43. *On a WELL-MARKED HORIZON of RADIOLARIAN ROCKS in the LOWER CULM MEASURES of DEVON, CORNWALL, and WEST SOMERSET.* By GEORGE JENNINGS HINDE, Ph.D., F.G.S., and HOWARD FOX, Esq., F.G.S. (Read June 5th, 1895.)

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I. INTRODUCTION.

THE general character and succession of the Culm Measures or Carboniferous series of Devon and adjacent portions of Cornwall and West Somerset, worked out by Sedgwick and Murchison, De la Beche, and John Phillips in the years 1836-1842, have in the main been regarded by geologists as correct; and the alterations and additions to their descriptions which have been made by the subsequent researches of the late Dr. Holl, Mr. T. M. Hall, and of

Mr. W. A. E. Ussher, who has spent many years in investigating this formation on behalf of the Geological Survey, have been principally in the direction of detailed filling up of the outlines laid down by the older geologists.

Stated briefly, the Devon Culm Measures have hitherto been described as consisting of a lower or basal series of dark argillaceous shales, with impersistent intercalated beds of dark limestone, which conformably succeed the fossiliferous shales and slates of the Upper Devonian. Next above this basal series there is a succession of what have been termed fine shaly grits and cherty mudstones, known as the 'Coddan Hill Beds.' Overlying these latter there is a further series of sandstones, grits, and shales of great thickness, with occasional thin layers of Culm, which form the higher beds. The entire series of the Culm Measures, as first shown by Sedgwick and Murchison, occupies a synclinal trough between the Devonian rocks of North Devon and West Somerset and those of Mid-Devon or South Devon and Cornwall. The rocks throughout have been highly folded and contorted as well as faulted, and in the southern area bands of tuff and diabase are not infrequent in them. A somewhat scanty fauna is found in the limestones and shales of the basal series, consisting of a few species of *Goniatites*, *Posidonomya*, *Chonetes*, *Spirifer*, and *Phillipsia*, while from the next succeeding Coddan Hill Beds only about four or five species of *Goniatites* and brachiopoda have hitherto been known. From the higher portion of the Culm Measures a number of plants and two species of fishes have been determined. It will thus be seen that if we except the thin lenticular beds of limestone in the basal series and the occasional layers of Culm in the higher series, the Culm Measures are at present regarded as consisting of a sequence of detrital or elastic mechanical deposits, which might have been laid down in comparatively shallow waters near a land area.

We have ascertained, however, that the division next above the basal limestones and shales, known as the Coddan Hill Beds, is essentially of organic origin, and that it is filled to a great extent with the remains of radiolaria, thus probably forming one of the thickest deposits of these microscopic organisms hitherto known in the geological series. We have made an examination of numerous exposures of the rocks of this horizon at various localities along their line of outcrop in North Devon and West Somerset from Templeton, south-west of Barnstaple, to Ashbrittle, near Wellington, a distance in a direct line of about 31 miles; also on the southern outcrop from near Boscastle on the Cornish coast to Tavistock for a distance of about 26 miles, as well as on the east and south-east of Dartmoor, near Bovey Tracey and Chudleigh: with the result of finding that, throughout, the beds of this horizon are characterized by the presence of radiolaria. We propose in the present paper to give a sketch of the distribution, the principal features and microscopic characters of these Coddan Hill radiolarian rocks in the different localities, and to describe the radiolaria in

them, so far as their imperfect condition of preservation will allow. We have not, as yet, had an opportunity of studying in the field the relation of these radiolarian rocks to the beds above and below them, except in one or two instances. As the organic character of these rocks has not hitherto been known or suspected, no strict attention has been devoted to the investigation of the character of the rocks which overlie them, and, owing to their disturbed condition, the succession is not likely to be definitely ascertained until a regular survey of the area has been carried out. We do not profess to have examined all the outcrops of the radiolarian rocks in the Culm area, and it is very probable that these beds will be found in many localities near the northern and eastern margins of the Dartmoor granite, which we have not had an opportunity of visiting.¹

In addition to the microscopic organisms, certain limited portions of the radiolarian rocks contain other fossils, some of which were collected by Mr. G. J. Hamling, F.G.S., and Mr. G. F. Tregelles of Barnstaple, and obligingly placed at our disposal for examination. In view of the importance of these fossils as showing the geological horizon of the rocks, we have availed ourselves of the kind assistance of Dr. Henry Woodward, F.R.S., P.G.S., to describe the trilobites, and of that of Mr. F. A. Bather and Mr. G. C. Crick to determine the brachiopoda and cephalopoda respectively.

We also wish here to acknowledge our obligations to Mr. J. J. H. Teall, F.R.S., Sec.G.S., for much valuable advice and assistance; to Mr. J. Hort Player, F.G.S., for making two chemical analyses of the rocks; and to Mr. W. A. E. Ussher, F.G.S., for readily affording us needful information respecting the best outcrops of the cherty beds.

II. LITERATURE RELATING TO THE RADIOLARIAN (CODDEN HILL) BEDS.

There is no specific mention of the Codden Hill Beds in the important memoir by the Rev. A. Sedgwick and Roderick I. Murchison on the 'Physical Structure of Devonshire and on the Subdivisions and Geological Relations of its Older Stratified Deposits,'² read before this Society in 1837, in which the Culm Measures were first described and delimited from the Devonian, or, as it was then termed, the Grauwacke Series. The authors state that the lower beds of the Culmiferous Series consist of black calcareous shale and black limestone with peculiar fossils, which appear on both sides of the great trough. In describing the shales of the Lower Culm³ as semi-indurated and as having the separate beds divided into innumerable prismatic masses by small transverse joints, while in the softer varieties the masses are generally rhombohedral, and in stating further that they pass into a light-grey, siliceous, jointed flagstone, which in some instances becomes almost

¹ See Postscript, p. 663.

² Trans. Geol. Soc. ser. 2, vol. v. pt. iii. (1837) pp. 633-687.

³ *Ibid.* p. 671.

white and porcellaneous, resembling a kind of china-stone, it is evident that these authors are referring to the distinguishing features of the Codden Hill Beds, though these are not specially designated.

Although De la Beche¹ gives a section of the lower beds of the Culm and points out that on the northern boundary there is no evidence of unconformity with the Devonian beds below, but a gradual passage from them into black carbonaceous slates and limestones with *Posidonomyæ*, he does not distinguish the Codden Hill Beds, though possibly they are included in the 'shales and slates occasionally carbonaceous, mingled with some grits,' which he says succeed the *Posidonomyæ*-beds.

The first record of the Codden Hill Beds appears in a paper read to this Society by the Rev. D. Williams² in April 1839, in which they form part of the No. 8 of this author's subdivision of the Grauwacke Series. The Codden Hill Grits, as he terms the beds, are divided into grits, limestones, and dark slates. The grits are stated to be lithologically distinct from any other strata in the country, they are slightly calcareous, fine-grained, flinty, thin-bedded, and dark-coloured, but often striped of different tints, and when decomposed resemble hard chalk. The grits are associated with large insulated masses of dark limestone, alternating with black shales containing *Goniatites* and *Posidonomyæ*, and below these are dark slates which gradually pass into the Trilobite Shales of the Devonian.

In a subsequent paper which appears to have been privately printed, entitled 'Tabular Synopsis in descending order of the Succession of the several Members of the Devonian System, as developed in W. Somerset, Devon, and Cornwall,' Mr. Williams further subdivides the Codden Hill Grit into the following four groups in descending order: (*i*) Black, dark, and smoky-grey schists, flags and roofing-slates containing some plants; (*k*) Flint and jasper rock; (*l*) Black-layered, fine-grained grit, almost a lydian-stone, containing a few Crinoidea; (*m*) *Posidonia*-limestone and culmy shales; and the thickness of the whole series is estimated at 1500 to 2000 feet. It is to the divisions *k* and *l* that our Radiolarian Beds belong.

Prof. John Phillips in 1841³ pointed out that the base of the carbonaceous group in North Devon consisted of black shales and limestones, with *Posidonia* and *Goniatites*, exposed at Venn, Swimbridge, and Bampton, which are overlain by the Codden Hill Beds. These consist of a whitish or grey or black chert in thin striped beds resembling some of the bedded chert of Leyburn in Wensleydale, associated with very soft, white, arenaceous, and argillaceous layers, which contrast greatly with the black bituminous shales of

¹ 'Report Geol. Cornwall, Devon, and West Somerset,' 1839, p. 103.

² 'On as much of the Transition or Grauwacke System as is exposed in the Counties of Somerset, Devon, and Cornwall,' Proc. Geol. Soc. vol. iii. p. 115.

³ 'Pal. Fossils of Cornwall, Devon, and West Somerset,' p. 189.

Swimbridge. He divides the Culm group of Central Devon as below in descending sequence (*op. cit.* p. 194):—

Upper or Grit Group of Central Devon.

Upper Shale Group.—A mass chiefly of dark shales. Carbonaceous grits and shales, the lowest part being the Coddan Hill chert series.

Middle or Calcareous Group.—Limestone, mostly black, irregularly bedded, associated with shales, often resting on trap rock, and fossiliferous.

Lower Shale Group.—Black argillaceous plate or very laminar shale, not subject to slaty cleavage, and scarcely fossiliferous.

It may also be mentioned that practically the same sequence of the Culm Measures is given by Phillips in the 'Manual of Geology,' 1855.¹ The Coddan Hill cherts and shales are stated to be of considerable but variable thickness, and they are placed with a query below the anthracitiferous gritstone series with plants of the coal-formation and above the black limestone and shale with *Posidonice*. In the subsequent edition of Phillips's 'Manual' by Mr. R. Etheridge in 1885,² the Coddan Hill grits, cherts, and shales are referred to the age of the Millstone Grit.

Dr. Harvey B. Holl in 1868³ traced out the succession of the Culm Measures in South Devon and East Cornwall, and states that the beds on both sides of the trough are symmetrical, the limestones near the base being precisely similar to those near Bampton in North Devon, and the succeeding grits and cherts resembling those of Coddan Hill. The direction of these chert-beds is followed in the Launceston district and also on the east of Dartmoor, between Bickington and East Down, where the chert is to some extent replaced by a siliceous but less flinty rock. Volcanic rocks are associated with the chert and other beds. Dr. Holl likewise describes the slates at Waddon Barton, near Chudleigh, with *Posidonomya* and *Goniatites* as resting on Devonian limestones and overlain by typical carbonaceous sandstones.

In the 5th edition of 'Siluria' (1872) Sir R. Murchison gives a section across North Devon⁴ and states that the Pilton and Petherwin Beds of the Devonian are surmounted by true Carboniferous schists with the *Posidonomya*-limestone of Swimbridge and Venn, which is a thin representative of the Carboniferous Limestone and is followed by the *Goniatite*-grits of Coddan Hill, and beds of Culm representing the Millstone Grit series of other parts of England.

In a sketch of the Geology of Devonshire (1878) Mr. Townshend M. Hall⁵ refers to the black limestones and shales with *Posidonomya* and *Goniatites* at Venn and Swimbridge, near Barnstaple, as representative of the Mountain Limestone of Derbyshire, Yorkshire, and the North of England, and states that in close proximity to the limestones are beds of whitish shale passing occasionally into a substance resembling porcellanite, with beds and veins of a hard white or grey chert, which are well shown at St. Stephen's Hill

¹ P. 171.

² Pt. ii. p. 220.

³ Quart. Journ. Geol. Soc. vol. xxiv. (1868) p. 400.

⁴ P. 272.

⁵ White's 'History, etc., of the County,' reprint, p. 9.

near Launceston, and at Codden Hill near Barnstaple, where they contain *Goniatites* and crinoidal stems.

Messrs. Champenowne and Ussher,¹ in 'Notes on the Structure of the Palæozoic Districts of West Somerset' (1879), describe the Codden Hill Beds exposed at Hulverton Hill, near Dulverton Station, as 'easily distinguishable by their baked appearance, whitish buff or dark-grey colour, and frequent chertoid texture; they consist of thick shales or thin fine-grained grits in tabular layers, so intersected by even joints as to afford a valuable road-metal without further fraction.'

Mr. H. B. Woodward, in the 2nd edition of the 'Geology of England and Wales' (1887),² places at the base of the Culm Measure series the shales, thin grits, and impersistent beds of limestone with occasional beds of Culm (*Posidonomya*-limestone) as probably representing the Lower Carboniferous; next above are the Codden Hill Beds (local), probably on the horizon of the Millstone Grit; and succeeding these are the sandstones, grits, and shales, with beds of Culm, which may be of the age of the Lower Coal Measures. The Codden Hill Beds are described as consisting of pale grey or black chert in thin striped beds, with black grits, jasper rock and lydian-stone and a variable thickness of shales, the total thickness of which had been estimated by the Rev. D. Williams at from 1500 to 2000 feet.

Lastly, these rocks have been very comprehensively described by Mr. W. A. E. Ussher in the 'British Culm Measures,'³ which contains, moreover, a summary and revision of his own previous works⁴ on the subject. He divides the Culm Measures from below upwards into Basement Beds, Exeter type, Ugbrooke Park Beds, Morchard type, and Eggisford Grits. It is only with the lower division, or the Basement Beds, that we are concerned in this paper. These consist of the dark limestones and shales and the Chert or Codden Hill Beds. The author considers that Phillips may possibly be right in placing these latter above the shales and limestones of Venn and Swimbridge, and he also assigns the same relative position to the outcrops at Ashbrittle, West Somerset. The typical beds at Codden Hill itself are described as thick, buff, whitish, and dark-grey shales, fine shaly grits and cherty mudstones, and they are stated to be represented in South Devon by hard, thin, evenly-bedded fine grit with an abundance of *Goniatites spiralis*, and, further, it is suggested that the hard beds with *Posidonomya Becheri* and the soft and hard beds at Waddon Barton may belong to the same type. No mention whatever is made of a possibly organic origin of the cherty beds, which are, however, recognized as identical in character with the kieselschiefer of the German and the phthanites of the French and Belgian geologists.

¹ Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 532.

² P. 197.

³ Proc. Somerset. Archæol. & Nat. Hist. Soc. vol. xxxviii. (1892) pp. 111-219.

⁴ Rep. Brit. Assoc. (1881) pp. 629-631; *ibid.* (1886) p. 676; Proc. Som. Archæol. & Nat. Hist. Soc. vol. xxv. (1879) pt. ii. pp. 1-20, vol. xxxvi. (1890) pp. 97-104; Geol. Mag. 1887, pp. 10-17; Congrès Géol. Int. 4^me sess. Londres, 1888, p. B 141.

III. DISTRIBUTION OF THE RADIOLARIAN (CODDEN HILL) BEDS.

The references given above show that the general petrological characters of the Codden Hill Beds are sufficiently distinct from those of the rocks above and below them in the same series to have caused them to be placed as a separate subdivision by observers who were unaware of their organic characters. But we do not consider that all the rocks which have been referred to this division by Mr. Ussher and other geologists properly belong to it, and we wish further to note that in one particular feature the description given by nearly all previous writers of the character of the Codden Hill Beds materially differs from what we have observed. Thus, it is stated by Williams that they are mainly of 'black-layered, fine-grained grit'; by Phillips that the chert is associated with soft, white, arenaceous layers; Hall conjoins grit and chert; Sir R. Murchison writes of the *Goniatite-grits* of Codden Hill; and Mr. Ussher also includes fine shaly grits with the cherts and shales of the typical beds. But neither at Codden Hill itself nor at the outcrop of these beds in any part of the Culm area have we met with any description of grit, or shaly grit, or arenaceous shales, associated with the cherts and shales containing radiolaria. There are, it is true, some beds which on ordinary superficial examination bear considerable resemblance to fine grits, but microscopic sections of these show that they are filled with radiolaria and that their supposed gritty structure arises from these organisms, which are more resistant than the soft siliceous shales in which they are embedded.

The Radiolarian or Codden Hill Beds occur along a comparatively narrow zone of country a short distance within the boundary-line of the Culm and the Devonian, which runs in a generally E.S.E. and W.N.W. direction both in North and South Devon. We propose to refer first to the series in North Devon, beginning with the exposures round Barnstaple and then going eastwards to Dulverton, Ashbrittle, and Holcombe Rogus. On the southern boundary of the Culm Measures we commence on the coast near Boscastle and continue eastwards to the district beyond Launceston, and then to Tavistock. On the east of Dartmoor we refer to exposures at Ramshorn Down near Bovey Tracey, at Chudleigh, and at Bishops-teignton near Teignmouth.

(a) Barnstaple District, North Devon.

Codden Hill itself may be taken as a convenient starting-point from which to follow the outcrop of the Radiolarian rocks in North Devon and West Somerset. The Hill is situated about 3 miles south-east of Barnstaple, following the high road on the east of the Taw River through the village of Bishop's Tawton. It is an elongate, hog-backed ridge, about $1\frac{1}{2}$ mile in length, running nearly east and west, and between 500 and 600 feet in height. The entire ridge consists of siliceous radiolarian rocks, which are well shown in several quarries on the western and southern slopes. At the western end the principal exposure is known

Fig. 1.—*Section of the Radiolarian (Coddan Hill) Beds of the Lower Culm Measures at the Coddan Hill Quarry, near Barnstaple, North Devon.*

[From a photograph taken in January 1895.]

as the Codden Hill Quarry (fig. 1). The face of this quarry is about 60 feet in height. The beds are mainly of hard, dark or light grey, sometimes banded, cherty, siliceous rock, with intermediate beds of soft grey or white siliceous shale, which run with an even thickness and in regular succession from the summit to the bottom of the quarry. The dip is 60° N. In the soft shaly beds here the radiolaria can be distinctly seen with a lens, but they are only visible in certain portions of the hard cherty beds.

