42. *On the OCCURRENCE of RADIOLARIA in CHALK.* By W. HILL, Esq., F.G.S., and A. J. JUKES-BROWNE, Esq., B.A., F.G.S. (Read June 19th, 1895.)

[PLATE XXII.]

CONTENTS.

	Page
I. Introductory Remarks	600
II. The Chalk in which the Radiolaria occur	601
III. The Instability of the Radiolarian Skeleton.....	603
IV. Description of the Forms met with	604

I. INTRODUCTORY REMARKS.

THE rarity of radiolaria in rocks of Upper Cretaceous age is a remarkable fact, and one for which it is not easy to account, seeing that they are not uncommon in Lower Cretaceous rocks on the Continent, and that they have been found in beds of Jurassic age in France, Hanover, and Bavaria. One would moreover have expected the physical conditions of the Upper Cretaceous period to have been more favourable to their existence than those of Lower Cretaceous or Jurassic times. It will be seen, from the descriptions which follow, that one cause of their rarity is undoubtedly the facility with which the siliceous skeletons of *Polycystina* disappear, when they are embedded in rocks which contain a large proportion of carbonate of lime.

Our knowledge of Upper Cretaceous radiolaria comes chiefly from Germany. In 1876 Prof. Zittel described six species,¹ occurring in a Greensand of Senonian age in Westphalia and Brunswick.

In 1888 Dr. Rüst described some well-preserved forms which he had detected in phosphatic nodules from the Gault of Saxony, Hanover, and Southern France, and in material filling the body-chambers of ammonites from the same formation.²

He also described *Dictyomitra anglica* from flints in the Upper Chalk of England (*op. cit.* p. 211 & pl. xxviii. fig. 16) and *Dictyospyris chlamydea*, same occurrence (*op. cit.* p. 204).

Besides those in the English flints mentioned by Rüst there are only two records of the occurrence of radiolaria in English Cretaceous deposits. Prof. W. J. Sollas, in 1873, describing the coprolites of the Cambridge Greensand,³ which were afterwards shown to have been derived from the Gault, says '*Polycystina* and *Xanthidia* occur in some sections,' but he does not figure or describe them. Prof. Sollas has been kind enough to lend us the slides in which these forms occur, but we find that they have well-preserved tests, and differ both in shape and mode of preservation from those which we have found in the Chalk.

In 1883 Dr. Wallich recorded the occurrence of radiolaria in the mealy material found inside hollow flints, mostly obtained from the

¹ Zeitschr. d. deutsch. geol. Gesellsch. vol. xxviii.

² 'Palæontographica,' vol. xxxiv. (1888) pp. 181, 185.

³ Quart. Journ. Geol. Soc. vol. xxix. p. 78.

Surrey gravel-pits.¹ Forms of *Astromma*, *Haliomma*, *Podocyrthis*, and others occur; these also, through the kindness of Prof. Rupert Jones, we have had the opportunity of seeing, and they are all silicified tests, many of them in good preservation.

Several hundred slides cut from almost all the various divisions of the Chalk, from many different localities, have been examined by us, but nothing ever presented itself in any of these which was unmistakably a radiolarian test. Many years ago, however, one of us had noticed that sections through nodules from the Melbourn Rock always contained spherical bodies which had a peculiar aspect, and did not occur in any other kind of Chalk. Being rather inconspicuous and apparently structureless objects, they somehow escaped attention when our joint paper on the Melbourn Rock² was being written, and no mention of them was then made.

A few years ago we had the good fortune to obtain and examine a large series of radiolarian earths, chalks, and siliceo-calcareous deposits from Barbados; a study of which made us familiar, not only with the forms of radiolaria as seen in a thin rock-slice, but also with the changes in structure and mineralization which they undergo during the consolidation and partial alteration of the deposits after these have been elevated and exposed to the action of percolating water.

Happening recently to examine some slides of Melbourn Rock again, we were struck by the resemblance of the spherical bodies above mentioned to the form and general appearance presented by calcified and semi-destroyed radiolaria in some of the Barbadian rocks. A careful comparison confirmed the fact of this resemblance, and an examination of other slides disclosed the existence of forms to which the spinous processes were still attached, so that we became convinced of the radiolarian origin of the bodies before us.

Finally some of the slides were submitted to Dr. Hinde, who writes that he agrees with us as to the nature of most of them, and though he at first suggested that some might possibly be diatoms, he subsequently writes that as the spined forms are almost certainly radiolaria it is most likely that the smooth circular bodies also belong to that group, and he would so consider them unless flattened circular *Coscinodiscus* diatoms were proved to be present.

