II.—ON THE GLAUCONITIC GRANULES OF THE CAMBRIDGE
GREENSAND.

By W. J. SOLLAS, B.A., F.G.S.

(PLATE XXI.)

THE Coprolites or phosphatic nodules of the Cambridge Greensand frequently contain amongst other included bodies a number of Foraminifera and glauconite granules, of the same kind as those found scattered loosely throughout the Greensand bed.

When a transparent slice is prepared of one of these coprolites, it of course reveals a number of these included bodies in section, and so offers a favourable opportunity for the examination of their internal structure, an opportunity which I have made use of, especially with a view to test the conclusions which I had published in 1872 on the origin of the Greensand glauconitic grains.

Position of the Green Granules and Foraminifera in the Coprolites.

—These, like most of the other foreign bodies contained in the phosphatic nodules, occur most usually and in greatest abundance in the secondary deposit of coprolite, which has, subsequently to the formation of the original nodule, incrustated its surface or filled in the cracks that fissured it as it contracted on fossilization; while in those nodules which owe their origin to sponges these included bodies are found, in addition to the former positions, in the material which has entered into and filled up what were once the canals and 'cloaca' of the sponge.

Foraminifera.—These are arenaceous and perforate vitreous forms, like those which occur in the Greensand bed; their chambers are filled with different materials in different cases, sometimes crystalline calcite, and occasionally glauconite has infiltrated them, but most commonly phosphatic material similar to that in which they are contained. These three minerals are found in the interior indifferently of both arenaceous and perforate foraminifera; and when glauconite fills the latter, it may be traced from the cast of the chambers passing into the fine tubulations which perforate the walls.

Green Grains. External Form.—Some of the green grains are of the regular shape which characterizes casts of perforate Foraminifera; but the majority of the sections are of such various and irregular outline, that from it alone no clue to their mode of origin can be obtained; of these irregular forms a few exhibit attached to their exterior fragments of arenaceous foraminiferous tests, the remnants probably of the moulds in which they were formed; but the greater number are free from any such incrustation, and are simply granules of glauconite of very irregular form. What the origin of these may be is very doubtful; judging by analogy it seems probable that many of them may be casts of arenaceous Foraminifera; but how far this is actually the case we have no means of saying.

Internal Structure.—The thin sections of the glauconite granules are of a light green colour, deeper in tint in some places than others, and transparent except where rendered opaque by the presence of included particles.

The substances usually scattered throughout the sections are small Foraminifera, Coccoliths, Coccospheres, minute granules, fragments of crystalline minerals, and other substances, the nature of which is uncertain.

Foraminifera.—These are very small, and in proportion to the size of the granule containing them absolutely insignificant (Pl. XXI. Fig. 1*f*). The walls of their tests are either well preserved as pseudomorphs in glauconite, in which case they are of the same green colour, but clearer and more transparent than the surrounding material, and well defined on both their inner and outer margins; or else they have disappeared altogether or in part, leaving only a few granules or a dark brown line to mark their original position.

The position of the Foraminifera in the green grains is very variable, sometimes a test may be seen in the middle of a section (Pl. XXI. Fig. 3*f*), but quite as often at the side (Pl. XXI. Fig. 1*f*); whilst in one instance (Pl. XXI., Fig. 2*f*) the outline of the grain intersects the inclosed Foraminifera, cutting off the interior from an exterior portion which has since disappeared. The intersecting edge of this grain (*l*.) is, however, a suspiciously straight one, and may possibly be due to fracture.

No appearance of a crystalline radiation from any of the included bodies towards the circumference of the granules is to be detected either with ordinary or by polarized light.

Coccoliths.—The Chalk-marl, which constitutes the greater part of the Cambridge Greensand bed, is to a great extent composed of coccoliths, entire and fragmentary, which in the number and variety of their forms surpass all that I have yet seen figured from recent seas. I have already drawn, and partly described, a large series of these bodies; but as it will be impossible to publish the description for some time, and as their presence in the glauconite granules is a subject which concerns us now, it may not be amiss to give a brief preliminary account of the forms which have been recognized in the granules, supplemented by the addition of one or two others from the Chalk-marl.