Overton Quarry, on the southern side of Codden Hill, is almost entirely of white and grey beds, which dip N.E. at 55° , while in the Tower Hamlet Quarry, at the eastern end of the hill, dark and light grey siliceous beds are intermingled.

East of Codden Hill is another elongate ridge, known as Hangman's Hill; at one end of this is Bableigh Quarry, in which the beds dip 60° S.S.W. At the opposite or eastern end of this ridge, on the road leading to Hannaford, is a quarry about 50 feet in height, in which the beds are alternately of dark, hard, compact, siliceous rock and of soft, white, siliceous shales. There are also one or two thin beds of a yellowish or buff, light, porous, siliceous shale or rottenstone containing casts of trilobites and brachiopods as well as empty casts of radiolaria. These latter, associated with hexactinellid sponge-spicules, are also very abundant in the soft white shales, but less recognizable in the harder compact beds. The strata in this quarry are nearly vertical, with an east-and-west strike.

Continuing farther eastward, at Swimbridge, about 5 miles S.E. of Barnstaple, a considerable thickness of siliceous rocks is exposed in a large quarry immediately north of the village. The beds are nearly vertical; they consist mainly of dark, hard, platy, compact rock, but occasionally lighter bands occur in which the radiolaria can be seen with a lens.

Beyond Swimbridge, following the high road for a distance of about 2 miles to the S.E., at the summit of Heddon High Down there are extensive quarries. At the most westerly of these, the beds are almost entirely made up of hard, dull black, siliceous rock with wavellite developed on the joint-planes. They dip 65° N. Some of these black beds are crowded with radiolaria, which are visible, however, only in thin microscopic sections. In the quarries at the eastern end the beds are nearly vertical; the lower ones are of black rock similar to that just mentioned, but above these there is a series of hard, light-grey, or whitish beds, without any admixture of the dark rock. Radiolaria are very abundant in the lighter beds, and they can be readily seen with a lens.

Returning now to the neighbourhood of Barnstaple, on the west side of the Taw River, nearly in a line with Codden Hill, is another ridge, extending for a little more than a mile in a westerly direction as far as Templeton, about 3 miles S.W. of Barnstaple. On this ridge quarries have been opened at Tawstock, Corffe Lodge, and at Templeton. We have not visited these quarries, but from information supplied to us by Mr. J. G. Hamling and from specimens of the beds we have ascertained that the rocks are precisely similar in

character to those of Codden Hill, and, like them, are filled with radiolaria associated with sponge-spicules. At Templeton and at a quarry west of Corffe Lodge, the beds dip north and south on either side of an anticlinal fold of 60° . At Tawstock Quarry also there are thin beds of the light, porous, yellow rock with casts of trilobites and crinoid-stems resembling those at Hannaford.

An outlier of radiolarian rock is exposed at the top of a ridge about a mile due north of Codden Hill itself, in a small quarry near Venn Cross, about one mile S.E. of Barnstaple. The beds here are for the most part hard, and either dark or light grey. They dip S. 15° E. at 45° . In the valley between this Venn Cross ridge and that of Codden Hill are situated the noted Venn quarries of dark limestones and shales, which are now disused and filled with water.

Thus on either side of Codden Hill, from Templeton on the west side of the Taw River to the High Down at Heddon, a distance of about 7 miles in an approximately east-and-west line, there are frequent exposures of the radiolarian rocks.

(b) Dulverton, West Somerset.

Eastward of Heddon the next outcrops of radiolarian rocks which we have examined are situated near Dulverton Station, about 17 miles distant. In this neighbourhood there are three important quarries: the most westerly is at Kent's Hill, a prominent conical hill about $\frac{1}{3}$ mile due south of Brushford village. The beds in this quarry are nearly uniformly of hard, dark, platy, siliceous rock, weathering to a slaty grey, without any admixture of soft shales. Only one thin band of the light-grey rock was noticed, which was filled with radiolarian casts. In the dark platy rock the radiolaria can be seldom distinguished, unless in microscopic sections; they are generally associated with sponge-spicules. The beds in this quarry are much less jointed than usual; they are tilted at a high angle, the strike is nearly east and west, and the total thickness of beds shown is about 190 feet.

East of Kent's Hill, a short distance south of Dulverton Station, is Hulverton Hill, a prominent hog-backed ridge, about 670 feet above sea-level, with a quarry on its south-eastern slope. The beds are nearly vertical, with an east-and-west strike, and a thickness of about 100 feet is shown. The beds are mostly of the hard, light-grey variety, but some are dark or speckled dark and white. Soft shaly beds are absent. Some of the lighter beds are crowded with radiolaria, and these can also be seen as whitish specks on the surfaces of some of the darker beds. Messrs. Champenowne and Ussher¹ state that some of the strata here are of thin fine-grained grits in tabular layers; but we failed to find any of this character, and it is probable that the beds referred to are those in which the radiolaria project slightly above the matrix and impart a gritty feeling to the touch.

¹ Quart. Journ. Geol. Soc. vol. **xxxv.** (1879) p. 533.

The third exposure in the Dulverton district is at Blackpool Copse, on the eastern bank of the River Exe, closely adjoining the Exebridge Works, and about $\frac{1}{2}$ mile due east of the Hulverton Hill Quarry*. The beds in this Blackpool Quarry are of the same hard, dark, siliceous rock as at Kent's Hill: they have been much disturbed, and dip S. 20° W. at a high angle. Some of the chert is of the striped or Leyburn variety. Very few radiolaria could be seen in this rock with a lens, but thin sections show that these are present in great numbers, and usually sponge-spicules also.

(c) Ashbrittle, West Somerset.

A short distance E.S.E. of the outcrop on the banks of the Exe, at Westbrook Farm near Bampton, and at Morebath there are, according to Mr. Ussher,¹ outcrops of shales (or phthanites) similar to the Coddan Hill Beds, but these we have not examined. Farther eastwards the radiolarian rocks are shown in a quarry on the summit of a hill $\frac{3}{4}$ mile west of the village of Ashbrittle, on the road to Tiverton. The beds here are very much crumpled and distorted; they are mostly of hard, black siliceous rock, with some thin, soft, shaly beds intervening. In thin sections of the black rock radiolaria are shown in great numbers, and they are present also in some of the soft shaly beds. Champernowne and Ussher mention that the village of Ashbrittle is situated on dark bluish slates or thick shaly beds of the Coddan Hill type, and exhibiting its characteristic features in adjacent hill-summits to the west of the village.²

(d) Holcombe Rogus, Canonsleigh, and Westleigh,
N.E. Devon.

A short distance east of Ashbrittle the Culm Measures disappear beneath the New Red rocks; south of it, and thus farther within the boundary of the Culm, are the prominent detached ridges of fossiliferous greyish-blue limestone at Holcombe Rogus, Canonsleigh, and Westleigh. Both Sedgwick & Murchison,³ and De la Beche⁴ as well, point out the differences which these limestones exhibit in the absence of carbonaceous matter and in other features, as compared with the black limestones of Bampton and of the Barnstaple district more to the west, and in general appearance they more nearly resemble the usual types of Carboniferous Limestone, though the occurrence of *Posidonomya* and *Goniatites*, discovered in these rocks by the late Rev. W. Downes,⁵ renders it probable that they are, in part at least, on the same horizon as the Bampton, Swimbridge, and Venn black limestones and shales. At the Canonsleigh Quarries, not far from Burtlescombe Station, there are cherty masses in the

¹ Proc. Som. Archæol. & Nat. Hist. Soc. vol. xxxviii. (1892) p. 122.

² Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 542.

³ Trans. Geol. Soc. ser. 2, vol. v. (1837) p. 675.

⁴ 'Report Geol. Cornwall, etc.', 1839, p. 105.

⁵ Trans. Devon. Assoc. vol. x. (1878) pp. 330, 335.

limestones, and sections of these show faint outlines of radiolaria and sponge-spicules. Some of the limestones are foraminiferal and contain a small form of *Endothyra*.

We have thus traced the radiolarian rocks along and within the northern boundary of the Culm Measures and the Upper Devonian from Templeton, west of the Taw River, near Barnstaple, to Ashbrittle in West Somerset, a distance of about 31 miles in a direct line.

(e) Boscastle District, Cornwall.

We now proceed to follow the outcrop of the radiolarian rocks on the southern margin of the Culm Measures, within, that is, north of the boundary-line between them and the Devonian, which is marked on the Geological Survey map as running from near Boscastle on the coast in a generally E.S.E. direction to the west side of the granite of Dartmoor near Tavistock.

As De la Beche pointed out,¹ the lowest beds of shale and arenaceous rocks belonging to the Culm series make their appearance in a bay between the Meachard Rock and Short Island, immediately south of Boscastle Harbour. For a distance of a little more than $1\frac{1}{2}$ mile from this place, in a N.E. direction, the coast-cliffs exhibit a succession of highly folded and contorted slates and grits, having a general dip to the north of about 25° , up to the northern end of what is marked on the 1-inch Ordnance Survey map as Beeny Cliff. At Fire Beacon Point, on the summit of the cliff, 469 feet above sea-level, there is a conspicuous ridge of cherty rock which extends northwards for a distance of 600 feet, and is shown on the slope of the cliff to within 150 feet of the beach. The chert rests on dark fine-grained slates or shales, which can be followed down for a distance of about 150 feet before there is any appearance of grits. The cherty rock itself, making due allowance for the folding of the beds, must be over 80 feet in thickness. It is mainly a very hard, dark or black rock, showing in places lines of lamination; it has been intensely squeezed and contorted, and it is traversed throughout with veins of white quartz. Near the base this rock is interbanded with and gradually passes into hard, dark, fine shales. Under the microscope the dark cherty rock is seen to consist of cryptocrystalline to microcrystalline silica with a considerable amount of dark material, either disposed in laminæ with light interspaces or dispersed generally throughout the rock. In the darker portions there are only a few indistinct casts of radiolaria, but in the lighter specimens they are more numerous, though but faintly shown. On the whole this Beeny Cliff rock might be termed an impure chert, in which the organic structures are nearly obliterated by the admixture of the dark carbonaceous material and the intense pressure.

Above the chert dark shales again come in, and as far as Fox Hole Point, north of Millook, about 5 miles distant from Beeny

¹ 'Report Geol. Cornwall, etc.,' 1839, p. 106, pl. iv. fig. 1.

Cliff, the cliffs show an apparently continuous succession of shales or slates and grits, marvellously folded and twisted and interpenetrated in all directions by quartz-veins, but without, so far as we could observe, any further developments of cherty rock. The dip of the beds throughout this distance is steadily northward, at an average angle of 25° . No mention of this cherty rock near Boscastle is made by De la Beche, although it forms a very prominent feature, and is markedly distinct from the shales above and below. It may also be mentioned that in this district no limestones have been noticed in the Lower Beds of the Culm Measures.

On the high grounds inland, east of Beeny Cliff, angular and sub-angular fragments of cherty rock, derived from the beds beneath, are scattered over the surfaces of the fields; they are collected, with other loose stones, for road-material, and as a consequence there are no quarry-exposures. One of these surface-fragments from near Ringford, about 2 miles east of Beeny Cliff, showed in thin section casts of radiolaria; also south of Tresparret Down, about 3 miles east of Boscastle, there were piles of stones, some of them from 2 to 6 inches in diameter, partly of the same dark impure chert as at Beeny Cliff and partly of a light reddish chert, laminated, filled with casts of radiolaria, containing also rhomboidal crystals, which in microscopic characters closely resemble the typical radiolarian beds of Codden Hill. Still farther eastwards, near Otterham, about 5 miles in a direct line from Boscastle, surface-fragments of dark chert showed numerous radiolaria in thin sections.

(f) Launceston District, Cornwall.

The next locality, east of Otterham, where we have met with radiolarian rocks is at Tregear Down, a hog-backed ridge 718 feet in height, situated between 5 and 6 miles W.N.W. of Launceston. There are on the slopes of the Down three quarries in a north-and-south line; that at the northern end is small, the beds are mostly of very hard, dark siliceous rock, with a few lighter bands in which radiolaria are readily seen with a lens. The other two quarries are on the south-western slopes of the Down, about $\frac{1}{2}$ mile distant from the first. In these the beds are partly of light grey and partly of dark cherty rock, with some soft shaly beds intervening. The rocks have been more compressed and disturbed than those in North Devon, and the light shaly beds show indications of incipient cleavage, but, with this exception, they resemble very closely the typical radiolarian rocks of Codden Hill. In the southern quarry the beds dip S.S.E. at 60° .

About 3 miles east of Tregear Down, by the side of the high road leading to Launceston, and near the junction of the Lower Truscott Road, there is another quarry in which the beds are very hard and flinty; some are black or bluish-black, others grey, and there are also some intervening beds of grey shale in which radiolaria are very numerous. The dip is N.N.W. at 22° .

Prof. Phillips¹ refers to the beds at this place as soft and hard, white, pink-stained, and black, the equivalents of the Coddan Hill grits, with quartz-veins; below these are laminated grey grits and shales, then thick dark grey or black limestone covered by black shale resting on trap.

Following the high road eastwards along the summit of the ridge, near St. Stephen, about 2 miles from Launceston, are two quarries, one on each side of the road, in which similar hard black and grey cherty rocks with radiolaria are shown. The beds dip W. at 21° .

On the same ridge, north of St. Stephen, in the Castlehill plantation, about $1\frac{1}{2}$ mile from Launceston, is a quarry which on the 6-inch Ordnance Survey map is marked as Barracadoes Quarry (killas). The beds in it, however, are not at all of the nature of killas, but consist mostly of light-tinted, banded, very hard, siliceous rock with interbedded soft, grey, shaly beds, which are crowded with radiolaria and sponge-spicules. The face of the quarry is 20 to 25 feet in height; the beds dip 28° north.

Another exposure of nearly similar chert and shale is shown by the roadside near Dutson, about 1 mile S.S.E. of the Barracadoes Quarry. The beds dip N. 10° W. at 38° . Lenticular patches of volcanic materials are interbedded in the cherty rocks at this place. Some of the beds here have a porous structure, the cavities apparently arising from the dissolving-out of small crystals. Traces of radiolaria can be occasionally seen in the rock, but only after careful search.

According to Dr. Holl,² the beds of chert (or radiolarian rock) on St. Stephen's Down and west of it, towards Tregeare Down, occupy the centre of a synclinal trough, the underlying Devonian rocks being brought up to the surface along a narrow axis on the north, which extends from Underwood Farm to Yeolm Bridge, while a lower axis on the south ranges east and west through the town of Launceston.

In a small quarry near Landlake Cross, about a mile east of South Petherwin and $2\frac{1}{2}$ miles south of St. Stephen's Ridge, there are beds of hard black and grey, platy, siliceous rock, dipping E.S.E. at 25° , which contain radiolaria, sometimes in great abundance, and also sponge-spicules, and resemble in other respects the cherty rocks of St. Stephen's Down. As mentioned by Mr. Ussher,³ these beds are situated within the general boundary of the Devonian, and have been included with this formation in De la Beche's map.

Farther eastwards we next meet with radiolarian rocks at Gordon Hill, a ridge 440 feet in height, about two miles E.S.E. of Launceston, and thus on a parallel more to the south than the beds of St. Stephen's Ridge. On the southern slope of the hill, at the village of Carzantic, is a quarry showing the best exposure of these

¹ 'Pal. Foss. Cornwall, etc.,' 1841, p. 195.

² Quart. Journ. Geol. Soc. vol. xxiv. (1868) p. 410.

³ Proc. Som. Archæol. & Nat. Hist. Soc. vol. xxxviii. (1892) p. 132.

rocks in the Launceston district (Pl. XXIV.). There is a regular succession of beds, mostly of grey and bluish-grey rocks, but with some of a dark tint as well, consisting of hard, brittle, compact chert without admixture of soft shaly beds. A thickness of about 50 feet is shown, and throughout the series radiolaria can be distinguished, being in some beds thickly crowded together. The face of this quarry is from 40 to 50 feet in height; the beds dip N.W. at 18°. Dr. Holl states¹ that the chert of the high ground of Gordon Hill is underlain on the north by black slate and the limestone south of Timber Bridge.

At Wooladon, on the north-eastern side of the River Tamar, about a mile distant from the Carzantic quarry in a direct line, and close to the Great Western Railway and the river, an extensive section of the Lower Culm Measures is shown in the face of the quarries formerly worked for limestone, which are marked in the 6-inch Ordnance Survey map as Lifton Quarry. The lowest beds exposed are the dark limestones and shales; these are succeeded above by thinly laminated, pyritous black shales containing impressions of *Posidonomya*, followed by a considerable thickness of grey, buff, and white shales, in places separating into thin papery laminae and minutely porous, which resemble in general appearance the soft radiolarian shales associated with the harder beds which occur in the other quarries of this district, but at this place no organisms can be seen in them. In the lower limestones, however, there are traces of sponge-spicules as well as some rounded bodies resembling radiolaria, but now infilled with calcite.

Above the papery shales, and forming the top beds of the quarry, there are thick and uneven beds of bluish cherty rock traversed by numerous veins of quartz. These are best shown on the southern side of the 'old quarry,' now filled with water, where they dip to the south. Radiolaria are present in this rock, which appears to be the lower portion of the Radiolarian Series, and if, as seems to be the case, the beds are here in their regular succession, they demonstrate a definite upward sequence from the dark limestones and shales with *Posidonomya* through beds of soft shales to the cherty rock with radiolaria. Mr. Ussher² refers to this Wooladon section, and mentions that in its upper portion phthanites or Coddan Hill Beds are present.