II. THE CHALK IN WHICH THE RADIOLARIA OCCUR.

The bodies which we take to be radiolaria were first noticed in the Melbourn Rock, and since our attention has been recalled to them we have found them in the nodules of samples of Melbourn Rock obtained from many parts of England. They do not occur in the coarser shelly matrix of that rock, but only in the nodules or lumps of hard fine-grained white chalk which make up so large a portion of the rock.

The nodules of the Melbourn Rock have been described by us in

¹ Ann. & Mag. Nat. Hist. ser. 5, vol. xii. (1883) p. 52.

² Quart. Journ. Geol. Soc. vol. xlii. (1886) p. 216.

previous publications,¹ and we regarded them as portions of some pre-existing deposit of chalk-ooze which had gained sufficient coherence to be rolled into lumps on the sea-bottom under the influence of the current which distributed the material whereof the enclosing matrix is composed. We have not changed this opinion, but it would seem that the chalk-ooze which yielded the Melbourn Rock nodules differed from the similar chalk which occurs both at lower and higher horizons, either in the fact of its containing radiolaria or in some special property which was favourable to their preservation.

We have recognized these calcitic replacements of radiolaria in the nodular portions of the lower beds of the Melbourn Rock taken from the following localities:—Melbourn and Royston, in Cambridgeshire; many exposures near Hitchin (Herts); Leagrave, near Luton, in Bedfordshire; Pitstone and Tring, in Bucks and Herts; near Watlington, in Oxfordshire; several localities in Lincolnshire and Yorkshire; in the deep boring at Richmond; in the lower part of the 'grit-bed' at Dover; also at Sutton Waldron, south of Shaftesbury (Dorset); Bincombe, in South Dorset; and quite recently in nodular chalk which may be considered as the equivalent of the Melbourn Rock, from Bindon Cliffs, near Axmouth, Devon.

They do not seem to occur in the nodules of the upper part of the Melbourn Rock, or in those of the Chalk Rock; and though one of us has been constantly cutting samples of chalk from many localities and from various horizons, he has never noticed any such organisms in any other part of the Chalk, except quite recently in nodules from the hard beds of the Chalk Marl in Norfolk, Lincolnshire, and Yorkshire.

One can hardly imagine that the epochs of the Chalk Marl and of the Melbourn Rock were the only times when radiolaria existed in that part of the Cretaceous sea which covered England and France, and it seems more reasonable to suppose that they were frequently present and were embedded in many portions of the Chalk-ooze, but were usually so rapidly and completely dissolved that no trace of them had been left in the consolidated material. Doubtless they contributed to that solution of silica which furnished the substance of the siliceous concretions which we call flints.

We conclude that the preservation of traces of radiolaria in the nodules of the Melbourn Rock is due to some specially favourable conditions, but at present we have seen nothing to indicate what these conditions were. The fact, however, agrees with Dr. Rüst's experience of their mode of occurrence in the Jurassic and Cretaceous rocks of Germany.

In the nodules that we have examined the proportion of radiolarians to the mass of the rock is usually small, but specimens varied considerably. Where these are most numerous the rock may be compared with the calcareo-siliceous deposits of Barbados, which

¹ Quart. Journ. Geol. Soc. vol. xlii. (1886) p. 230, and 'The Geology of London,' Mem. Geol. Surv. 1889, vol. i. p. 521.

contain 12 to 13 per cent. of colloid silica, but this proportion is exceptional, and recognizable radiolarian forms are, as a rule, widely separated.

In the present communication we propose to describe only those forms which we have found in the nodules of the Melbourn Rock, leaving further notice of their occurrence in the Lower Chalk for a future occasion, by which time we may perhaps have discovered some clue to the relation between the occurrence of radiolaria and the formation of the nodules in which they occur.

III. THE INSTABILITY OF THE RADIOLARIAN SKELETON.

Slices cut from some of the consolidated deep-sea deposits of Barbados give valuable indications of the manner in which radiolarians are gradually destroyed in the process of fossilization. Those in the more purely siliceous earths do not seem to undergo much change, but those contained in material which is partly siliceous and partly calcareous are more rapidly altered. If a thin section of a calcareo-siliceous rock be viewed by transmitted light, the radiolarian is usually seen in annular outline marked by clear crystalline material (which occupies the position of the original siliceous skeleton), while the interior is filled with a denser, amorphous, calcareous matrix like that of the surrounding rock. The continuity of the clear outline is broken by the pores of the test which, as well as the interior, have become filled with the denser calcareous material. Not infrequently the infilling matter is slightly more crystalline than the matrix of the rock, and, the light passing more readily through it, the outline of the radiolarian acquires greater definition.