The form represented in Pl. XXI. Fig. 5, is one of the most abundant in the Chalk-marl, and occurs most commonly in the glauconitic granules. It consists of a transparent, colourless or faintly greenish oval ring (Fig. 5*a*.), well defined on its outer and inner circumference, inclosing an oval space, clear and transparent (*c*.) at its outer margin, close to the inside of the ring, but cloudy and granular (*s*.) towards the centre, at or near which is situated a single granule (*g*.), larger than the rest, transparent and of the same green tint as the outer annulus. Viewed sideways this form appears like a simple rod.

The whole of this structure consists of carbonate of lime, and on solution in weak acid dissolves entirely or with the exception of a delicate membranous film, which is dotted over with a number of faintly marked granules; and which on the addition of carmine or magenta stains to a light red colour. Fig. 20 represents such a film left on the solution of a form like that shown in Fig. 8.

W. J. Sollas del.

W. West & Co. imp.

Glauconitic granules from the Cambridge Greensand.

This membrane may be composed of sulphate of lime, which has impregnated the calcareous skeleton of the coccolith after its death, though I doubt this.

The form we have just described is evidently a flat or somewhat concave disc, thickened at its edges into a ring-like border, and at its centre into a granulated area with one of the granules much larger than the rest. It is well enough preserved in the glauconitic granules to show clearly the outer annulus and the central granule.

Figs. 6 and 6*a*. represent a very common modification of this form, which appears to me to result from a circumferential constriction round the edge, grooving it, so as to produce a resemblance to a pulley-wheel. It has not been observed within the green grains. Fig. 7 is a large form of Fig. 5, which attains relatively to the latter form a size fully double that which is shown here. The outer ring much thickened appears to be marked along the middle of its upper margin by a rounded ridge, which on focussing down resolves itself into a number of granules, somewhat irregularly arranged. Broken pieces of this variety are to be seen in the green grains.

The next form, Fig. 8, is similar to Fig. 5, but differs from it by the presence of a transverse bar produced from the annulus, along the minor axis of the ellipse, and which divides the central oval area into two parts, each with its cloudy centre and refractile granule.

To all appearance this is simply Fig. 5 undergoing fission, and yet the whole structure consists of carbonate of lime. In connexion with this, it is noticeable that while both of these coccoliths vary in size, yet that of Fig. 5 does so to a much greater extent than that of Fig. 8.

In the next variety, Fig. 9, the process of sub-division has gone a step further, and the space within the ring is partitioned off into four by a thickening of the disc along two axes at right angles to each other.

The next division of the coccolith is into eight, as shown in Fig. 10, and so far each step in the process has followed the geometric progression, 1, 2, 4, 8; in Fig. 13, however, we have an exception to this rule, since it exhibits nine sub-divisions within its inclosing annulus, and we omitted in passing to notice another very rare form where the loculi number three. Fragments of the forms Figs. 10 and 13 are found in the Chalk-marl (Fig. 11) looking like a residue left on the dehiscence of the other part of the coccolith; such a fragment (Fig. 14) is the only instance of these last complicated forms which I have observed in the green granules, and it appears to have been derived from an even still more complex type, since if the missing part be supplied, the restored ring would present, I should judge, nearer 16 than 8 loculi. All the forms from Fig. 5 to 13 vary in the relative length of their major and minor axes, and sometimes become quite circular; Fig. 12 represents the round variety of Fig. 10.

All again may develop stalks or stems at right angles to the plane of the disc, *e.g.* Fig. 15, which is derived from a form like Fig. 5; Fig. 17*a*, from Fig. 17; and Fig. 18 from Fig. 6. In forms like Figs.

8, 9, 10, the stalk is produced from the centre of the transverse thickening; of these stalked varieties only forms like Fig. 15 have been observed in the green grains. (See Pl. XXI. Fig. 3 d.)