At Lifton Down, about $\frac{1}{2}$ mile due north of the western end of the Wooladon quarry and at a higher level, somewhat similar beds of hard dark and bluish cherty rock, traversed by quartz-veins and accompanied by light siliceous shales, are exposed. The beds are much compressed, and in the chert only a few indications of radiolaria could be seen; but the shaly beds, which have become hard and platy and interpenetrated with numerous minute strings of quartz in the same way as the chert, show in thin sections radiolarian casts in abundance.

¹ Quart. Journ. Geol. Soc. vol. xxiv. (1868) p. 408.

² Proc. Som. Archæol. & Nat. Hist. Soc. vol. xxxvi. (1890) p. 100; also vol. xxxviii. (1892) p. 127.

On the high ridge of the northern border of Lifton Wood, about $\frac{1}{2}$ mile east of Wooladon, radiolarian rocks are exposed in a quarry at its western end. The beds dip 25° S., and a thickness of about 20 feet is shown. They are for the most part dark, with light or speckled intermediate beds in which radiolaria can be seen with a lens. There is also another quarry, near the Lodge at the eastern end of the wood, showing a section, about 70 feet in height, of very regular beds of black siliceous rock of a platy or *kiefelschiefer* character which dip 12° S.S.E. Microscopic sections of the rock show radiolaria in considerable numbers. Mr. Ussher states that the chert (Codden Hill) beds of this locality are overlain by yellowish-brown conglomeratic beds, but these did not come under our notice.¹

Beyond Lifton Wood we have not traced the radiolarian rocks any farther in an easterly direction, but Dr. Holl² states that the chert of Gordon Hill extends as far as Sydenham and Leigh Down to Lew Water, which is 4 miles beyond Lifton Wood.

(g) Tavistock District, Devon.

At the east end of Tavistock, ascending Greenhill, above the Tavy Iron Works, a road-cutting has been made for a distance of about 90 yards through massive beds of a dark, hard, compact, finely-laminated siliceous rock. The dip is not clearly shown, but a thickness of over 30 feet is exposed of the cherty rock which appears to rest on dark clay-shales and to be followed by them. The rock is much traversed by quartz-veins and seems to pass gradually into the clay-shale. In microscopic sections the beds are seen to be crowded with casts of radiolaria now filled with micro-crystalline silica.

No other exposure of cherty rock was noticed at Tavistock, but pebbles and rounded boulders of dark siliceous rock, occurring in the bed of the river and in trenches lately opened on its banks, proved, when thin sections were examined, to be filled with radiolaria.

At Artiscombe, about 2 miles west of Tavistock, just beyond the Lumburn Bridge and near the extensive slate quarry of Mill Hill, there is a quarry mainly of a hard, dark, bluish-grey rock in which there were also some thin beds of a laminated grey, platy, siliceous rock, which proved on subsequent examination to contain numerous radiolaria. As the organic character of the rock was not suspected at the time of our visit, its relation to the other rocks in the quarry was not ascertained.

Dr. Holl refers³ to two small outlying patches of Culm Measures at Painter's or Pentre Cross, near St. Mellion, Cornwall, 8 miles W.S.W. of Tavistock, and 4 miles N.E. of Saltash, as the most southerly point at which the Culm Measures had been observed. At one locality, about 600 yards north-west of the Cross, chert occurs, forming the gutter on the east side of the road. It is hard,

¹ Proc. Som. Archæol. & Nat. Hist. Soc. vol. xxxviii. (1892) pp. 128, 144.

² Quart. Journ. Geol. Soc. vol. xxiv. (1868) p. 408.

³ *Ibid.* p. 405.

dark or bluish grey, and traversed in all directions by veins of quartz. The rock is filled with radiolaria, some even showing traces of structure. Another small patch of similar chert is seen in the foundation of some cottages on the east side of Vinegar Hill, south of Painter's Cross.

The district north of Stoke Climsland is also stated by Dr. Holl¹ to show chert, but none could be found there. On the high ground just south of this village, however, there are some beds, from 1 to 3 inches in thickness, of partially decayed bluish chert with shales dipping S., but no organisms could be recognized in it.

(h) Ramshorn Down, near Bovey Tracey, S.E. Devon.

Passing now to the Culm Measures east and south-east of Dartmoor, in the narrow irregular area between the granite and the Devonian rocks, there is an important outcrop of cherty rocks on Ramshorn Down, a prominent rounded ridge about 3 miles S.S.W. of Bovey Tracey, to which our attention was called by Mr. Ussher. Two quarries are shown by the side of the road which skirts the western end of the Down, one about $\frac{1}{4}$ mile north of the other. The rocks in both quarries are very similar; they mainly consist of very hard, dark, siliceous rocks and a few bands of lighter shaly material, resembling very closely in character those of Codden Hill in North Devon and of the Launceston area in Cornwall. Radiolaria are very abundant in the dark beds and also in some bands of a bluish or brownish tint; sponge-spicules are also associated with them. In the northern quarry a vertical thickness of about 25 feet is shown; the dip is 38°–40° S.E. In this thickness there is but one bed, about 6 inches in thickness, of the light shaly rock; the rest is either dark or bluish brittle rock, or of a platy character. In the southern quarry the cherty beds have been locally crumpled and pushed over one another, and Mr. Ussher has referred to and figured this as an instance of false bedding,² which of course would indicate the action of currents during their deposition. But, so far as we could observe, the present disturbed condition of the beds results from mechanical forces acting long after their formation.

Mr. Ussher³ considers that the chert-beds of Ramshorn Down and its vicinity rest on the Upper Devonian and apparently below the shaly arenaceous beds and *Posidonomya*-bands, and thus on a different horizon from the Radiolarian Beds of Codden Hill and North Devon generally, and from those of the Launceston area, which, so far as present evidence goes, are above the *Posidonomya*-beds. The actual contact of these beds with the Devonian slates has not, however, as yet been seen.⁴ It is further stated that the chert-beds seem to pass beneath sandstones and shales with traces of plants, but here again the succession has not yet been definitely ascertained.

¹ Quart. Journ. Geol. Soc. vol. xxiv. (1868) p. 404.

² Proc. Som. Archæol. & Nat. Hist. Soc. vol. xxxviii. (1892) p. 134, fig. 2.

³ *Ibid.* pp. 134, 135.

⁴ *Ibid.* pp. 134, 144.

(i) Chudleigh District, Devon.

To the right of the main road leading from Chudleigh Station to the town, radiolarian rocks are met with in the grounds north of Lawell House. A section of not more than 10 feet in thickness is here shown by the side of a hedge; the beds dip 20° N.N.W. They consist of a dark, hard, compact and brittle siliceous rock, in which there is a small proportion of lime. The rock weathers on the exterior to a dark rottenstone. Radiolaria are fairly numerous and with them are some detached spicules of hexactinellid sponges. We are indebted to Mr. Ussher for directing us to the chert-beds at this place; he states¹ that they occur in faulted association with their surroundings.

At Winstow Cottage, the lodge at the western entrance to Ugbrooke Park, about $\frac{1}{3}$ mile south of Lawell House hedge-section, there is a small quarry showing nearly vertical beds of dark or brownish siliceous rocks of a shaly character, also containing a small quantity of lime. Thin sections show radiolaria and sponge-spicules, and in addition there are fragments of trilobites and crinoid-stems.

Another exposure of radiolarian rocks, for the particulars of which we are indebted to Mr. A. Somervail, of Torquay, occurs about 4 miles north by west of Chudleigh Railway-station, in a cutting just north of Ashton Station. Beds of dark, hard, brittle chert are here shown from 15 to 20 feet in thickness. Hand-specimens of the rock forwarded to us are crowded with radiolaria, which can be seen with a lens. Microscopic sections show that they are only casts, for the most part filled with cryptocrystalline silica, but in some cases with chalcedonic silica. Mr. Ussher has pointed out² that cherty kieselschiefer occurs as an inlier of the Codden Hill Beds at Lea Cross, somewhat north of the present locality.

We have not examined further exposures of the radiolarian rocks in the district between Ramshorn Down and Chudleigh, but the road-material largely used in this neighbourhood consists of a hard, white or light radiolarian rock, closely similar in appearance to the Codden Hill Beds—thus showing that not only the dark kinds but the lighter varieties also are developed in the neighbourhood.

(k) Bishopsteignton, near Teignmouth, S.E. Devon.

Mr. Ussher informed us of the occurrence of a few beds of chert belonging to the basal Culm Measures, exposed in a rugged by-lane near the eastern end of the village of Bishopsteignton. The specimens of this chert which he has forwarded to us are of a light bluish tint; they are traversed by numerous fine reddish cracks,

¹ Proc. Som. Archæol. & Nat. Hist. Soc. vol. xxxviii. (1892) pp. 138, 142.

² *Ibid.* p. 136.

and radiolaria are abundant in them. The beds are very near the boundary of the New Red Rocks; but their relation to the dark shales of this locality (? Culm or Devonian) is concealed.

Respecting the thickness of the Radiolarian rocks generally, we have not at present sufficient grounds on which to base an estimate. The Rev. D. Williams¹ placed the maximum approximative thickness of the series of his Codden Hill Grit, which included not only the Codden Hill Radiolarian Beds, but also the dark shales and limestones (*Posidonomya*-beds) down to the summit beds of the Upper Devonian, at 1500 to 2000 feet, but a large proportion of this would belong to the dark shales. In some of the sections of the Radiolarian rocks exposed in the large quarries of North Devon there is a vertical thickness of from 100 to nearly 200 feet shown. In the southern area the exposures are less extensive, but even here the Carzantic quarry, in the Launceston district, has a thickness of 50 feet of radiolarian cherty rock without admixture of shales. It is very probable that the thickness of the Radiolarian rock may vary considerably in different areas, but it would perhaps not be rash to assume that the Radiolarian Series may be some hundreds of feet in thickness, not all indeed purely organic, but with intercalated beds of fine shales.

IV. MODE OF OCCURRENCE OF THE RADIOLARIAN ROCKS.

Both in the northern and southern areas the Radiolarian rocks occur in evenly stratified beds, usually from 2 to 4 inches in thickness, though they range from 1 to 9 inches, and in very exceptional instances to a foot in thickness. The beds are intersected in different directions by numerous fine and even joint-planes which have the effect of dividing the rock up into comparatively small rectangular or rhombohedral fragments with smooth, flat surfaces. It is owing to this feature that these rocks are largely quarried for road-metal, for which the harder beds are well adapted, since in the process of quarrying they readily fall into these cuboidal and rhombohedral fragments, which require very little additional breaking to reduce them to suitable dimensions for this purpose. In spite of these joints, however, the beds usually remain intact until they are actually worked, and in the Barnstaple district and in other places in North Devon quarries are not uncommon with faces from 50 to 70 feet in height, showing a regular succession of these thin, even beds extending uninterruptedly, generally at high angles, from the summit to the floor of the quarry.

¹ 'Tabular Synopsis of the several Members of the Devonian System, etc.'; Mr. Ussher, under the mistaken impression that this estimate referred only to the Codden Hill cherts, etc., and did not include the *Posidonomya*-limestones and shales, says that it could be obtained only by adding an unknown amount of the overlying shales and sandstones to the Basement-beds, Proc. Som. Archæol. & Nat. Hist. Soc. vol. xxxviii. (1892) p. 114.

Even in the same quarry the radiolarian rock presents itself under very different aspects. Some of the beds are of a very dark or even black, intensely hard, brittle chert with a hackly fracture; others are of a nearly uniform dull grey tint or quite white, but equally hard though less brittle, while yet other beds show alternate light and dark bands which give a striped appearance recalling that of the Carboniferous chert of Leyburn in Yorkshire, with which this rock has been compared by Prof. Phillips.¹ Of a less degree of hardness than those just mentioned are beds of dark to light grey, siliceous, platy rock. In some of these the rock is mottled, patches of dark and white alternate on the same surface-plane, and very frequently the margins of the joint-planes are grey or white while the interior of the rock is dark.

Alternating with the beds of hard chert and platy siliceous rock there are beds, mostly of a white or greyish tint and of a very soft shaly character, which readily break up into thin flakes or laminae, and in the softest kinds disintegrate when placed in water into a very fine, cream-coloured mud. These soft incoherent beds are filled with radiolaria equally as much as the hard chert, and, as a rule, the organisms can be more easily recognized in the soft than in the hard rock. The soft shales in some instances appear to result from the partial decay of harder beds, for within them there are in places thin layers of a bluish unchanged platy rock. The shales seem to have been less affected by jointing than the harder beds; but, on the other hand, in some localities they show incipient traces of cleavage by delicate parallel lines crossing obliquely the planes of lamination. They are also much less common than the harder rocks; generally a single bed of not more than 1 or 2 inches in thickness intervenes in a considerably thicker series of cherty or platy rock, and in some exposures the very soft shaly beds are altogether absent.

There are numerous gradations between the extremely hard and compact cherty rocks and the very soft shaly beds; not infrequently a very thin lamina of the softer shale is interposed as a partition between harder beds. The central portion of the beds of the cherty rock is generally harder and denser than the exterior layers.

In addition to the regular bedding the radiolarian rocks throughout, both hard and soft, show that they are built up of a series of thin laminae. These are seen best in some of the light-grey harder rocks, as so many delicate parallel lines of slightly varying lighter and darker tints which succeed each other with great regularity and evenness throughout the beds, thus indicating extremely slow and long-continued conditions of tranquil deposition and consolidation.

¹ 'Pal. Foss. Cornwall, etc.,' 1841, p. 190.

V. CHEMICAL COMPOSITION OF THE RADIOLARIAN ROCKS.

We are indebted to Mr. J. Hort Player, F.C.S., for making two analyses of the rocks, which are given below.

	I. <i>Hard, dark chert from Ramshorn Down.</i>	II. <i>Soft, grey shale from Barracadoes Quarry, near Launceston.</i>
Silica.....	87.3	67.8
Alumina	5.7	19.8
Ferric oxide	1.3	1.4
Ferrous oxide	1.4	.4
Lime	.3	—
Magnesia	1.2	1.2
Potash	.7	4.8
Loss at 100°	—	.9
Loss by ignition	1.9	3.6
Totals	99.8	99.9

Both these analyses are taken from specimens which, under the microscope, can be seen to contain numerous radiolaria; these were, however, more abundant in No. II. The Ramshorn Down specimen is a typical example of the hard, dark, brittle chert, and, as the analysis shows, the proportion of silica is large. No. II. specimen, on the other hand, is a typical example of the soft grey shales which come in between the harder beds. In this the silica is in less proportion, while there are larger amounts of alumina and potash, the latter originating, as suggested by Mr. Teall, from mica present in the rock. The analysis of a siliceous slate (Wetzschiefer) from the Culm formation at Teufelsberg, near Lautenthal, in the Harz, which contained very numerous radiolaria, is given by Dr. Rüst¹ as silica 69.9, alumina 17.6, soda 3.5. In this rock the proportions of silica and alumina are nearly the same as in the Barracadoes shale, but instead of potash it contains soda.

A marked feature of the Radiolarian rocks is the very general absence of carbonate of lime; even in beds which contain casts of brachiopods, crinoids, and other calcareous organisms, all traces of lime seem now to have disappeared. The only exceptions met with are in some of the rocks at Ramshorn Down and the Chudleigh district, in which a small quantity of lime is present.

VI. MICROSCOPIC CHARACTERS OF THE RADIOLARIAN ROCKS.

For the study of the rock-structure and the radiolaria we have had about 300 thin sections prepared from the typical rocks in the different localities mentioned above. These show under the microscope a general resemblance in consisting of a siliceous groundmass, in some cases clear and transparent, in others dark and turbid from the presence of fine particles of carbonaceous or ferrous materials

¹ 'Palæontographica,' vol. xxxviii. (1892) p. 111.

Fig. 2.—*Microscopic Section of Radiolarian Rock, showing casts of Radiolaria. From the Lower Culm Measures at Ramshorn Down, near Bovey Tracey, S.E. Devon. From a photograph taken by Mr. J. J. H. Teall, F.R.S. (Enlarged about 35 diameters.)*

Fig. 3.—*Microscopic Section of Radiolarian Rock, showing Radiolarian casts and a cube of pyrites (the dark spot). From the Lower Culm Measures at Carzantic Quarry, near Launceston, Cornwall. From a photograph taken by Mr. J. J. H. Teall, F.R.S. (Enlarged about 32 diameters.)*

and minute crystal-needles of rutile and zircon. The siliceous groundmass in polarized light, between crossed nicols, usually exhibits the faint speckled aspect of cryptocrystalline silica similar to that of a section of a flint from the Chalk; sometimes it is almost entirely dark, in other instances certain bands of the rock in which the radiolaria are very crowded show the lively tints of chalcedony. The radiolaria in the rock generally have been infilled with clear, nearly transparent silica, free to a great extent from the rutile-crystals and the dark substances disseminated in the groundmass, and either cryptocrystalline or microcrystalline in character. Within the radiolarian casts the silica has not unfrequently a radiate fibrous arrangement, and in this case a black cross is shown in polarized light. The more distinctly crystalline structure of the radiolarian casts facilitates their recognition in the rocks with a clear groundmass, where in ordinary light they are scarcely visible, but between crossed nicols they appear as so many circles of speckled or bright light on a nearly dark ground.