But in some cases the interior of the test is filled entirely with clear crystalline material, and it then stands out in strong relief to the darker grey shade of the matrix. Between these two extremes there is every gradation, the lattice-work of the test being sometimes partly visible and sometimes partly destroyed, in others so completely obliterated that nothing but the outline of the test remains for recognition.

The crystalline material infilling the tests of radiolaria in the rocks of Barbados may be either calcite or silica in the colloid state, according to the nature of the rock: calcite where calcite predominates, silica where the rock contains the greater proportion of radiolarians; but often in these mixed rocks the polariscope proves both calcite and silica in the same test. It is evident that the siliceous skeleton of the radiolarian enters into solution and is re-deposited in the matrix of the rock, binding its ingredients into a compact calcareo-siliceous mass; this material fills the chambers of the foraminiferal shells and the tests of the radiolaria.

We also observe that the preservation of a radiolarian, even in the form of a cast, depends greatly on the shape and structure of the test. From the examination of a number of slides of the Barbadian rocks we find that Sphæroid, Discoid, and Prunoid tests are the most prominent, the enclosed cell-like character of these shapes seeming to favour the accumulation of glassy material within them.

while the Cyrtoid test is only feebly outlined. Radiolarians with the sponge-like character of the test can be sometimes recognized by a greater opacity of the material within the outline.

While the siliceous network of the test is frequently obliterated in these Miocene radiolarians, one structural characteristic is sometimes retained,—namely, ‘the medullary shell.’ This is often defined by an inner ring, a clearer central area, or a central area filled with the denser semi-opaque material of the matrix of the rock. Even when the whole test is completely filled with clear material, and no trace of the skeleton is left, the position of the medullary chamber can often be seen. Radiating spines, the striking feature of many radiolarians, are not well shown in sections of Barbados rocks.

Thus it will be seen that, while in calcareous rocks where radiolarians are indubitably present it frequently happens that nothing but their outline remains, our slides show all stages in the transformation of a siliceous radiolarian into a structureless ball or disc filled with calcareous matter or into a mere patch of clear crystalline material. Without the aid of these slides we could hardly have understood how the radiolaria of the Chalk have become so completely obscured as we know them to be.

It must be premised, therefore, that in the forms about to be described the siliceous skeleton of the radiolarian is lost, and the body now visible under the microscope is the section of a cast—either in crystalline granular calcite or in fine calcareous paste. It is this fact which has prevented the earlier identification of the organisms, for all trace of the beautiful radiolarian structure is gone, and nothing remains but a mere patch, which is, however, in most cases easily distinguishable from the surrounding matrix. Many of them have a clearly marked periphery, and others are definite spheres of crystalline calcite, but in no case is there any trace of the actual cell-wall.¹

This absence of a test is a character which at once distinguishes these radiolarian remains from almost all the other organic bodies which occur in the Chalk, and especially from all kinds of foraminifera, the tests of which are always preserved. Had we not the proof of the manner in which the radiolarian test disappears, it might have been supposed that it would have been simply replaced by calcite, as in the case of sponge-spicules, which are frequently so replaced, though in some parts of the Chalk Marl they remain unaltered.

IV. DESCRIPTION OF THE FORMS MET WITH.

As the chief characteristic of the radiolarians of the Chalk is wanting, the siliceous skeleton having disappeared, it is impossible to refer the various forms we have met with to their respective orders and genera with accuracy, but it is necessary to describe them in some way. Therefore in provisionally arranging them we

¹ Since writing this paper, on examining a slide which had been overlooked, we found a single specimen in which the network of the skeleton can be faintly traced; the silica is entirely replaced by calcite. This form, shown in Pl. XXII. fig. 16, may be referred to the family *Liosphærida*.

follow as nearly as possible the system of Prof. Haeckel in his report on the radiolarians of the 'Challenger' Expedition, also following Dr. Hinde in his recent description of radiolarians in the Lower Palæozoic Rocks of the South of Scotland, *Ann. & Mag. Nat. Hist.* ser. 6, vol. vi. (1890) p. 40.

It will be understood that the forms described below are those seen in thin sections of Chalk, and therefore there is the initial difficulty in our being unable to say positively whether the tests are spherical or discoid.

Class RADIOLARIA, Müller.

Subclass SPUMELLARIA, Ehrenberg.

Order SPHÆRELLARIA, Haeckel.

Suborder Sphæroidea, Haeckel.

Family 1. LIOSPHÆRIDA, Haeckel.

Sphæroidea without radial spines on the surface of the spherical shell, living solitary (not associated in colonies): 'Chall.' Rept. pt. i. p. 59.