Fig. 19 is a variety of Fig. 9, differing from it by its granulated edge; Fig. 16 is a stalked form, granulated sharply on its upper margin, so as to resemble a crown-wheel.

Coccospheres.—These I have observed in several instances in the Chalk-marl as spherical bodies covered loosely with the oval form of coccolith like Fig. 5. On solution a faint granular membrane corresponding in outline and size with the original sphere remains behind; it stains faintly with magenta. In the glauconitic granules I have several times noticed small spherical bodies with thin walls, marked with refractile ridges and granules, which closely resemble coccospheres; the best marked of these is shown in Fig. 3 at c.

Granules.—These bodies, which are exactly similar in size and appearance to those which make up so large a proportion of the Chalk-marl, and which resemble also the refractile granules inside the coccoliths, occur very abundantly in the green grains, and can be distinguished therein by their greater transparency and different refractive index.

Bodies of uncertain nature.—Small angular fragments of colourless and transparent crystalline minerals resembling felspar, splinters of an indeterminate substance, bacilli and other small bodies, are sometimes inclosed. One green grain $\frac{1}{16}$ " diameter was observed to be entirely filled with a faintly defined, fine, polygonal reticulation, a part of which is shown, magnified 435 diameters, in Fig. 4. What this may be it is hard to say; but clearly the organism from which the grain was derived had no connexion with the Foraminifera.

Conclusion.—The coccoliths and granules which characterize the green grains of irregular form, are also present in the glauconite casts of foraminiferal chambers, and in the phosphatic material and crystalline calcite, which occupy the interior of the foraminiferal tests; while all the bodies described from the interior of the granules occur also in the phosphatic matrix of the coprolite which imbeds both the foraminifera and the green grains, and in the Chalk-marl which contains the coprolites. The character, in fact, of the irregular granules and of the foraminiferal casts is that of Chalk-marl, which has become changed by a mineral replacement into glauconite. What the cause is which has induced this change is another question, but apparently the presence of organic matter in some form or other has been essential to it; thus we frequently find glauconitic material forming a cast of the interior of a foraminifer and infiltrating its tubules, without in the least affecting its calcareous walls, which retain their original composition. It here then occupies the place of animal matter to the total disregard of the associated mineral shell. To this it may be objected that the glauconite may also be regarded as occupying a space separated from the external Chalk-marl by a limiting foraminiferal test, and that the presence of this separation was sufficient to bring about the infiltration which has taken place; but if this view be true, one would expect to find some trace of a

progressive growth in the glauconite from the exterior inwards, while in fact no signs of any such increase can be detected, neither in successive incrustations, nor in any crystalline arrangement, like that which one observes when a mineral infiltration has really taken place in this stalactitic manner.

The glauconite is indeed not crystallized, but simply cryptocrystalline, in exactly the same way as flint and coprolite are cryptocrystalline. Accepting then, as seems to be generally allowed, that the presence of animal matter has been one of the essential determining causes for the deposition of glauconitic material, we have next to find animal matter for this purpose. The inclosed Foraminifera seem too minute to have furnished a sufficient supply, nor have they been proved to be constantly present in the granules, especially since the sections of many of the latter show no signs of them; it thus appears that we must have recourse to the agency of such minute and soft-bodied organisms as are to be found amongst the Protista and Protozoa; these scattered throughout the Chalk-marl in which the green grains were originally formed would, on their death, lead to a deposition of glauconite about themselves, and thus necessarily include the immediately adjacent Foraminifera and coccoliths, and the other bodies which they now contain; while the shape of the resulting glauconitic mass would be simply determined by the irregular extension of the decaying organic matter.

The resemblance of the glauconitic granules to flints and coprolites, which appears on this view, is very striking. Both flints and coprolites are found filling the interior of certain shells, most notable instances of which are the coprolitic casts of *Pleurotomaria*, and the flint which fills the interior of *Ananchytes*; both frequently surround, even to the extent of inclosing, the organisms, which at other times they simply occupy as casts; and both also have served to mineralize the soft animal matter furnished by various kinds of sponges; the glauconitic granules similarly are frequently confined to the interior of foraminiferal tests, from which, however, they sometimes extend so as to spread over the exterior and form a complete inclosure, while finally, according to our view, they present a further analogy in that they have also formed about the soft bodies of decomposing animals, of the previous existence of which they now supply the only trace.