These rocks, more particularly the harder and more cherty varieties, very frequently contain minute casts of rhombohedral crystals, ranging from .015 to .065 mm. in diameter, which are irregularly scattered in the siliceous matrix. Probably they were originally of carbonate of lime or dolomite, which has now been dissolved and removed. They not only occur in the groundmass of the rock, but also within the casts of the radiolaria enclosed by the siliceous infilling, and in some cases they seem to have become filled with silica themselves. Dr. Rüst¹ notes the occurrence of similar rhombohedra of calcite within the casts of the radiolaria of the Culm in the Harz, and there can hardly be any doubt that the crystals² must have been formed where they, or the empty casts, now occur.

Microscopic cubes of pyrites are present in some of the rocks, and, like the calcite-crystals or casts mentioned above, they are not infrequently found within the radiolaria, enclosed by cryptocrystalline silica either singly or in small aggregates (fig. 3). There are, further, in some of the harder and more cherty beds, some very minute rounded bodies, ranging from .006 to .013 mm. in diameter, either detached singly or grouped together in small masses; these, in size and other characters, bear a general resemblance to the small bodies in the pre-Cambrian

¹ 'Palæontographica,' vol. xxxviii. (1892) p. 116.

² Similar rhombohedral crystals and casts are very generally found in siliceous rocks of organic origin, and the carbonate of lime of which they consist may well have been derived from the remains of calcareous organisms associated in the same rock with the siliceous sponges, radiolaria, or diatoms, but in much smaller proportions. The crystals are likewise found in some siliceous rocks, such as the novaculites of Arkansas, in which no siliceous organisms have as yet been recognized, and Mr. F. Rutley has lately contended that the crystals are merely the residue of an original dolomite or dolomitized limestone which has been replaced by silica (Quart. Journ. Geol. Soc. vol. 1. 1894, p. 382). A more probable explanation is that the novaculites were originally organic—the same as the radiolarian beds of the Harz and Devon.

phanites of Brittany which have been described by M. Cayeux¹ as radiolaria and foraminifera. On this account we have carefully examined them under the microscope, with the kind assistance of Mr. Allan Dick. The bodies in question are now either hollow or filled with colloid silica; their walls are of an amber tint in transmitted light, with bright specks here and there, in some cases resembling perforations. They are apparently formed of a flocculent material without definite outlines, the nature of which is doubtful, but Mr. Dick suggested that it might be a film of limonite remaining after the removal of pyrites. Some of these bodies occur within the radiolaria, in the same manner as the larger cubes of pyrites and the rhombic crystals. There is no evidence to show that they were of organic origin.

The finely laminated character which is so marked a feature of the radiolarian rock is seen under the microscope to be due to regular lines of dark amorphous material and finely granular particles, probably in part carbon and in part a compound of iron. In the darker varieties of the rock this material is so abundant that, save in extremely thin sections, the rock is opaque; but in the lighter and harder varieties it is arranged in alternating bands or laminae from .12 to 5 mm. in thickness. The radiolaria are more conspicuous in the darker bands or laminae than in the lighter, but they are not limited to any particular variety of the rock, and they occur both in the very hard and cherty and in the soft shaly beds.

Thin sections of the comparatively soft shaly radiolarian beds are not materially different under the microscope from the hard cherty varieties. The siliceous matrix is similarly cryptocrystalline; it contains minute cubes and grains of pyrites and needles of rutile, and there are also in it numerous small flakelets of mica. In some beds there are dark parallel lines crossing obliquely the lines of bedding, and between them the radiolaria are often closely packed in regular layers. The radiolaria in these softer beds are, as a rule, in the same mineral condition of solid casts of microcrystalline silica as in the harder rock, and owing to the soft nature of the matrix these solid casts weather out and project, as already mentioned, above the general surface of the rock. In some beds of the soft shales the radiolaria are now represented by empty casts, or these are filled with loose powdery material, and the rock has a light and porous character resembling that of rottenstone.

Some of the shales are sufficiently soft and unconsolidated to disintegrate in water to a milky sediment; the finer portions of this consist of minute siliceous granules, flakelets of mica, and rutile-needles; in the coarser portions are detached radiolaria, but these are usually partially incrustated with the flaky matrix. Under favourable conditions of light, the lattice-structure can be indistinctly seen in some of these detached forms.

Beyond radiolaria and fragmentary sponge-spicules there is a

¹ Bull. Soc. géol. France, ser. 3, vol. xxii. (1894) p. 197; Comptes-rendus Acad. Sci. Paris, vol. cxviii. (1894) p. 1433.

singular absence of other microscopic organisms in these Culm siliceous rocks, and the only forms met with are a few minute dentated plates of a dark or brownish tinge which have a general resemblance to the radulæ of gastropods. Bodies of a similar character are occasionally present also in the Ordovician radiolarian rocks of the South of Scotland.¹

In the greater number of the microscopic sections of the Radiolarian rocks which we have examined, detrital materials—beyond perhaps some minute flakelets of mica—are not shown; but in some beds, more particularly in the hard, dark, platy varieties, there is a certain admixture of minute chips of quartz and flakes of mica which appear to be of detrital origin. The particles are very small, ranging from .03 to .065 mm. in diameter, and thus not larger than the detrital grains which occur in typical recent radiolarian ooze or in the radiolarian rocks of Barbados. Radiolaria are present in the same rock with these detrital grains, but they are less numerous than in the rocks in which they are not found.

The very generally siliceous nature of the Radiolarian rocks has been already mentioned: exceptions to this occur in the exposures near Lawell House, Chudleigh, where there are some beds of dark limestone alternating with siliceous beds; the limestones contain casts of radiolaria and sponge-spicules which in some instances are replaced by calcite, in others the radiolaria are infilled either with microcrystalline silica or partly with this mineral and partly with calcite. The limestone-matrix is finely granular, and some indeterminate fragments of calcareous organisms are present in it.

We have also examined microscopic sections of the dark limestones which, both in the Launceston district and near Barnstaple, appear below the Radiolarian rocks. The limestone of the Wooladon quarry near Launceston is finely granular, with some traces of calcareous organisms and a few rounded bodies, now infilled with calcite, which may possibly be casts of radiolaria. The dark limestone of the Tinhay quarry, a little farther east, appears to be almost entirely crystalline, and no organisms can be seen in it. A thin section of the black limestone of Swimbridge near Barnstaple was fine-grained and filled with fragments of entomostracan shells and crinoids, also a few rounded bodies of uncertain character. The limestone at Venn, near Barnstaple, is very similar to that at Swimbridge.

The bluish-grey limestones of Canonsleigh, near Burlescombe Station, are very crystalline; they contain, however, foraminifera of the genus *Endothyra*. In sections of the hard, grey, cherty layers associated with these limestones the matrix is of cryptocrystalline silica, in which there are numerous rhombohedra of calcite and casts of radiolaria, precisely similar to those in the normal Radiolarian rocks.

VII. DESCRIPTION OF THE RADIOLARIA.

Although there are many varieties of the Culm radiolarian rocks, and these organisms are abundant in all, we have not succeeded in

¹ Ann. & Mag. Nat. Hist. ser. 6, vol. vi. (1890) p. 45.

finding any specimens in which their structural characters are satisfactorily preserved. In the large majority of the Culm siliceous rocks the radiolaria are now in the condition of solid casts of the original forms; their skeletal walls have entirely disappeared and the individual casts are only bounded by the siliceous matrix of the rock and without definite even outlines. In such instances, only the size and general form, with the radial spines, can be distinguished.

In some of the hard cherty and platy rocks of Ramshorn Down and the Chudleigh district the radiolarian tests have been stained of a brownish or amber tint, so that the lattice-like structure can be seen; but they are now so crushed and obscured in a confused mass of broken spines and fragmental débris that it is seldom that a specimen is sufficiently clear to be figured. In other instances the silica of the test is of a pinkish tint, and thus distinguishable from the clear silica surrounding it. For some not apparent reason the tests thus preserved nearly all belong to discoidal forms of *Lithocyclus* and *Porodiscus*.

The radiolaria in the soft, incoherent, shaly beds are in much the same state of preservation as those in the harder cherty rocks—that is, they are mostly casts, and the original tests have been either dissolved or if preserved they cannot in sections be distinguished from the infilling silica.

With radiolaria thus imperfectly preserved determination is extremely difficult; in only a very few instances, as in some of the Discoidea, has it been possible to recognize specific characters; with respect to many, even the generic determination has been a matter of inference. It can be seen that a considerable variety of forms are present in these rocks, and the following Orders are represented—Beloidea, Sphæroidea, Prunoidea, Discoidea, and Cyrtidea—by 23 genera. Both in the number of the forms and in their state of preservation the radiolaria in our Culm Measures fall far short of those which Dr. Rüst has described¹ from the corresponding formations in the Harz, Sicily, and Russia. Most of these, however, were obtained from two or three small nodules in which the minute structure of the tests was preserved, and should specimens in similar condition be met with in our rocks they would probably be found to contain equally as many species.

Subclass SPUMELLARIA, Ehrenberg.

Order BELOIDEA, Haeckel.

Genus SPHÆROZOOM, Meyen.

Pl. XXV. figs. 1 *a*–1 *g*. In this genus there is no latticed test; the skeleton consists of free siliceous spicular bodies, which are now found detached in the rock. According to Dr. Rüst² the spicules have four rays extending from a common centre at angles of 120°;

¹ 'Palæontographica,' vol. xxxviii. (1892) pp. 107–192, pls. vi.–xxx.

² *Ibid.* p. 133.

but it is very seldom that more than three rays are visible, and these appear to be nearly in a plane. The rays may be either simple and of uniform thickness as in fig. 1 *g*, or swollen at the ends to a bulb or knob as in figs. 1 *c*, *d*, *e*, *f*, or they dichotomize and each branch becomes lobed as in figs. 1 *a*, *b*. They vary considerably in size; a small form is $\cdot 03$ mm., and a large one $\cdot 085$ mm. in width. They are generally distributed, and have been recognized at Heddon, Swimbridge, and Kent's Hill in North Devon, at Carzantio near Launceston, and at Ramshorn Down and Winstow Lodge near Chudleigh. Rüst has figured a form resembling our fig. *a* from the Silurian of Cabrières, and he states that the spicules are very abundant in the Devonian and Carboniferous radiolarian rocks of the Southern Ural ('Palæontographica,' vol. xxxviii. p. 133, pl. viii. fig. 11).

Order SPHÆROIDEA, Haeckel.

Genus CENOSPHERA, Ehrenberg.

The test is a simple latticed sphere, without radial spines. It is probable that most of the rounded casts, abundant in nearly every microscopic section of these rocks, belong to forms of this genus. They vary in diameter from $\cdot 065$ to $\cdot 275$ mm. It is only exceptionally that anything beyond the mere outline of the cast is shown in these forms.

Cenosphaera pachyderma, Rüst. Pl. XXV. fig. 2 ('Palæontographica,' vol. xxxi. 1885, p. 286, pl. xxvii. figs. 2, 3). The test is $\cdot 165$ mm. in diameter and about $\cdot 015$ mm. in thickness, and the apertures in it are also $\cdot 015$ mm. in width. From Ramshorn Down. Rüst states that this form is present in all Palæozoic radiolarian deposits, as well as in many of those of Jurassic and Cretaceous age.

Cenosphaera sp. *a*. Pl. XXV. fig. 3. Test relatively large, ranging to $\cdot 27$ mm. in diameter and $\cdot 03$ mm. in thickness; the apertures are about $\cdot 022$ mm. in width. This form is near to *C. ingens*, Rüst ('Palæontographica,' vol. xxxviii. p. 134, pl. vi. fig. 8), but the walls are distinctly thicker. It is common at Ashbrittle, West Somerset.

Genus CARPOSPHERA, Haeckel.

The test consists of two concentric spheres connected by rays. No radial spines.

Carposphæra sp. *a*. Pl. XXV. fig. 4. The outer test is $\cdot 14$ mm. in diameter, and the inner $\cdot 05$ mm. Neither the connecting rays nor the lattice-structure has been preserved. A form of nearly similar proportions occurs in the Mullion Island chert (Quart. Journ. Geol. Soc. vol. xlix. 1893, p. 216, pl. iv. fig. 2). Ramshorn Down.

Carposphæra sp. *b*. Pl. XXV. fig. 5. The outer thin test is

·125 mm. in diameter; it is connected by a number of short, stout rays with the inner sphere, which is ·07 mm. in width. *C. macractinia*, Rüst, from the Culm of the Harz, has similar stout connecting-rays, but it is a much larger form ('Palæontographica,' vol. xxxviii. 1892, p. 136, pl. vii. fig. 4). Artiscombe Quarry, near Tavistock.

Carposphæra sp. c. Pl. XXV. fig. 6. The outline of the test is now slightly elliptical; it is about ·1 mm. in diameter, the inner sphere is ·05 mm.; it is connected by three stout rays. In a boulder from the Lower Culm at Tavistock.

Carposphæra sp. d. Pl. XXV. fig. 7. Test now slightly elliptical, with in places a bluntly-spined or dentate margin, diameter ·13 mm.; the inner sphere with a thick wall, diameter ·05 mm.; numerous stout rays connect it with the outer test. Ramshorn Down, South Quarry.

Genus THECOSPHÆRA, Haeckel.

The test consists of three concentric latticed spheres connected by rays.

Thecosphæra sp. a. Pl. XXV. fig. 8. The spheres in this form are ·14, ·065, and ·015 mm. in diameter respectively. There are six rays connecting the spheres; probably more were originally present. Hedge section, Lawell House, Chudleigh.

Genus XIPHOSPHÆRA, Haeckel.

The test is a simple latticed sphere with two similar free rays or spines, one from each pole.

Xiphosphæra sp. a. Pl. XXV. fig. 9. The test is ·06 mm. in diameter, and each of the spines about ·11 mm. in length. Ramshorn Down, North Quarry.

Xiphosphæra sp. b. Pl. XXV. fig. 10. The test is considerably larger than the preceding; its diameter is ·13 mm. The spines are stout at the base; they gradually taper, and end obtusely. They are ·09 mm. in length. Ramshorn Down, North Quarry.

Genus XIPHOSTYLUS, Haeckel.

Test a simple latticed sphere, with a spine or ray from each pole. The spines are unequal in length.

Xiphostylus sp. a. Pl. XXV. fig. 11. The test is depressed spherical, ·11 mm. in diameter; one spine is stout and ·12 mm. in length, the other slender and only ·09 mm. long. Ramshorn Down, North Quarry.

Xiphostylus sp. b. Pl. XXV. fig. 12. The sphere is ·12 mm. in diameter; at one pole is a short acute spine, and at the other a much stouter spine of which only the base remains. The test shows traces of the lattice-structure. Ramshorn Down.

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Xiphostylus? sp. c. Pl. XXV. fig. 13. The test is depressed spheroidal, $\cdot 11$ mm. in diameter; at one pole is a short conical spine, at the other a double spine apparently springing from a common base, about $\cdot 1$ mm. in length. Ramshorn Down.

Genus DORYSPHÆRA, Hinde.

The test is a simple latticed sphere with a single radial spine.

Dorysphæra sp. a. Pl. XXVI. fig. 9. The test is $\cdot 18$ mm. in diameter; the spine conical, pointed, $\cdot 11$ mm. in length. Carzantic Quarry, near Launceston. A form somewhat smaller occurs at Ramshorn Down.

Dorysphæra sp. b. Pl. XXVI. fig. 5. The test is $\cdot 22$ mm. in diameter and $\cdot 02$ mm. in thickness; spine stout at base, tapering slightly and obtusely ended, length $\cdot 18$ mm., thickness at base $\cdot 03$ mm. Ashbrittle, West Somerset.

Genus ACANTHOSPHERA, Haeckel.

The test is a simple latticed sphere, with numerous simple radial spines of equal size.

Acanthosphæra laxa, sp. nov. Pl. XXVI. fig. 6. The test is $\cdot 16$ mm. in diameter; the lattice-structure is not shown, but within there are traces of six rods radiating from an excentric point. From the margins of the test five long slender spines extend in different directions; the longest measures $\cdot 5$ mm. This form is not uncommon at Ramshorn Down, but the spines are usually displaced and the test distorted.

Genus STAUROLONCHE, Haeckel.

The test consists of two concentric latticed spheres with four similar radial spines.

Staurolonche sp. a. Pl. XXV. fig. 14. The outer test is $\cdot 18$ mm. in diameter, and the inner one $\cdot 05$ mm. From the inner sphere two rays extend to just beyond the outer test, where they terminate in minute points; the other two rays or spines are not preserved. Hedge-section at Lawell House, Chudleigh.

Genus STYLOSPHÆRA, Haeckel.

Test of two concentric latticed spheres, with a free radial spine at each pole.

Stylosphæra sp. a. Pl. XXV. fig. 15. The outer sphere is $\cdot 13$ mm. in diameter, and the inner $\cdot 06$ mm.; the spine at one pole is slender and $\cdot 1$ mm. in length, the opposite spine is stouter and broken off near the base. Ramshorn Down.

Order PRUNOIDEA, Haeckel.

Genus CENELLIPSIS, Haeckel.

The test is a simple elliptical latticed shell, without radial spines. Forms of this genus are very numerous and generally distributed in the Culm radiolarian rocks.

Cenellipsis sp. a. Pl. XXVI. fig. 1. Test regularly oval; long diameter $\cdot 21$ mm., transverse $\cdot 16$ mm., thickness of wall $\cdot 015$ mm. Both in form and size this agrees closely with specimens from Mullion Island (Quart. Journ. Geol. Soc. vol. xlix. 1893, p. 217, pl. iv. figs. 5, 6). From Carzantic Quarry, near Launceston.

