite a different manner by numerous sharply defined cracks. In consequence of this contraction, we should scarcely expect to find more than mere traces of canals now preserved, and as a general rule we do not. There are, however, some exceptional cases; for sometimes lighter streaks are seen drifting through the dark-brown Coprolite somewhat like the digitations of a river in its delta; and in single instances a vacant tube, circular

[1] A descriptive account of four subspherous sponges, Arabian and British. J. H. Carter, F.R.S., Ann. Mag. Nat. Hist., ser. 4, vol. iv., p. 1, 1869.

in section, is preserved, into which canals may be seen opening on all sides from the surrounding matrix.

On a review of the evidence I have just brought forward, few, I think, will be disposed to deny to a large proportion of the Coprolites, whose nature has for so long remained doubtful, a spongeous origin; their constancy in sponge form, the characters and arrangement of their well-marked oscules, their spicules, and the general connexion of coprolitic deposition with pre-existing animal matter, seem to force upon us the conclusion that to a large extent they owe their origin to sponges. The task now remains to determine the families and genera of recent sponges to which these fossils are most nearly allied; this will be a matter for laborious research, but so far as my investigations have yet carried me, I feel myself justified in pointing to the families *Esperiadæ* (Dr. J. E. Gray) and *Tethyadæ* (Gray) as those to which a number of these forms approach most nearly; while others hold most undoubted relations to the *Halichondridæ* (Gray).

In connexion with this subject, I may mention that spicules of *Geodidæ*, *Tethyadæ*, and other genera have already been definitely determined from the Upper Greensand of Blackdown.[1]

Besides this comparison of the Greensand fossil sponges with living forms, there also remains to be accomplished their correlation with the Coprolites of other deposits, a work only just entered upon; it is interesting to note, however, that so low down as the Lower Silurian of Canada, Coprolites have been found, one specimen of which, unusually rich in organic matter, contained small cylindrical bodies closely resembling the spicula of Sponges.[2]

Travelling upwards in the stratigraphical series, we find that as the close of the *Gault* is characterized by the occurrence of a large number of phosphatic nodules or Coprolites, so the close of the *Chalk* is distinguished by an abundance of peculiar siliceous nodules or Flints. There is, moreover, between these Flints and Coprolites so decided a parallelism, that in speaking of the Coprolites as the Flints of the Gault, one can scarcely be said to be indulging in metaphor. Both have been placed in the category of concretions, both alike have been formed by the mineralization of highly decomposable organic matter. It has been shown in both cases, that this animal matter has been largely derived from sponges; the Foraminifera and Xanthidia so characteristic of the Flints are found also in the Coprolites; and the Ventriculites which so generally accompany the former are not absent from the latter, since I have recently shown that several species of Ventriculites and Cephalites are far from uncommon in our deposit, and, indeed, that it is characterized by the very same species which appear later on in the Chalk strata (*V. tesselatus, mammillaris, cavatus, quincuncialis; Cephalites guttatus, capitatus*, etc., etc.).[3]

[1] Fossil sponge spicules. Ann. Mag. Nat. Hist., ser. 4, vol. vi. p. 192, 1870, and Devon Assoc. Advt. Science, Lit., and Art, 26th July, 1870.

[2] Geological Survey of Canada, *loc. cit.*

[3] Quart. Journ. Geol. Soc., vol. xxix., p. 63.

The difference existing between Flints and Coprolites is merely this: that in the one case the basis of animal matter combined with a gelatinous hydric calcic phosphate, and in the other with a gelatinous silicic acid. In both cases after combination the organic elements carbon, hydrogen, and nitrogen were slowly dissipated, while the *mineral* matter remained behind as we see it now.

The *source* from which the Coprolites seem to have derived their calcic phosphate is to be attributed directly or indirectly to the waste of the volcanic rocks of the Lammermuirs and of other Northern localities. Its *means of conveyance* the cold current which subsequently eroded the Gault, and brought down in solution the ferrous and other silicates to infiltrate the Foraminiferal casts.

Once more passing upwards in the Geological series to recent seas, we come upon what seem to be Coprolites even now in process of formation, for it is asserted by Prof. Edwards,[1] that a large part of the guano of the Chincha Islands in no way bears any resemblance to the excrement of birds, but, on the contrary, is a stratified deposit of Sponges and various Protists still in process of fossilization. The anchors of ships weighed there are said to frequently bring up guano from the bottom of the ocean, and microscopic analysis has shown that the insoluble parts of the deposited guano consist of sponge skeletons, *Diatoms* and *Polycystinæ*, far too well preserved to allow us to conclude that they have passed first through the intestines of Molluscs, and then through those of Birds. However this may be—and one would not wish to put too much weight on these statements till they have been abundantly verified—we cannot but feel that the dignity of excrement has already been somewhat detracted from; and while on the one hand the sponges have recently received a great elevation in rank in the Zoological kingdom, they have on the other increased somewhat in importance in the Geological world.

NOTICES OF MEMOIRS.

I.—On the Geology of the Eastern Portion of European Turkey.

Die Geologischen Verhältnisse des östlichen Theiles der Europäischen Türkei. Von Professor Dr. Ferdinand von Hochstetter. 2te Abtheil. Jahrbuch der K. K. geologischen Reichsanstalt, 1872. xxii. Bd. 4 Heft.

STRABO mentions as the principal mountain ranges of Roumelia the Bertiscus, Scardus, Orbelus, Scomius or Scombrus, the Rhodope, and the Haemus. He also asserts that these ranges reach in a straight line from the Adriatic to the Black Sea, which notion was until recently expounded in all the handbooks of geography, treating these ranges, as a central mountain ridge, and a continuation of the Eastern Alps. Only lately the discoveries of Boué, Viquesnel,

[1] Essex Inst., Salem, Mass., Bull. vol. i., p. 11, 1866. Ann. Lyc. Nat. Hist., New York, vol. x., p. 225, 1871. Quart. Journ. Micr. Soc., new ser. no. xlv., p. 71.