EXPLANATION OF PLATE XXI.

- FIG. 1. Section of a glauconitic granule, magnified 140 diameters; (*f*) included Foraminifer; (*g*) granules; (*m*) fragment of crystalline mineral.
- FIG. 2. Section of a glauconitic granule, including a part of a Foraminifer (*f*); the rest of which is cut off by the edge (*l*). ($\times 140$.)
- FIG. 3. Section of a glauconitic granule, magnified 435 diameters; (*d*) coccoliths; (*c*) coccosphere; (*s*) splinter of uncertain nature. The other letters as in Fig. 1.
- FIG. 4. Part of the polygonal reticulation of which one of the green granules is composed. ($\times 435$.)
- FIG. 5. Simple form of coccolith; (*a*) the outer annulus; (*c*) the clear zone; (*s*) the clouded central area; (*g*) the central granule.
- FIG. 6. Coccolith with marginal groove, seen face on, but slightly tilted at one end; (*6a*) side view of the preceding.

FIG. 7. Large form of simple coccolith, showing superficial ornamentation of the annulus.

FIGS. 8 to 13. Coccoliths exhibiting the successive stages in which the central area becomes subdivided.

FIG. 14. Fragment of a complex coccolith included in a glauconitic granule.

FIGS. 15 to 18. Various stalked forms of coccolith.

FIG. 19. A variety of Fig. 9, granulated at the margin.

FIG. 20. Membranous film left after the solution of a form like Fig. 8.

Figs. 5 to 20 are magnified from 1500 to 2000 diameters.

III.—ON SCOTTISH MONOGRAPTIDÆ.

By CHARLES LAPWORTH, F.G.S.

(Concluded from page 507.)

§ VIII.

Genus CYRTOGRAPTUS, Carruthers.

This genus was founded by Mr. Carruthers to include those compound forms of monoprionidian *Graptolites* in which the polypary is unilateral, growing from the initial point in one direction only. There can be no hesitation in regarding it morphologically as a branching *Monograptus*; its mode of development, the characters of its hydrothecæ, and its geological distribution, all pointing unmistakably in this direction. It is also very variable in its mode of branching; and occasionally simple examples are met with, undistinguishable in every respect from typical specimens of *Monograptus*. This negative evidence is, however, of no great weight, as these examples previous to fossilization may have been deprived of the branches they once possessed. Unlike *Monograptus*, the species of this genus are few in number, and even individuals are of rare occurrence. Recollecting, however, the fragmentary state in which all the forms of the present family are preserved to us, and the impossibility of identifying a species of *Cyrtograptus* unless we possess unequivocal evidence of the compound character of the polypary, it may be regarded as certain that our present scanty list will be greatly augmented in the future.

35. CYRTOGRAPTUS CARRUTHERSI, sp. nov. Plate X. Figs. 6a-c.¹

Polypary unilateral, compound, monoprionidian. Principal branches long, slender and flexuous, originating similar secondary and simple branches at distant intervals. Hydrothecæ 16 to the inch: conical, adnate, in contact only; apertural margin of each inclined: denticle mucronate, conspicuous.

The principal branch exhibits the peculiar circinate proximal termination so frequent in the allied genus *Monograptus*, and is more or less curved throughout the whole of its extent. Extremely slender at its origin, it almost insensibly expands to the normal diameter of one-twentieth of an inch, including the projection of the hydrothecæ. As a rule the polypiferous margin is that of the outer edge of the curve, but great irregularity in this respect is caused by the frequent entanglement of the secondary branches. These exactly resemble the primary branch in size, length, and amount of curvature, but appear to be invariably simple.

¹ See GEOL. MAG. for July, p. 321.