Cenellipsis sp. b. Pl. XXVI. fig. 8. Test elongate oval; long diameter $\cdot 2$ mm., transverse $\cdot 14$ mm., thickness of wall about $\cdot 02$ mm. Codden Hill Quarry, near Barnstaple.

Cenellipsis sp. c. Pl. XXVI. fig. 2. Test short oval; length $\cdot 17$ mm., breadth $\cdot 145$ mm., thickness of test $\cdot 01$ mm. From Ramshorn Down and Carzantic Quarry, near Launceston.

Cenellipsis sp. d. Pl. XXV. fig. 16. Test regularly elliptical; length $\cdot 125$ mm., breadth $\cdot 1$ mm., and $\cdot 01$ mm. in thickness. Ramshorn Down.

Genus ELLIPSOXIPHUS, Dunikowski.

The test is a simple elliptical latticed shell, with a radial spine at each pole.

Ellipsoxiphus sp. a. Pl. XXVI. fig. 10. Test oval, $\cdot 22$ mm. in length and $\cdot 2$ mm. in breadth, with a stout, tapering, obtusely-pointed spine at each pole. The spines probably were equal in length originally; the longest is now $\cdot 17$ mm. From Tregeare Down, near Launceston.

Genus DRUPPULA, Haeckel.

Test elliptical, of two concentric latticed shells without radial spines.

Druppula sp. a. Pl. XXV. fig. 17. The test is regularly elliptical; length $\cdot 14$ mm., breadth $\cdot 115$ mm., the inner test $\cdot 04$ mm. in diameter. No connecting-rays are shown. Ramshorn Down.

Druppula sp. b. Pl. XXVI. fig. 7. Test regularly elliptical; length $\cdot 18$ mm., breadth $\cdot 155$ mm. The inner test is $\cdot 07$ mm. in diameter; it is connected by numerous rays with the outer. Carzantic Quarry, near Launceston.

Order **DISCOIDEA**, Haeckel.

Genus **THEODISCUS**, Haeckel.

Test a simple lenticular latticed shell, with three marginal spines.

Theodiscus aculeatus, sp. nov. Pl. XXVI. fig. 3. The test is now partially crushed; originally it seems to have been somewhat oval in outline; the diameter is .2 mm. The three marginal spines are unequal in length; the longest measures .5 mm., and .04 mm. in thickness at the base; there are also some smaller spines. Traces of lattice-structure are shown. This form is allied to *Th. gigas*, Rüst., from the Silurian of Cabrières ('Palæontographica,' vol. xxxviii. 1892, p. 163, pl. xx. fig. 4); the test is slightly larger; the spines are longer but less robust. Not uncommon at Ramshorn Down.

Genus **SETHODISCUS**, Haeckel.

Test consisting of a lenticular latticed cortical shell connected by radial beams with a simple medullary shell, and having the margin of the circular disc simple.

Sethodiscus chudleighensis, sp. nov. Pl. XXVI. fig. 13. Only a vertical section of this form has been recognized. The cortical test is lenticular, .15 mm. in length, and .09 mm. in breadth; the inner test is circular in outline, .05 mm. in diameter, and it is connected with the outer test by numerous radial beams. Within the smaller test are several rods, which radiate from an excentric point to the margin. From the hedge-section at Lawell House, Chudleigh.

Genus **LITHOCYCLIA**, Ehrenberg.

Test discoid, with a lenticular latticed cortical shell connected by radial beams with a simple medullary shell surrounded by one or more concentric chambered equatorial rings, without radial appendages.

Lithocyclia devoniensis, sp. nov. Pl. XXVI. fig. 4. The test, as shown in section, is elliptical; the long diameter is .23 mm., the lenticular shell is .115 mm., and the central chamber .065 mm. There are four rings; the inner one is somewhat wider than the others. The radial beams are only faintly shown. Ramshorn Down, Devon.

Genus **TRIGONOCYCLIA**, Haeckel.

Test discoid, with lenticular latticed cortical shell, simple medullary shell, and three solid radial spines on the margin of the disc.

Trigonocyclia ? sp. a. Pl. XXVI. fig. 11. Test triangular in outline, two sides nearly straight, the third slightly curved, with long stout spines from the angles. Diameter of disc .2 mm.; length of

spines .25 mm. No structure is shown, and it is doubtful whether it rightly belongs to this genus. Not uncommon. Ramshorn Down.

Trigonocyelia? sp. b. Pl. XXVI. fig. 12. Test subtriangular in outline, the sides curved. Diameter of disc .21 mm.; length of spines .2 mm. No structure preserved. Ramshorn Down.

Genus PORODISCUS, Haeckel.

Discoidea without phacoid shell; with a flat discoidal shell, in which a simple spherical central test is surrounded by concentric chambered rings (each ring divided by radial beams into imperfect chambers). Surface on the two flat sides covered by a porous sieve-plate; the margin simple.

Porodiscus lens, sp. nov. Pl. XXVII. fig. 10. As shown in section the test is elliptical, with a long diameter of .14 mm. and transverse .095 mm.; the central chamber is .06 mm. in width. It has two rays diverging from an excentric point to its margin, and it is surrounded by two chambered rings, partitioned off by numerous rays. The surface-pores are not shown. Not uncommon. Hedge-section at Lawell House, Chudleigh.

Porodiscus brevis, sp. nov. Pl. XXVII. figs. 2, 3. Test elliptical to nearly circular in outline, diameter .13 to .15 mm.; central chamber relatively large, diameter .08 mm. Within it are four beams radiating from an excentric point, and it is surrounded by one or two rings divided by radial beams. This form differs from the preceding in the larger size of the central chamber and the less development of the rings. Hedge-section at Lawell House, Chudleigh.

Porodiscus percinctus, sp. nov. Pl. XXVII. figs. 1, 11. Nearly circular in outline; diameter .25 mm., with wide central chamber, .08 mm. in diameter, surrounded by about seven concentric chambered rings of approximatively equal width. Radial beams numerous. The surface-pores not shown. Fig. 11 is a vertical section, probably of this species. Common at Ramshorn Down; in the hedge-section, Lawell House, near Chudleigh; and at Bishops-teignton.

Porodiscus sp. a. Pl. XXVII. fig. 13. This is a vertical section of a similar form to the preceding, but it is larger; the central chamber is .09 mm. in width, and there are from seven to eight chambered rings. Ramshorn Down.

Porodiscus clathratus, sp. nov. Pl. XXVII. figs. 4, 12. The discoid test, of medium size, is .18 mm. in diameter; the central chamber is .06 mm. in width. It is surrounded by four concentric chambered rings; the innermost is wider than the others. The radial beams are numerous. In fig. 12 the outer porous test is shown. Not infrequent. Ramshorn Down.

Genus AMPHIBRACHIUM, Haeckel.

Test consisting of a central chamber and two opposite chambered arms.

Amphibrachium, sp. a. Pl. XXVII. fig. 7. The test is .25 mm. in length, the central chamber .09 mm. in diameter; the arms are equal and of the same width throughout, their ends are rounded or truncate. Only the outlines of the form are shown. Not uncommon. Carzantic Quarry, near Launceston.

Amphibrachium, sp. b. Pl. XXVII. fig. 5. As seen in section the central chamber is oval, and the arms fusiform or elliptical in outline, with obtuse ends. Total length .39 mm., length of central chamber .1 mm., greatest width of the arms .05 mm. Carzantic Quarry.

Genus RHOPALASTRUM, Haeckel.

The test consists of three chambered arms.

Rhopalastrum ingens, sp. nov. Pl. XXVII. fig. 6. As shown in section, the three arms are unequal; the longest is fusiform in outline, thickest in the middle portion, and gradually tapering to an obtuse end; its length is .63 mm., and greatest width .11 mm. The other two arms are even throughout; the longest measures .56 by .08 mm., and the other, which appears to be incomplete, is .45 by .095 mm. No structure has been preserved, but its form and proportions readily distinguish it from other species which have been described. Rare. Ramshorn Down.

Rhopalastrum clavatum, sp. nov. Pl. XXVII. fig. 9. The test is not inflated in the centre, and gives no indication of a central chamber; the arms are club-shaped and subequal. Length of each arm .47 mm., greatest width .1 mm. Traces of pores are shown. Ramshorn Down.

Rhopalastrum, sp. a. Pl. XXVII. fig. 8. Only two of the three arms remain in this specimen. The arms are club-shaped and rounded at the ends and subequal. Length .53 mm., breadth .17 mm. in the thickest parts. There is no central inflation. In general form this specimen resembles *R. Isselii*, Rüst, from the Lower Carboniferous of Sicily, but is much larger. Ramshorn Down.

Subclass NASSELLARIA, Haeckel.

Order CYRTOIDEA, Haeckel.

Genus SETHOCAPSA, Haeckel.

The latticed test is divided by a constriction into two chambers, and the aperture is covered by a latticed plate.

Sethocapsa, sp. a. Pl. XXVII. fig. 17. The lower chamber is nearly circular in outline, and .13 mm. in diameter, the upper is represented by a subcylindrical extension, .16 mm. in length by

·04 mm. in width. No structure is shown, and the form is placed here from its resemblance to specimens from the Swiss Jura, figured by Rüst ('Palæontographica,' vol. xxxi. 1885, p. 306, pl. xxxvi. figs. 15-18). From Carzantic Quarry, near Launceston.

Genus LITHOSTROBUS, Haeckel.

The conical latticed test has three or more transverse constrictions and a horn-shaped extension at the summit.

Lithostrobos, sp. a. Pl. XXVII. fig. 16. The test is divided into four chambers, the summit has an obtuse curved horn, the last chamber is much larger than the others, and the aperture is oblique. Length ·23 mm., greatest width ·08 mm. Heddon Quarry, near Barnstaple.

Genus LITHOCAMPE, Haeckel.

The conical, oval, or fusiform latticed test has the aperture contracted, and it is without a horn-shaped process at the summit.

Lithocampe, sp. a. Pl. XXVII. fig. 15. Test conical, the constrictions indicate eight chambers, gradually increasing in size; the summit chamber is rounded, and the basal one contracted. Length ·25 mm., greatest width of last chamber ·09 mm. Not infrequent. Ramshorn Down.

Genus STICHOCAPSA, Haeckel.

Test conical, without horn at the summit; the aperture of the last or basal chamber is closed by a latticed plate.

Stichocapsa, sp. a. Pl. XXVII. fig. 14. Test evenly conical, with nearly straight sides and curved base, the summit pointed; the number of chambers is not shown. Length ·28 mm., greatest width ·09 mm. Common. From Ramshorn Down.

The following is a list of the genera of radiolaria which have been recognized in the Lower Culm Measures of the different areas referred to in the paper :—

Order BELOIDEA.

Genus *Sphærozoum*.

Order SPHÆROIDEA.

Genus *Cenosphæra*.
Carposphæra.
Thecosphæra.
Xiphosphæra.
Xiphostylus.
Dorysphæra.
Acanthosphæra.
Staurolonche.

Order PRUNOIDEA.

Genus *Cenellipsis*.
Ellipsoxiphus.
Druppula.

Order DISCOIDEA.

Genus *Theodiscus*.
Sethodiscus.
Lithocyelia.
Trigonocyelia.
Porodiscus.
Amphibrachium.
Rhopalastrum.

Order CYRTOIDEA.

Genus *Sethocapsa*.
Lithostrobos.
Lithocampe.
Stichocapsa.

Of the 23 genera enumerated above, 21 have been previously determined from the Palæozoic formations of this country and the continent, the larger proportion—17 genera—from the Culm of Germany, Sicily, and Russia by Dr. Rüst. Of the other 2 genera, one (*Trigonocyclus*) has not previously been recognized below the Jurassic, and the other (*Sethodiscus*), although a very simple form, does not seem to have been hitherto met with in the fossil state.

VIII. DESCRIPTION OF THE OTHER FOSSILS ASSOCIATED IN THE SAME ROCKS WITH THE RADIOLARIA.

The Radiolarian or Codden Hill Beds of the Lower Culm Measures have hitherto been considered as practically unfossiliferous, and indeed their distinctive characters have been attributed to metamorphism.¹ Prof. J. Phillips,² however, who appears to have himself very diligently searched these rocks, described and figured from them the following 5 species:—*Turbinolopsis pauciradialis*, Phill., *Leptæna mesoloba*, Phill., *Terebratula (Atrypa) insperata*, Phill., *Goniatites micolobus*, Phill., and *Cyathocrinus distans*, Phill., this last being merely detached joints of crinoid-stems. The other fossils which Phillips described in the same work from his so-called 'Carbonaceous group'³ did not come from the Radiolarian or Codden Hill rocks, but from the dark limestones and shales underlying them at Swimbridge, Venn, Bampton, etc., in North Devon, and at Truscott, Lew Trenchard, and other localities in Cornwall and South Devon. The fossils enumerated by Mr. Ussher, in his 'British Culm Measures,'⁴ from the Basement Beds of the Culm do not appear to include any at all from the Radiolarian or Codden Hill Beds; those given are from beds at Waddon Barton and other places in the Chudleigh district discovered and determined by Dr. Henry Woodward and Mr. R. Etheridge, Jun., in the celebrated shales with trilobites, in which no radiolaria have as yet been met with, and which are probably at a slightly lower horizon than the Codden Hill Radiolarian Beds.

Certain thin beds, however, in the Radiolarian series at Codden Hill and its neighbourhood, and also west of the Taw river near Barnstaple, contain a fairly varied but scanty fauna in addition to the radiolaria, and in view of the importance of these fossils in determining the geological horizon of the radiolarian rocks, and since many of them have not hitherto been recorded from this country, we give below detailed references to them. These fossils do not seem to be generally distributed in the Radiolarian rocks; so far they have been met with only in limited thin bands of whitish or yellowish soft shaly or platy rock, in which radiolarian casts are also abundant. With hardly an exception the calcareous

¹ Proc. Som. Archæol. & Nat. Hist. Soc. vol. xxv. (1879) pt. ii. p. 5; also T. M. Hall, 'Sketch Geol. Devon,' (White's Gazetteer), 1878, p. 9, reprint.

² 'Palæozoic Fossils of Cornwall, etc.,' 1841.

³ *Ibid.* pp. 189, 194.

⁴ Proc. Som. Archæol. & Nat. Hist. Soc. vol. xxxviii. (1892) pp. 159-161.

structure of these fossils has been wholly removed, and they are now preserved as casts in the soft siliceous matrix; but the casts, as a rule, retain very sharp and distinct impressions of the different forms.

(a) Sponges.

The only remains of sponges found are microscopic fragments of the long needle-like spicules which form the anchoring-wisps of hexactinellid sponges, and an occasional cruciform spicule of the same group. The fragments are in the same condition of preservation as the radiolaria in the same beds; they are not very abundant, but have been recognized at Codden Hill, Hannaford, and Templeton near Barnstaple; at Hulverton, North Devon; Ramshorn Down, hedge-section at Lawell House, Winstow Cottage, near Chudleigh, and at Landlake near Launceston.

(b) Corals.

Pleurodictyum Dechenianum, Kayser. Pl. XXVIII. figs. 18, 18a, 18b.

1882. Jahrb. der königl. Preussisch. geol. Landesanst. f. 1881, p. 84, pl. iii. figs. 20, 21.

This form is at present known only from casts; it seems to have been hemispherical or semioval, the base flattened or slightly concave; the corallites are conical, either round or subprismatic in transverse section, and connected with each other by small rods (the solid infillings of the pores) disposed in vertical rows. There are from eight to ten rows in a single corallite. No traces of tabulæ or septal spines are present, nor is there any coiled tube as in *P. problematicum*.

The corallum is very diminutive; the base of a small specimen is only 5 mm., and the largest noted only 12 mm. across; the height of the coral appears to have been a little more than the basal width. The corallites range from 2 to 5 mm. in length, by .7 to 2 mm. in width at the summit.

The forms are not infrequent in yellowish shales at Hannaford Quarry, near Barnstaple. Kayser's specimens were from the Culm kiesel-schiefer at Aprath, between Elberfeld and Wülfrath, Rhenish Prussia.

Cladochonus Michelini, M.-Edwards & Haime. Pl. XXVIII. figs. 19 & 19a.

1851. *Pyrgia Michelini*, M.-Ed. & Haime, 'Polyp. foss. Terrains paléoz.' p. 310, pl. xvii. fig. 8.

1872. *Cladochonus* —, de Koninck, 'Nouv. Recherch. Anim. foss. terr. carbon. Belg.' p. 153, pl. xv. fig. 6.

1879. —, Nicholson & Etheridge, Jun., Geol. Mag. p. 292.

1882. —, Kayser, Jahrb. königl. Preuss. geol. Landesanst. f. 1881, p. 85, pl. iii. fig. 19.

1889. —, Holzapfel, Pal. Abhandl. n. s. vol. i. (1889) p. 69.

The only example met with of this species is a very perfect cast of a single cup and pedicel, which together are 15 mm. in length. The pedicel is 10 mm. in length and 1 mm. in thickness near the

calice, but less in its lower portion; it is covered with concentric rugose striæ; the calice is slightly compressed, 5 mm. in width at the summit, and about the same in height. On the surface of the cast there are very regular vertical lines, about 20 in number, of delicate blunt spines or pustules, which would correspond to as many rows of minute holes in the actual calice, a feature which has not been noticed by previous authors, but in some of the specimens from the Carboniferous Limestone of Tournay, Belgium, now in the British (Nat. Hist.) Museum, there are within the calices rows of small holes instead of the usual septal striæ. From near the margin of the calice of our specimen the pedicel of another corallite is given off, and this is nearly completely separated from the parent form by a plaited septum. Our specimen is of similar size to those from the Tournay Limestone, but distinctly larger than that figured by Kayser from Aprath.