Genus *Cenosphara*? (Pl. XXII. fig. 1.)

A simple well-defined circular outline, usually filled with clear granular calcite, but sometimes with denser material (the finer amorphous matrix of the chalk). There is no evidence of radiate spines or of a medullary shell.

Diameter .22 to .35 millim.

It occurs in every locality where we have found radiolarians.

Genus *Spongoplegma* or *Spongodictyon*? (Pl. XXII. figs. 2 & 3.)

Another form which we refer to this family is in section a simple, well-defined circle without spines. Within the outline the infilling material is usually dense, and suggests a radiolarian with 'sponge-like' test. In several cases there is a well-marked centre of clearer crystalline material occupying the position of a medullary shell.

Diameter .25 to .45 mm.

Localities: Hitchin, Luton, Dover. *Horizon*: Melbourn Rock.

Family 2. ASTROSPHÆRIDA, Haeckel.

Sphæroidea with numerous (8 to 12 or more, commonly between 20 and 60) radial spines on the surface of the spherical shell; living solitary (not associated in colonies): 'Chall.' Rept. pt. i. p. 206.

Forms which we refer to this family are circles with radiating spines, the number of which does not in any case exceed six; these appear to proceed from the surface of the test, and to be irregularly disposed over its surface, not arising in pairs or with any degree of symmetry with regard to each other. The spines are not bristle-like, but have considerable width and length; none seem quite perfect, nor can their junction with the test be seen in every case.

We can do no more than refer them to the family *Astrosphærida*, there being insufficient detail to place them in any particular genus.

Pl. XXII. fig. 4 shows a circular outline enclosing comparatively clear granular crystals of calcite; periphery clear and unbroken. No trace of medullary shell. Three primary spines arranged unsymmetrically around the test.

Diameter .35 mm. Length of spines .37 mm.

Locality: Wilbury Hill, Hitchin. *Horizon*: Melbourn Rock.

Pl. XXII. fig. 5 seems to be the same species, though the general outline is less regular. Five spines are seen, with the base possibly of a sixth. Clear granular calcite occupies the place of the test. No medullary shell.

Diameter .27 mm. Length of spines .22 mm.

Locality: Legrave Road, Luton. *Horizon*: Melbourn Rock.

Pl. XXII. fig. 7 resembles fig. 4. The test is filled with clear granular calcite. Only one primary spine can be seen, though the bases of three others can be made out. There are indications at two or three points of secondary spines. There is also a distinct ring occupying the position of the medullary shell in the centre of the test.

Diameter .48 mm. Length of spine .35 mm.

Locality: Legrave Road, Luton. *Horizon*: Melbourn Rock.

(?) Family STAUROSPLÆRIDA, Haeckel.

Sphæroidea with a simple lattice shell traversed by four crossed and equal spines in one plane.

The two forms which we somewhat doubtfully refer to this family have three spines, two opposite and one nearly at right angles. We assume, therefore, that the fourth spine has either been broken off, or did not come quite within the plane of the section. They do not seem to agree either with the three-spined genus *Spongotropus* of the family Spongodiscida, or with the three-spined forms of the discoidal genus *Triactiscus* ('Challenger' Report, pt. i. pp. 580 & 432).

Rüst figures a three-spined radiolarian from the coprolites of Zilli (*Staurocromyum Muelleri*)¹ which resembles those we describe, except that the pair of spines is not exactly opposite, though nearly so.

Pl. XXII. fig. 6 shows a circular outline filled with dense, amorphous calcareous material, the outer portion marked by a comparatively wide belt of clear crystalline calcite, which is regularly broken by alternate light and dark spaces, probably indicating a shell with large pores. There are faint indications of a medullary shell. Three spines visible, short, broken, the odd one not quite equidistant from the other two.

Diameter .18 mm. Length of spines .10 mm.

Locality: Royston. *Horizon*: Melbourn Rock.

Pl. XXII. fig. 15 shows a circular cast, with clearly marked

¹ 'Palæontographica,' vol. xxxiv. (1888) p. 193, pl. xxiii. fig. 8.

outline, filled with finely granular crystalline calcite. No outer band and no medullary shell. Three thin delicate and rather long spines, one pair opposite and the third spine at right angles to it.

Diameter .21 mm. Length of spines .23 mm.

Locality: Royston. *Horizon*: Melbourn Rock.

Suborder Discoidea, Haeckel.

Spumellaria with discoidal or lenticular central capsule (often with radial prolongations, rarely allomorphic); with discoidal, or lenticular fenestrated, siliceous shell (often with radial spines or fenestrated arms, rarely allomorphic). Growth reduced or diminished in the direction of one dimensive axis (Haeckel, 'Challenger' Report, pt. i. p. 402).