Distribution. In the yellowish shales at Hannaford, associated with *P. Dechenianum*. The only other locality in which it has been found in Britain is in the Lower Carboniferous Limestone series near Dunbar, whence it has been recorded by Nicholson and Etheridge, Jun. On the Continent this species has been found in the Culm shales of Aprath, Liebstein, and Kramberg, and in the Lower Carboniferous Limestone of Tournay.

Petraia, sp. Pl. XXVIII. figs. 20 & 20 a.

Cf. *Petraia* (*Turbinolopsis*) *pauciradialis*, Phill., 'Pal. Foss. Cornwall, etc.' 1841, p. 5, pl. i. fig. 4.

Only the cast of the interior of the calice has been preserved; this is obliquely conical, truncate, 5 mm. in depth, 5·2 mm. wide at the summit, and 4·2 mm. at the bottom. The septa are 16 in number, and they have a distinct bilateral arrangement. A cardinal septum reaches nearly to the centre of the base of the calice, and there is a small depression at its free end. It has on each side a group of three septa. The alar septa connect with a low ridge which curves round the small central depression, and connected with this is the counterseptum and three other septa on each side of it. The septa appear to be narrow, with smooth, free margins. On both sides of each septum there is a row of minute holes—shown in the cast as small pustules—which are probably connected with the insertion of the mesenteric muscles.

In *P. pauciradialis*, Phill., there is a greater number of septa, and their margins are said to be denticulate.

From Hannaford Quarry, near Barnstaple.

(c) Crinoids.

Casts of detached joints of crinoidal stems, similar to those which Phillips provisionally named *Cyathocrinus distans* ('Pal. Foss.' 1841, p. 135, pl. lviii. fig. 49*), are fairly numerous in the same beds with the other fossils, but there is nothing in them to distinguish the particular genus to which they might belong.

(d) Trilobites. By Dr. HENRY WOODWARD, F.R.S., P.G.S.

The intimate knowledge which Dr. Woodward possesses of Carboniferous trilobites, and especially of those from the Lower Culm Measures of Waddon Barton, near Chudleigh, South Devon, which he described in the Palæontological Society's volume for 1883-84, led us to seek his assistance in determining the forms from the Radiolarian Beds of North Devon, from which hitherto no trilobites have been recorded, and he has prepared the subjoined descriptions of them, for which we desire to express our sincere obligations to him.

Phillipsia Leei, H. Woodw. Pl. XXVIII. figs. 1 & 1a.

1883-84. 'Brit. Carbonif. Trilobites,' Pal. Soc. p. 66, pl. x. figs. 1, 2, 3, & 4.

This is a detached cheek of rather larger size than those obtained from the Culm of Waddon Barton, and it is interesting as showing the facets of the eye, which are not well seen in Mr. Lee's specimens; the surface is covered with fine, waving, anastomosing lines, of a different colour from the cheek. Also a conical glabella from the same bed.

Length of cheek 8 mm., breadth 4 mm.; the extremity of the cheek-spine is broken off. The glabella is 4 mm. in length by 2.5 mm. in breadth.

From the buff rottenstone with radiolaria at Hannaford Quarry, near Barnstaple. Collected by Mr. G. F. Tregelles. Also from the red shales of the Lower Culm at Waddon Barton, near Chudleigh, Devon.

Phillipsia minor, H. Woodw. Pl. XXVIII. fig. 2.

1883-84. 'Brit. Carbonif. Trilobites,' Pal. Soc. p. 68, pl. x. figs. 5, 6a & b, 7, & 8a.

This species is represented by two pygidia, both from Hannaford Quarry, the smaller one measuring 4 mm. in length by 4.5 mm. in breadth, and the larger 6 mm. in length by 7 mm. in breadth. The axis of the tail is elevated, and diminishes rapidly in size from before backwards; it is surrounded by a broad, smooth margin. There are about 12 segments on the axis; the pleuræ bifurcate.

This form also occurs in the Lower Culm of Waddon Barton.

Phillipsia Cliffordi, H. Woodw. Pl. XXVIII. figs. 3 & 3a.

1883-84. 'Brit. Carbonif. Trilobites,' Pal. Soc. p. 69, pl. x. figs. 8b, 9, 10, 11, & 12.

This species is represented by a head and tail of a small individual, the thoracic segments having been displaced or lying underneath. This specimen, together with the impression and counterpart of a small tail, come from Combe Wood quarry, Coddan Hill, near Barnstaple.

An impression and counterpart of 5 thoracic segments attached to a pygidium comes from the soft radiolarian shales of Tawstock, near Barnstaple.

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Also an impression and counterpart and two rilievo tails are before us from Hannaford Quarry.

None of these specimens call for special remark. They vary in size, but agree very well with *Ph. Cliffordi* from the Lower Culm of Waddon Barton.

Phillipsia ? (larval form). Pl. XXVIII. fig. 4.

This little specimen, which is represented by the impression and counterpart, exhibits the head-shield and pygidium with about 5 thoracic segments united together. The head-shield and pygidium are semicircular in outline, and the free cheeks are furnished with short spines projecting slightly outwards, as in *Ph. minor*.

The entire length of the specimen is 4.5 mm. and the greatest breadth 4 mm. The thorax measures 1.5 mm. in length, and the head and pygidium are each 1.5 mm. long.

This is probably a larval form, but it would be unsafe to hazard an opinion as to the species; possibly it may be *Ph. Cliffordi*: the pygidium has too round an outline for *Ph. minor*.

The specimen is in a white siliceous rock from Hannaford Quarry.

Griffithides acanthiceps, H. Woodw. Pl. XXVIII. figs. 5 & 5a.

1883-84. 'Brit. Carbonif. Trilobites,' Pal. Soc. p. 32, pl. vi. figs. 2, 10, & 11, and pl. vii. figs. 2 & 3.

This specimen seems to agree best with it consists of the free cheek of the right impression and counterpart are preserved in a pale yellow shale (resembling rottenstone in friability). The facets of the eye on the rilievo half, fig. 4 *e*, are exquisitely preserved, but only faintly to be detected upon the counterpart. Length of outer margin of head or cheek 18 mm., breadth of margin of cheek 2 mm., breadth of cheek 6 mm., length of eye 2.5 mm., breadth of eye 1.5 mm.

Griffithides acanthiceps; side only, of which the

Fig. 4.

This species has hitherto been recorded only from the Carboniferous Limestone of Craco, near Grassington, Settle, Yorkshire, and Castleton, Derbyshire. We are now able to record it from the Lower Culm of Hannaford Quarry, near Barnstaple. Collected by Mr. G. F. Tregelles.

Griffithides longispinus, Portlock, 1843. Pl. XXVIII. fig. 6.

1843. Portlock, 'Geol. Rept. Lond.' p. 312, pl. xxiv. fig. 12.

1883-84. H. Woodward, 'Brit. Carbonif. Trilobites,' Pal. Soc. p. 36, pl. vii. figs. 5 *a*, *b*, *c*, & 6.

This specimen, which is one of the most complete from the radiolarian Culm of Coddan Hill, has the head-shield, thoracic segments, and pygidium preserved together; they are, however, unfortunately decorticated, so that the ornamentation of the surface

cannot be discerned save in a few spots, and the intaglio side (which may have retained the external shelly crust) has not been preserved. The specimen measures 25 mm. in length and 12 mm. across the thoracic segments; the length from the front of the glabella to the point of the cheek-spine is 20 mm., the length of the cheek-spine itself being 8 mm., and its breadth where it joins the cheek 2 mm. The head is much broken up and squeezed back under the axis of the thorax, displaying more or less the first three thoracic segments which thus override the head; the six posterior thoracic segments remain undisturbed and in their normal position united to the pygidium. The pygidium is rather narrow and somewhat pointed, and it has a smooth border; the number of coalesced segments cannot be ascertained, as the subdivisions are obliterated, but its general form agrees very well with that of *Griffithides longispinus*.

In consequence of the squeezing in of the glabella, the cheek-spines with the free cheeks are pressed apart and bent outwards, giving the cheek-spines the appearance of diverging from the head at a wide angle on either side. The impression indicates that the spines were long, flat, and striated, which is Portlock's description of the spines in *G. longispinus*.

This species has hitherto been recorded only from the Carboniferous Limestone of Carnteel, Tyrone. At Coddan Hill it occurs in a platy, grey, siliceous rock. Collected by Mr. J. G. Hamling, F.G.S., of Barnstaple.

Proetus, sp. a. Pl. XXVIII. figs. 7 & 7 a.

This species is represented by a body consisting of nine thoracic segments and a pygidium, also by one detached pygidium; the latter retains the shelly covering, but the former is decorticated.

Breadth of thorax at anterior border 6 mm., at union with pygidium 5 mm., length of the 9 segments 3 mm., breadth of axis 2 mm. Breadth of axis of pygidium 2 mm., breadth of pygidium 4.5 mm., length 2 mm.

Detached pygidium: breadth 7 mm., length 3 mm., width of axis 3 mm.; this specimen shows from 6 to 7 coalesced segments in the axis and about 5 ribs on each lateral border; these ribs pass from the axis into the lateral border, and show a tendency to bifurcate near the margin. The specimen is in a white siliceous rock from Combe Wood Quarry, and that described in the previous paragraph comes from the Coddan Hill Quarry, near Barnstaple. Collected by Mr. J. G. Hamling.

Proetus, sp. b. Pl. XXVIII. fig. 8.

This small trilobite agrees best with the genus *Proetus*; it is represented by an intaglio of the head with 5 to 6 segments of the thorax attached, and a pygidium with 3 thoracic rings joined to it, slightly separated from the rest of the specimen on the same surface of rock. The head-shield is imperfect; but one cheek shows the small eye, the raised margin of the lateral border, and the short

lateral spine. The ribs are rounded and separated by deep furrows; the axis is somewhat narrow; the pygidium seems to consist of from 6 to 7 coalesced segments, its axis is bluntly triangular, is marked on either side by a parallel groove, and does not extend to the posterior border. The ribs on the lateral border, which are 6 in number, die away leaving a smooth margin.

Breadth of head at the neck-furrow 6 mm., length 5 mm., breadth of cheek 2.5 mm. Length of five thoracic segments following the head 4.5 mm., breadth 5.5 mm. Pygidium with three thoracic segments united to it 5 mm.; pygidium alone, length 2.5 mm., breadth 4.5 mm., width of axis at tail 2 mm.

In white siliceous rock from the Combe Wood Quarry, near Barnstaple. Collected by Mr. J. G. Hamling.

(e) Brachiopoda. By F. A. BATHER, Esq., M.A., F.G.S.

Mr. Bather has kindly examined for us the brachiopoda from the Radiolarian (Codden Hill) Beds, and has supplied us with the following notes on their identification:—

Discina nitida, Phillips, sp.

1836. *Orbicula nitida*, 'Geology of Yorkshire,' vol. ii. p. 221, pl. xi. figs. 10-13.
1857. *Discina nitida*, Davidson, 'Brit. Carbonif. Brachiop.' Pal. Soc. vol. ii. pt. v. p. 197, pl. xlviii. figs. 18-25, p. 268.
1874-82. ———, 'Brit. Carbonif. Brach. Suppl.' vol. iv. p. 268, pl. xxx. figs. 12 & 13.

A rather imperfect specimen, apparently of this species. At any rate it differs from the species of *Discina* described by Holzapfel from the Lower Carboniferous of Liebstein (Pal. Abhandlung. n. s. vol. i. 1889, p. 67) and from *Discina marginata*, Sandberger, which Sarres recorded from the Culm of Aprath. Length 12 mm., width 9 mm.

From Codden Hill Quarry (coll. J. G. Hamling). It is widely distributed also in the Carboniferous Limestone of Yorkshire, Scotland, Ireland, etc.

Productus plicatus, Sarres. Pl. XXVIII. figs. 10, 10 a, & 10 b.

1857. 'Inaugural Dissertation,' p. 20.
1882. Kayser, Jahrb. d. königl. Preuss. geol. Landesanst. f. 1881, p. 81, pl. iii. figs. 1 & 2.

The specimens are smaller and finer than those described by Sarres and Kayser, while the ears seem to project a little more. Spines are only shown in one specimen. Kayser compares the species with *P. Carringtonianus*, Davidson; but that is a larger, coarser, and more vaulted form. There is no other British species with which comparison is possible, but the *P. concentricus* of Sarres is clearly, as Kayser says, a very close ally. Length 5 mm., breadth 8 mm.

From Hannaford Quarry, near Barnstaple. Also from the Lower Culm at Aprath, Rhenish Prussia.

Productus concentricus, Sarres. Pl. XXVIII. figs. 9, 9 a, & 9 b.

1857. 'Inaugural Dissertation,' p. 21.

1882. Kayser, Jahrb. d. königl. Preuss. geol. Landesanst. f. 1881, p. 83, pl. iii. figs. 3 & 4.

The greater relative width of the shell and the well-marked sinus induce me to refer the specimens to this species rather than to *P. plicatus*. Possibly this is the *Leptaena mesoloba* (?), of Phillips ('Pal. Fossils, etc.' 1841, p. 61, pl. xxv. fig. 102). The specimens, in common with the others described, are only casts, and they are as a rule very diminutive. Length 2·7 mm., breadth 4 mm. One specimen is a specially wide form of the species; its length is 4·5 mm., and breadth 11·5 mm.

Not uncommon in Tower Hamlet Quarry and Hannaford Quarry, near Barnstaple. Also at Aprath in the Lower Culm.

Productus cf. *P. lævipunctatus*, Sarres. Pl. XXVIII. figs. 11 & 11 a.

1857. *Productus lævipunctatus*, Sarres, 'Inaug. Dissert.' p. 21.

1882. ———, Kayser, Jahrb. d. königl. Preuss. geol. Landesanst. f. 1881, p. 80, pl. iii. fig. 5.

The specimen is an internal cast; it has a sinus on the ventral valve similar to that in the above species, but the shell is proportionately somewhat wider than in the specimen figured by Kayser. Length 3·25 mm., breadth 6 mm.

From Hannaford Quarry, near Barnstaple. Also from the Lower Culm at Aprath.

Chonetes rectispina, von Koenen? Pl. XXVIII. figs. 12, 12 a, & 12 b.

1870. Neues Jahrb. für Mineralogie, etc. p. 327, pl. vii. fig. 4.

1882. Kayser, Jahrb. d. königl. Preuss. geol. Landesanst. f. 1881, p. 78, pl. iii. figs. 13 & 14.

It is difficult to distinguish the specimens from some varieties of *Ch. hardrensis*, as understood by Davidson. Length 4·5 mm., breadth 6 mm.

Frequent in the soft yellowish shale at Overton Quarry and Hannaford Quarry, near Barnstaple. Also in the Lower Culm of Aprath and at Herborn.

Chonetes Laguessiana, de Koninck. Pl. XXVIII. figs. 13 & 13 a.

1843. 'Descript. des Anim. foss. du Terrain Carbonif. Belgique,' p. 211, pl. xii. bis, fig. 4 a, b.

1857. *Chonetes hardrensis*, Davidson, 'Brit. Carbonif. Brachiop.' Pal. Soc. vol. ii. pt. v. p. 186, pl. xlvii. figs. 12–16, 17, 18.

1874–82. ——— *Laguessiana*, *ibid.* vol. iv. p. 312, pl. xxxiv. fig. 18.

1882. Kayser, Jahrb. d. königl. Preuss. geol. Landesanst. f. 1881, p. 77, pl. iii. figs. 17 & 18.

This differs from the specimens referred to *Ch. rectispina* in its greater relative breadth. Length 3 mm., breadth 5·2 mm.

From Hannaford Quarry, near Barnstaple, and from Westleigh (Rev. W. Downes). Also from the Lower Culm at Aprath (Kayser), and from the Carboniferous Limestone of Yorkshire, Shropshire, North of England, Scotland, Ireland, and Belgium.

Leptæna analoga, Phill. Pl. XXVIII. figs. 14 & 14 a.

1836. *Producta analoga*, Phill. 'Geol. Yorks.' vol. ii. p. 215, pl. vii. fig. 10.

1841. *Leptæna* —, Phill. 'Pal. Foss. Cornw.' p. 56, pl. xxiv. fig. 93.

1857. *Strophomena rhomboidalis*, var. *analoga*, Davidson, Pal. Soc. Mon. "Carb. Brach." vol. ii. pt. v. p. 119, pl. xxviii. figs. 1, 2; Supplement, vol. iv. p. 291, pl. xxxvi. fig. 23.

1882. — *analoga*, Kayser, Jahrb. d. königl. Preuss. geol. Landesanst. f. 1881, p. 77.

The specimen is rather smaller and finer than the usual forms of this species, agreeing in these respects with the other Culm brachiopoda. Length 4.5 mm., breadth 5.75 mm.

From Hannaford Quarry, near Barnstaple, also from the Lower Culm of Aprath. Phillips has figured it from the Devonian of Croyde Bay, North Devon, and Davidson states that it is common in the Carboniferous Limestone of Yorkshire, Derbyshire, Scotland, Ireland, and Belgium.

Orthis crenistria, Phillips, sp. Pl. XXVIII. figs. 15 & 15 a.

1836. *Spirifer crenistria*, Phill. 'Geol. Yorks.' vol. ii. p. 216, pl. ix. fig. 6.

1857. *Streptorhynchus* —, Davidson, 'Brit. Carb. Brachiop.' Pal. Soc. vol. ii. pt. v. p. 124, pl. xxvii. figs. 1-6, pl. xxvii. figs. 1-7.

1874-82. —, *ibid.* vol. iv. p. 288, pl. xxxvii. figs. 1-5.

1882. —, Kayser, Jahrb. d. königl. Preuss. geol. Landesanst. f. 1881, p. 77, pl. iii. fig. 12.

A specimen of the ventral or peduncle-valve and the internal cast, showing median septum and four muscle-scars. Common. Length 7.5 mm., breadth 6 mm. The specimens are small, but even smaller occur in the Lower Culm of Aprath.

From quarries at Hannaford and Coddan Hill, near Barnstaple. It has a wide distribution in the Carboniferous Limestone of Yorkshire, Scotland, Ireland, Belgium, etc.

Spirifer, sp. Pl. XXVIII. figs. 16 & 16 a.

Two specimens of internal casts of the dorsal or brachial valve clearly belong to this genus, but are not sufficiently preserved to be referred to any species. They do not, however, appear to belong to any species hitherto described from the Culm or to any Carboniferous *Spirifer* figured by Davidson. The approximative proportions are:—height $\frac{2}{3}$ width; hinge $\frac{3}{4}$ width of shell. The brachial valve shows a wide median rib about $\frac{1}{4}$ width of shell. On either side are 4 or 5 radiating ribs, which gradually diminish in width. The area of the valve appears to have been fairly pronounced, and marked with horizontal and vertical striæ; its hinge-margin was crenulate. The interior shows a ribbed cardinal process and a fine median septum.

From Hannaford Quarry, near Barnstaple.

Athyris, sp. Pl. XXVIII. figs. 17 & 17 a.

In the absence of calcareous structures one cannot definitely say whether this specimen belongs to the looped *Dielasma* or to the spire-bearing *Athyris*, but on the whole the features that it possesses in common with *Athyris* seem of more importance than those which resemble *Dielasma*.

From Hannaford Quarry and Overton Quarry, near Barnstaple.

(f) Cephalopoda. By G. C. CRICK, Esq., F.G.S.

For the subjoined notes on the Cephalopods we are indebted to Mr. G. C. Crick, of the Natural History Museum.

Among the specimens from the Radiolarian (Codden Hill) Beds I recognize the following Goniatites :—

1. *Goniatites* [*Prolecanites*] *mixolobus*, Phillips.
2. " " " sp.
3. " " [*Nomismoceras*] *spirorbis*, Phillips.
4. " " [*Pericyclus*], sp.

1. *Goniatites* [*Prolecanites*] *mixolobus*, Phillips.

This species is represented by at least one specimen. It shows a portion of the suture-line and agrees with Phillips's type ('Geol. Yorksh.' vol. ii. pl. xx. fig. 43) from the Carboniferous Limestone of Bolland, Yorkshire, with which I have carefully compared it.

I have examined the specimen belonging to the Museum of Practical Geology, from the Lower Culm Measures of Westleigh, North-east Devon, which is marked as one of the specimens figured as *G. mixolobus* by Prof. Phillips in his 'Palæozoic Fossils of Cornwall, Devon, etc.' (pl. li. fig. 235; probably fig. 235 f); but the fossil is so imperfectly preserved that I am unable to confirm this identification. There are, however, in the same Museum examples from Westleigh which I think are quite correctly referred to Phillips's *G. mixolobus*.

From Codden Hill Quarry, and Overton Quarry, near Barnstaple, and from Westleigh. It also occurs in the Lower Culm of Aprath and Herborn, and in the Carboniferous Limestone of Bolland, Yorkshire, and Visé, Belgium.

2. *Goniatites* [*Prolecanites*], sp.

In addition to the specimen referred to above there are several forms which belong to *Prolecanites*, but, since only fragments of their suture-lines can be made out, they are not specifically determinable. They may be crushed examples of *G. (Pr.) mixolobus*, but in their general character they approach closely *G. (Pr.) ceratitoides*, von Buch, as figured by Holzapfel (Pal. Abhandl. n. s. vol. i. pls. iii. & iv.) from the Lower Carboniferous of Erdbach-Breitscheid, near Herborn. The Jermyn Street Museum contains a similar specimen from Westleigh, North-east Devon.

From Codden Hill Quarry and Overton Quarry, near Barnstaple, and from Westleigh.

3. *Goniatites* [*Nomismoceras*] *spirorbis*, Phillips.

One specimen is clearly referable to this species, as identified by Phillips from Westleigh, North-east Devon, from which locality there is an example in the Museum of Practical Geology, Jermyn Street. These specimens do not show the suture-line, but they are most probably identical with the *G. spirorbis* which Phillips had

previously described from the Carboniferous Limestone of Bolland, Yorkshire.

From Beacon Quarry, Codden Hill, near Barnstaple, and from Westleigh. It also occurs in the Carboniferous Limestone of Visé, Belgium.

4. *Goniatites* [*Pericyclus*], sp.

A small goniatite, although specifically indeterminable, belongs to the section *Pericyclus*, a section which, so far as is known, is confined to the Lower Carboniferous. It appears to be near either *G.* [*Pericyclus*] *virgatus*, de Koninck, or *G.* [*Pericyclus*] *Hauchecornei*, Holzapfel, both figured by the latter author from the Lower Carboniferous of Erdbach-Breitscheid.

From the Overton Quarry, Codden Hill, near Barnstaple (coll. J. G. Hamling).

Table II. (p. 655) has in part been drawn up from the List of Fossils determined by Dr. Henry Woodward and Mr. R. Etheridge, Jun.,¹ from the Lower Culm shales of Waddon Barton, near Chudleigh, to which have been added the fossils from the limestones and shales of Canonsleigh and Westleigh, North-east Devon, obtained by the late Rev. W. Downes,² which appear to have been determined with some care. The cephalopoda in this list have been revised by Mr. G. C. Crick, and we are indebted to Mr. A. Smith Woodward³ for the information respecting the two species of fishes from Instow.

We have omitted references to fossil plants in the above-mentioned list, for the reason that none are known to occur in the Radiolarian Beds, and it is doubtful whether any have been determined from the Lower Culm Measures as distinct from those in the Culm itself and shales immediately associated therewith, which may be said to belong to the Upper Culm Measures, with which we are not concerned in the present paper. Mr. R. Kidston, F.G.S. (quoted by Dr. Henry Woodward),⁴ gives a list of 8 species of plants from the Culm, which have a Calciferous Sandstone facies and are equivalent to the Culm in Germany, but the precise horizon and locality whence these plants came are not stated, and it appears that one of the forms (and possibly others also) is from the Marwood Beds at Sloly quarry, near Barnstaple, which are regarded⁵ as of Upper Devonian age. Prof. Phillips⁶ has stated that plants occur in beds corresponding to the Codden Hill Series at Lew Trenchard and Truscott in the Launceston district, but it is doubtful whether these plant-bearing beds are really the equivalents of the Radiolarian rocks.

¹ 'Brit. Carbonif. Trilobites,' Pal. Soc. 1883-84, p. 64.

² Trans. Devon. Assoc. vol. x. (1878) p. 331.

³ Catalogue Foss. Fishes Brit. Mus. pt. ii. (1891) pp. 403, 490.

⁴ 'Brit. Carb. Trilob.' p. 59.

⁵ T. M. Hall, 'Sketch Geol. Devonsh.' 1878, repr. p. 6.

⁶ 'Pal. Foss. Cornwall, etc.' 1841, p. 195.

1. Spicules of Hexactinellid Sponges
2. *Platodictyum Decheminum*, Kayser
3. *Cleodochonus Micheltini*, M. E. & H.
4. *Petraria* sp., cf. *P. pauciradiata*, Phill.
5. Crinoidal stems = *Cyathocrinus distans*, Phill.
6. *Phillipsia Leei*, H. Woodw.
7. *Phillipsia minor* H. Woodw.
8. *Phillipsia Cliffordi*, H. Woodw.
9. *Phillipsia*, sp.
0. *Griffithides acanthiceps*, H. Woodw.
1. *Griffithides longispinus*, Portl.
2. *Proetus*, sp.
3. *Proetus*, sp.
4. *Discina nitida*, Phill. sp.
5. *Productus plicatus*, Surres
6. *Productus concentricus*, Surres
7. *Productus levipunctatus*, Surres
8. *Chonetes rectispina*, v. Koenen
9. *Chonetes Laguesiana*, de Kon.
0. *Leptæna analoga*, Phill.
1. *Orthisotes crenispira*, Phill. sp.
2. *Spirifer*, sp.
3. *Athyris*, sp.
4. *Goniatites [Prolecanites] microlobus*, Phill.
5. *Goniatites [Prolecanites]*, sp.
6. *Goniatites [Noniomceras] spirorbis*, Phill.
7. *Goniatites [Percyulus]*, sp.

TABLE II.—LIST OF OTHER FOSSILS from the Lower Culm Measures of the S.W. of England NOT KNOWN TO OCCUR IN THE
RADIOLARIAN (CODDEN HILL) BEDS, and THEIR DISTRIBUTION in the Culm and in the Carboniferous Limestone of other localities.

LOWER CULM SERIES.						CARBONIFEROUS LIMESTONE.			
Dark Lime- stones and Shales of Venn, Swimbridge, Bampton, and Freming- ton, N. Devon.	Limestones and Shales of Canons- leigh and Westleigh, N.E. Devon.	Shales of Bampton, N. Devon, and Waddon Barrow, S.E. Devon.	Nodular Shales of Inslow, N. Devon.	Germany, Ayrath, Herborn.	Yorkshire and N. of England.	Scot- land.	Ireland.	Bel- gium.	
<i>Endothyra</i> , sp.	...	*	...	...	...	...	*	*	
<i>Michelinia favosa</i> , Goldf.	...	*	...	...	...	...	*	*	
<i>Zaphrentis cylindrica</i> (?), Seouler ..	...	*	...	...	...	...	*	*	
<i>Philipsia articulosa</i> , H. Woodw.	...	*	...	...	...	...	*	*	
<i>Fenestella</i> , sp.	...	*	...	...	...	...	*	*	
<i>Spirifer</i> , sp.	...	*	...	...	...	...	*	*	
<i>Spirifer Urvi</i> , Fleming ..	...	*	...	...	...	...	*	*	
<i>Orthis Michelinii</i> , Davids.	...	*	...	...	...	...	*	*	
<i>Chonetes deflexa</i> , v. Koenen ..	...	*	...	...	...	...	*	*	
<i>Avicula lepidula</i> , Goldf.	...	*	...	...	...	...	*	*	
<i>Pteronites</i> , sp.	...	*	...	...	...	...	*	*	
<i>Pteronites</i> , sp.	...	*	...	...	...	...	*	*	
<i>Pecten</i> , sp.	...	*	...	...	...	...	*	*	
<i>Posidonomya corrugata</i> , Eth.	...	*	...	...	...	...	*	*	
<i>Posidonomya Becheri</i> , Bronn ..	...	*	...	...	...	...	*	*	
<i>Posidonomya tuberculata</i> , Sow.	...	*	...	...	...	...	*	*	
<i>Posidonomya lateralis</i> , Sow.	...	*	...	...	...	...	*	*	
<i>Goniatites</i> [<i>Glyptioceras</i> <i>sphaericus</i> , Mart.	...	*	...	...	...	...	*	*	
<i>Goniatites</i> [<i>Glyptioceras</i> <i>spiralis</i> , Phill.	...	*	...	...	...	...	*	*	
<i>Goniatites</i> [<i>Glyptioceras</i> <i>arenistria</i> , Phill.	...	*	...	...	...	...	*	*	
<i>Goniatites</i> [<i>Glyptioceras</i> <i>striatus</i> , Sow.	...	*	...	...	...	...	*	*	
<i>Goniatites</i> [<i>Glyptioceras</i> <i>Listeri</i>	...	*	...	...	...	...	*	*	
<i>Orthoceras cylindraceum</i> , Sow.	...	*	...	...	...	...	*	*	
<i>Orthoceras striolatum</i> , Sandb.	...	*	...	...	...	...	*	*	
<i>Catacanthus elegans</i> , Newberry ..	...	*	...	...	...	...	*	*	
<i>Elonchithys Aitkeni</i> , Traquair ..	...	*	...	...	...	...	*	*	

IX. POSITION OF THE RADIOLARIAN (CODDEN HILL) BEDS IN
THE LOWER CULM SERIES.

It has been already mentioned that De la Beche states very distinctly that in North Devon there is no evidence of unconformity between the Devonian and Carboniferous or Culm Measures, but that there is a gradual passage from the shales and slates of the Upper Devonian rocks into black carbonaceous shales and limestones with an abundance of *Posidonomya*. These black beds have been generally regarded as the lowest fossiliferous beds of the Culm Measures, both in North and South Devon and in Cornwall. They contain but few species of fossils; as shown in the List given above, there appear at present to be but 7 species known in them, namely 3 species of *Posidonomya*, including *P. Becheri*, *Goniatites sphaericus*, Mart., *G. crenistria*, Phill., *G. striatus*, Sow., and *Orthoceras cylindraceum*, and none of these forms has as yet been met with in the Radiolarian (Codden Hill) Beds. These dark *Posidonomya*-limestones and shales are shown more particularly near Fremington, and at Venn and Swimbridge, near Barnstaple, also at Bampton in North Devon and near Wooladon, Lifton, etc., in the Launceston district. We think that there is sufficient evidence for the view that these rocks occupy a lower position in the series than the Radiolarian (Codden Hill) Beds. As already mentioned, we have ourselves observed in the Wooladon quarries near Launceston a clear upward succession from the dark limestones and shales containing *Posidonomya* into cherty rocks containing radiolaria, which appear to be the lower beds of the Radiolarian Series. Mr. Ussher, on the other hand,¹ gives no decided opinion as to the order of succession in the Lower or Basement Culm Measures, but while admitting that Phillips might be correct in placing the Codden Hill Beds above the dark shales and limestones, he thinks it best, as the lithological characteristics are not permanent but recurrent on the same or nearly the same horizons, to group the Basement Beds in one series rather than subdivide them.

Probably next in the upward order of succession to the *Posidonomya*-limestones and shales are the bluish-brown and reddish shales of Waddon Barton, near Chudleigh, and adjoining localities in the Bovey Tracey district in South-east Devon; near Bampton in North Devon; and, according to Mr. Ussher,² in some localities south of Launceston. These shales do not seem to be always developed above the dark *Posidonomya*-limestones and shales, and in some localities they appear rather to take the place of the latter. They possess a very distinct fauna, the principal feature of which is the great abundance of *Goniatites spiralis*, Phill., of which some thin layers of the shale are almost entirely composed. The only

¹ Proc. Som. Archæol. & Nat. Hist. Soc. vol. xxxviii. (1892) pp. 120, 121.

² *Ibid.* p. 132.

other cephalopod¹ is *Orthoceras striolatum*, Sandb., a species also occurring in the Lower Culm of Germany. Besides these, there are four species of *Phillipsia*, three of which also pass up into the Codden Hill Radiolarian Beds; three species of brachiopods, one of which is found in the Codden Hill Beds; and several species of lamellibranchs, including *Posidonomya Becheri*, the only form in common with the dark limestones and shales below. The presence of the trilobites shows that these *Goniatites spiralis*-shales are more nearly related to the Radiolarian Beds than to the underlying *Posidonomya*-beds.

As possible equivalents of the dark *Posidonomya*-limestones and shales of Venn, Swimbridge, etc., De la Beche considered² the massive bluish limestones with intercalated cherty beds and associated reddish shales which form the conspicuous ridges of Westleigh, Canonsleigh, and Holcombe Rogus in North-east Devon. They are very different in appearance from the *Posidonomya*-rocks and resemble in general characters the ordinary types of Carboniferous Limestone, so that they might almost be regarded as a local development of this rock, which comes in here between the Devonian and the Culm Measures in much the same way as in the Rhine Province near Düsseldorf referred to by Dr. Kayser.³ In addition to foraminifera and species of corals and brachiopods which also occur in the Carboniferous Limestone, these beds likewise contain two species of cephalopods: *Goniatites mixolobus*, Phill., and *G. spirorbis*, Phill., which are present as well in the Codden Hill Radiolarian Beds, and the cherty portions of the beds also show casts of radiolaria. The only species common to these limestones and the dark *Posidonomya*-beds to the westward are *P. Becheri* and *P. lateralis*, Sow.

The Radiolarian (Codden Hill) Beds are next higher in the series, but their junction with the beds below has been seldom observed. At Wooladon, near Launceston, they rest upon the *Posidonomya*-beds; in other parts of this and the Tavistock district Mr. Ussher⁴ states that below them are beds with *Goniatites spiralis*. At Ramshorn Down the same author⁵ considers that they are at the base of the Culm and even below the *Posidonomya*-beds, but definite junctions are not exposed. Excluding the radiolaria, 25 species have been recognized in these beds, a greater number than in any of the other divisions. Only 7 of these occur in the other divisions of the Culm Series in this country, while 8 are known as well from the Lower Culm of Aprath and Herborn in Germany, and a similar number are likewise present in the Carboniferous Limestone of the British Islands and Belgium. The distinguishing features of the

¹ We have been unable to verify the occurrence in these beds of *Goniatites mixolobus* and *G. sphericus* as stated in 'Mon. Carb. Trilobites,' Pal. Soc. 1883-84, p. 64.