We refer Pl. XXII. figs. 8 & 9 to the suborder Discoidea. Similar forms are common in sections of the Barbados rocks, but the absence of all structure makes it difficult to do more than indicate the suborder to which we believe them to belong.¹ Length .37 millim.

Localities: various. *Horizon*: Melbourn Rock.

Like Dr. Hinde, we find forms apparently belonging to the suborder Sphæroidea, but not described by Haeckel in his 'Challenger' Report. They are radiolarians with a single spine extending from the surface of the test. To include these Dr. Hinde has instituted a new genus *Dorysphaera*, and to this we refer the following:—

Dorysphaera, Hinde.

Pl. XXII. fig. 10 shows a circle filled with dense amorphous calcareous material, or finely granular crystalline calcite, its limit usually well defined. One long, thin, bristle-like spine.

Diameter variable, .15 to .22 mm. Length of spine .20 to .35 mm.

Localities: One of the most common forms at Hitchin, Royston, Luton, Dover, Richmond Well, 702 feet.

Pl. XXII. fig. 11 is very similar to fig. 10, but the single radial spine is much thicker at the periphery of the test and diminishes to a point at the distal end.

Diameter .17 mm. Length of spine .13 mm.

Locality: Hitchin Station railway-cutting. *Horizon*: Melbourn Rock.

Pl. XXII. fig. 12 is circular in section, filled with dense amorphous material: its periphery being well marked by minute, clear, calcitic crystals. No indications of a medullary shell. A short, strong radial spine, broad at its base, terminating in a point. The minute calcitic crystals extend outside the periphery of the circle, and seem to mark the position of small secondary spines.

Diameter .16 mm. Length of spine .08 mm.

¹ Dr. Hinde, however, writes with reference to these as follows:—'As regards form, I should not hesitate in placing figs. 8 & 9 in the genus *Amphibrachium*.'

Locality: Royston. *Horizon*: Melbourn Rock.

Pl. XXII. fig. 14 shows a well-marked circular outline, the walls of the test still faintly indicated, and filled with finely granular crystalline calcite. No medullary shell. A single spine, thin at its base, but clubbed at its distal end.

Diameter .36 mm. Length of spine .27 mm.

Locality: Royston. *Horizon*: Melbourn Rock.

The following form is probably imperfect:—

Pl. XXII. fig. 13. In section a circle filled with clear, fine granular calcite. No medullary shell. A single primary radial spine, strong, and markedly twisted. There is no evidence of other spines, primary or secondary.

Diameter .18 mm. Length of spine .25 mm.

Locality: Wilbury Hill, Hitchin. *Horizon*: Melbourn Rock.

These are the more striking figures which we recognize as radiolarians of the Chalk; we do not think that the list is by any means exhausted. Many other forms exist in our slides, the outlines of which may possibly indicate other families and species, which further study may enable us to identify; we have only described those of whose identity we have little doubt.

PLATE XXII.

Microscope-sections of radiolaria from the Melbourn Rock.

DISCUSSION.

Dr. G. J. HINDE said that the discovery of radiolaria for the first time in the English Chalk, as distinguished from their occurrence in Chalk-flints, was an interesting fact. One might naturally have expected that some would be present in association with the foraminiferal deposits of the Chalk, but they had hitherto eluded observation, probably owing to the fact that, in common with other siliceous organisms in beds mainly calcareous, their structures were dissolved and only casts now remained, which without careful scrutiny might be passed over as those of foraminifera. He had seen the Authors' sections, and could corroborate their conclusions. The Authors had also done good service in describing the various phases of the fossilization of radiolaria in the calcareo-siliceous beds of Barbados and comparing them with those of the Chalk of this country.

Prof. T. RUPERT JONES stated that, in the Trans. Hertfordshire Nat. Hist. Soc. vol. iii. (1885) p. 152, he had referred to the discovery of *Polycystinæ* in the Chalk,—namely, *Astromma*, *Haliomma*, *Podocyrthis*, and some of the allied *Dictyochidæ*, by Dr. Wallich, in 1883. Some were found in solid flint, and some in flint-meal from hollow flints, from Surrey and elsewhere.

Mr. W. HILL regretted that the communication of Prof. R. Jones to the Herts. Nat. Hist. Soc. should have been overlooked. He thanked the Society for their reception of the paper.

Quart. Journ. Geol. Soc. Vol. LI. Pl. XXII.

RADIOLARIA FROM THE MELBOURN ROCK.