² 'Report Geol. Cornwall, etc.' 1839, p. 105.

³ Jahrb. d. königl. Preuss. geol. Landesanst. f. 1881, p. 52.

⁴ Proc. Som. Archæol. & Nat. Hist. Soc. vol. xxxviii. (1892) p. 129.

⁵ *Ibid.* p. 134.

fauna of this division (excluding the radiolaria) are the number of the species of trilobites, of which 8 have been recognized by Dr. Woodward, and the numerous diminutive brachiopods, mainly of the genera *Productus*, *Chonetes*, and *Orthotetes*. Crinoids also must have been abundant, judging by the number of the casts of the stem-joints. Corals are few in number, and they are markedly small types. The cephalopods include *Goniatites mixolobus*, Phill., *G. spirorbis*, Phill., and two other undetermined species. The Radiolarian Beds are probably continuous round the margin of the Culm Measures, but for the most part only the microscopic organisms are recognizable in them—the larger fossils being known only from some thin shaly layers in the Barnstaple district.

It is only at Beeny Cliff, near Boscastle, and in the section in the town of Tavistock that we have observed the beds above the Radiolarian (Coddan Hill) rocks, and in these localities they pass up conformably into fine dark shales in which no fossils were observed. According to Mr. Ussher,¹ the Coddan Hill Beds of Lifton Wood, near Launceston, are overlain by yellowish-brown conglomeratic beds, those at Ugbrooke Park² and near Oldchard, in the Chudleigh district, by coarse, partially conglomeratic sandstones, and those at Ramshorn Down³ by sandstones and shales with traces of plants. It is hardly probable that the Radiolarian Beds are directly succeeded by beds of coarse clastic materials, and the fact that the Ugbrooke Park conglomerates contain fragments of dark cherty rock similar to the Radiolarian Beds below suggests, as Mr. Ussher remarks, a prior denudation of the lower rocks.

Distinctly higher in the Culm Measures than the Radiolarian Beds are some dark nodular shales near Instow in North Devon. These contain *Goniatites Listeri*, Mart., a fossil which also occurs in the Carboniferous Limestone; and two species of fishes which elsewhere are found in the Millstone Grit and Coal Measures. Mr. T. M. Hall⁴ places these beds on the horizon of the Millstone Grit; but it remains to be determined whether these beds really belong to that horizon.

X. CORRELATION OF THE RADIOLARIAN BEDS.

The rocks most nearly related to the Radiolarian Beds and the associated strata of the Lower Culm Measures in the South-west of England are to be found in the Culm Series of Westphalia, Nassau, and the Harz. In the first-named region, at Aprath, between Elberfeld and Wülfrath, Dr. E. Kayser⁵ states that the Culm beneath the Flötzleerer Sandstein, or Millstone Grit, consists of alum shales, *Posidonia*-shales, kieselschiefer, and limestone, and beneath this latter is the Carboniferous Limestone, at first only slightly developed below the Culm, but gradually increasing in

¹ Proc. Som. Archæol. & Nat. Hist. Soc. vol. xxxviii. (1892) p. 128.

² *Ibid.* p. 140.

³ *Ibid.* pp. 134, 144.

⁴ 'Sketch Geol. Devonsh.' 1878, repr. p. 10.

⁵ Jahrb. d. königl. Preuss. geol. Landesanst. f. 1881, p. 53.

thickness until on the left side of the Rhine near Aix-la-Chapelle it replaces the Culm Beds altogether. Of the 29 species of fossils recorded by Dr. Kayser from the Culm of Aprath, 11 are found in our Culm Series, and 9 of these in the Radiolarian Beds. The correspondence is further shown by the occurrence at Aprath of 5 species of *Phillipsia* which are nearly related to the forms of this genus in the Radiolarian Beds of North Devon. So far as we are aware, no radiolaria have as yet been described from the Kieselschiefer of Aprath.

Dr. Holzapfel states¹ that the Culm Beds at Herborn in Nassau consist of Thonschiefer with *Posidonomya Becheri*, below which is a thin zone of Kieselschiefer resting on diabase, and this in some places is succeeded by black or dark limestones with *P. Becheri*. Holzapfel considers that the *Posidonomya*-shales are in character nearer to the Devonian than to the Carboniferous Limestone, especially in the abundance of cephalopods and the rarity of corals and brachiopods, and that they indicate a deep-water formation. Dr. von Koenen² has described 44 species of fossils from the Herborn Culm, but there are only 7 identical with the English beds.

The Culm Series in the Upper Harz is shown by A. von Groddeck³ to consist of an upper series of conglomerates, shales, and grauwacke, known as the Grunder Grauwanke and the Clausthaler Grauwanke; below these are beds of Thonschiefer with *Posidonomya Becheri* and *Goniatites crenistria*, which rest on basal beds of Kieselschiefer.⁴

From this lowest division of the Culm near Clausthal, Lautenthal, and Lerbach, in the Upper Harz, in beds of adinole, wetzschiefer, and kieselschiefer, or lydite, Dr. Rüst⁵ has described a large number of radiolaria, showing that, like the Culm Radiolarian Beds in this country, these rocks are mainly composed of siliceous organisms. So far as comparison is possible the forms from the Harz mostly belong to the same genera, and probably many are specifically identical with those in the corresponding beds in this country. Dr. Rüst further mentions⁶ that dark carbonaceous beds of kieselschiefer and lydite from the Culm of Hesse, Waldeck, Russia, and Sicily often consist almost entirely of the shells and spines of radiolaria, with occasionally some sponge-spicules.

The Culm Measures farther east in Germany—in Thuringia; between Zwickau and Dresden in Saxony; in Silesia; and in Moravia—consist principally of conglomerates, sandstones, and

¹ Pal. Abhandl. n. s. vol. i. (1889) p. 3.

² Neues Jahrb. für Mineralogie, etc. 1879, pp. 309–346, & pls. vi.–vii. The list is quoted by Dr. Woodward in 'Carb. Trilobites,' Pal. Soc. 1883–84, p. 63.

³ Jahrb. d. königl. Preuss. geol. Landesanst. f. 1882, pp. 44–67. See also Ussher, Proc. Som. Archaeol. & Nat. Hist. Soc. vol. xxxviii. (1892) p. 171.

⁴ Mr. H. M. Cadell states that the Kieselschiefer, which in the Upper Harz rests conformably on the Upper Devonian, is 100 feet in thickness—this includes the Adinole, Wetzschiefer, Grauwanke, and some lenticular limestones. The thickness of the *Posidonomyenschiefer* and Culm Limestone which rests above the Kieselschiefer of the same region is placed at 425 feet. See Proc. Roy. Phys. Soc. Edinb. vol. viii. (1884) p. 216.

⁵ 'Palæontographica,' vol. xxxviii. (1892) pp. 111, 112. ⁶ *Ibid.* p. 122.

shales. They thus present more points of comparison with the Upper than with the Lower Culm of this country. In these regions the siliceous or Kiesel-schiefer beds of the Lower Culm are either not developed or they have been denuded away, since fragments of them are not infrequently found in the conglomerates. At Wildenfels in Saxony,¹ moderately thick limestones occur in the Lower Culm, which contain *Endothyra* and corals common to the Carboniferous Limestone, similarly to the limestones at Canonsleigh, etc., in North Devon.

There are no rocks elsewhere in the British Isles which show any close relationship to the radiolarian cherty and shaly beds of the Lower Culm Measures. Siliceous organic rocks² of considerable thickness do indeed occur in the Yoredale series of the Carboniferous, in Yorkshire, Lancashire, North Wales, and Ireland, and some of them have been compared by Prof. Phillips, with the cherts of Coddan Hill; but microscopic examination shows that they are composed of sponge-remains, and no radiolaria have as yet been recognized in them.

The macroscopic fossils which occur in the Radiolarian (Coddan Hill) Beds are either identical with or closely similar to species found in the Carboniferous Limestone of Yorkshire, Scotland, Ireland, and Belgium; many of them are present in the Lower Culm Beds of Germany, and they indicate that these radiolarian beds represent the Carboniferous Limestones of other portions of the British Isles.

The relationship of the Waddon Barton Beds with trilobites and *Goniatites spiralis*, and the dark *Posidonomya*-shales and limestones of Devon, etc., to the Lower Carboniferous (or Culm) of Westphalia and the Harz was pointed out some years since by Dr. Henry Woodward³; that of the Radiolarian Beds of Coddan Hill to the Kiesel-schiefer with radiolaria of the same districts is of a still closer character.

XI. SUMMARY AND CONCLUSIONS.

The main fact brought out in this paper is the presence of a series of organic siliceous rocks, some of a very hard, cherty character, others platy, and yet others soft, incoherent shales, which are developed in the lower portion of the Culm Measures of Devon, Cornwall, and West Somerset. These rocks can be traced along, and a short distance within, the line of the boundary between the Upper Devonian slates and shales and the conformably succeeding Culm shales from a few miles west of Barnstaple, North Devon, to Ashbrittle, near Wellington in West Somerset, where the Culm Measures disappear beneath the New Red rocks. On the southern margin of the synclinal trough of the Culm Measures the same rocks are shown from near Boscastle, on the coast, up to and beyond

¹ K. Dalmer, *Zeitschr. d. Deutsch. geol. Gesellsch.* vol. xxxvi. (1884) p. 379.

² 'Brit. Pal. Sponges,' *Pal. Soc.* vol. for 1887, pp. 98-103; *Geol. Mag.* 1887, pp. 435-446.

³ 'Brit. Carb. Trilobites,' *Pal. Soc.* 1883-84, p. 63.

Launceston, Cornwall; at Tavistock, and as far south as Painter's Cross, near St. Mellion, Cornwall, where a small outlier is exposed. On the east of Dartmoor they are shown at Ramshorn Down, near Bovey Tracey, also near Chudleigh, and at Bishopsteignton. These rocks, throughout, are characterized by radiolaria, occasionally associated with sponge-spicules. These organisms in some instances are thickly crowded in the beds, in other cases they are sparsely scattered in a siliceous groundmass. Detrital materials are, as a rule, absent in the Radiolarian Beds, but in some instances they occur as microscopically minute fragments of mica and quartz. Dark carbonaceous and ferrous materials, crystals of pyrites, and rhombohedral crystals or negative crystals of carbonate of lime or dolomite are also abundant in these rocks.

The radiolaria occur both in the hard, cherty beds and in the soft, friable shales; they are not well preserved, and are now mostly in the condition of siliceous casts. Forms belonging to 23 genera have been recognized; they are included in the following orders:—Beloidea, Sphæroidea, Prunoidea, and Discoidea. In addition to the radiolaria, a scanty but significant fauna of corals, trilobites, brachiopods, and goniatites is present in some limited thin shaly beds in the Barnstaple district. Nearly all the forms are diminutive; of the 23 species which have been determined, several are only known elsewhere from the Lower Culm of Germany, others are common to the Carboniferous Limestone of the British Isles and Belgium. From the other divisions of the Lower Culm Measures below the radiolarian rocks about 36 species are known, and 8 of these occur in the Radiolarian Beds.

No definite thickness can as yet be assigned to these beds. In common with the other strata of the Lower Culm they have been considerably disturbed, and continuous sections showing their relations to the other beds of the series are rarely shown. That they are of no inconsiderable thickness is proved by sections in quarries where a series of beds from 50 to 190 feet in vertical thickness are exposed.

Radiolarian deposits of a similar character to these fossil-beds are now known only from great oceanic depths, and we are justified in regarding these Culm radiolarian rocks as laid down in the deep water of an open sea at some distance from a shore-line. Such a conclusion must needs very considerably modify the current ideas as to the character and origin of the Culm Measures in the South-west of England, which have been regarded as a continuous series mainly of detrital deposits of shallow-water origin. Thus we find them described in recent text-books as a thick series of well-bedded grits, sandstones, and occasionally thin limestones, which pass down conformably into Upper Devonian strata and contain plants resembling those in the Calceiferous Sandstone Series in Scotland, as well as animal-remains which point to a position low down in the Carboniferous system.

The facts now ascertained as to the real nature of the Lower Culm Measures show that the series of rocks included under the general

term of Culm Measures, instead of being, as at present supposed, an uniform series of shallow-water detrital deposits, really consist of two groups of rocks, which in their nature and origin present the widest possible differences. In the Lower Culm Measures, the basal *Posidonomya*-beds and the Waddon Barton Beds with *Goniatites spiralis* consist of fine shales and occasional thin limestones which may have been formed in a moderately deep sea, but not beyond the reach of the finer sediments brought from the land; and overlying these are the Radiolarian Beds, mainly made up of these organisms, and formed by the gradual accumulation of their remains in a deeper sea too far removed from a land-surface for any but the finest detrital particles to be carried out and mingled with them.

In the Upper Culm Measures, on the other hand, which are of great thickness and extend over the greater part of the Culm area, the beds consist of conglomerates, grits, sandstones, and shales, with occasional thin bands of the Culm itself and plant-remains, which show with sufficient clearness that this Upper Division has been formed under shallow-water conditions.

We are at present quite in the dark as to the nature of the changes which set in after the deposition of the Radiolarian Beds; the conglomerates overlying these latter in certain areas give evidence of an elevation and partial denudation of the Radiolarian Beds at an early period in the history of the Upper Culm Measures.

The additional fossils (excluding radiolaria) which we have found in the Radiolarian Beds tend to confirm the view that these and the Lower *Posidonomya*- and Waddon Barton Beds are the representatives and equivalents of the Carboniferous Limestone in other portions of the British Isles; not, however, in the at present generally understood sense that they are a shallow-water facies of the presumed deeper-water Carboniferous Limestones, but altogether the reverse, that they are the deep-water representatives of the shallower-formed calcareous deposits to the north of them. Regarded in this light, the occurrence of these Lower Culm Measures in Devon and Cornwall, within about 30 miles of the great development of Carboniferous Limestone in the Mendips to the north-west, no longer presents such an anomaly as seemed to be the case when they were believed to be of shallow-water formation. Under this impression as to their character, Mr. A. J. Jukes-Browne¹ considers that they indicate a muddy sea which received the sediments brought down by large rivers draining continental land, which probably existed south-west of these areas, and the shore-line lay not very far south of Devonshire. The picture, however, that we can now draw of this period is that while the massive deposits of the Carboniferous Limestone—formed of the skeletons of calcareous organisms—were in process of growth in the seas to the north, there existed to the south-west a deeper ocean in which siliceous organisms predominated and formed these siliceous radiolarian

¹ 'Building of the British Isles,' 2nd ed. 1892, p. 139.

rocks. These are of much less thickness than the equivalent Carboniferous Limestones, but this may arise from the fact that the siliceous organic deposits are of far slower accumulation than calcareous beds, and they may well have occupied in their formation an interval of time as great as that taken by the formation of the limestones.

It is worthy of note that the deep-sea character of the Lower Culm of Germany, which corresponds with our Lower Culm Measures, had been maintained by Dr. Holzapfel,¹ even before the discovery of radiolaria in the beds of Kieselschiefer furnished such strong evidence in support of this view.

Much field-work has to be done before a satisfactory knowledge of the 'British Culm Measures' can be obtained, and the present paper only professes to be an introduction to the study of the one division of the Radiolarian Beds. The Upper Culm Measures, which in our opinion should include the beds above the Radiolarian rocks (with perhaps the exception of the shales with fishes and goniatites at Instow), have only incidentally been considered, and the question of their relative age can be determined only by their plant-remains. We have, further, not referred to the igneous rocks which in Central Devon and Cornwall are of not infrequent occurrence in the Lower Culm Measures.

POSTSCRIPT.

[Since this paper was read, one of us has examined the Lower Culm area to the north of the granite of Dartmoor, between Bridestow and Drewsteignton, in order to ascertain if the Radiolarian rocks could be also recognized in this district. The rock-exposures are mainly limited to the quarries, now for the most part disused, which have been worked for the Culm limestones. The following is a brief notice of the different exposures, beginning at Bridestow and from thence to the north-east:—

Bridestow.—In the large disused limestone-quarry about half a mile S.W. of the village there are angular masses of chert remaining on the refuse-heaps, and at the S.W. end of the quarry chert is shown in position associated with grey shale. The chert is dark, and traversed throughout with thin quartz-veins; microscopic sections show in it traces of radiolarian casts and also numerous rhombohedral crystals.

Sourton.—In the limestone-quarry about half a mile east of Bridestow village, a clear vertical section of more than 100 yards in length is exposed. The beds at the top consist of chert interbedded with dark siliceous shales; below these are impure limestones and shales, and, near the base of the section, dark limestones and shales. The prevailing dip is N.N.W.; the upper beds are much folded. The chert of the uppermost beds is partly dark and partly of a bluish tint; a microscopic section of the dark variety showed

¹ Palæont. Abhandl. n. s. vol. i. (1889) p. 6; see also 'Text-book of Comp. Geol.' Kayser-Lake, 1893, p. 126.

some bands crowded with radiolaria, with intermediate bands of siliceous shale. The limestone in this quarry is seen in thin section to be largely crystalline, with a few traces of organisms.

At *Sourton Down*, about a mile N.E. of the quarry just mentioned, there are two small quarries of chert on the crest of the hill, and the summit of the hill appears mainly to consist of chert. The beds are much folded and contorted; a thickness of 10–12 feet is shown. The chert is laminated, bluish, weathering grey, and traversed in all directions by fine quartz-veins. Radiolarian casts may be distinguished in it both with a lens and under the microscope.

On the south side of the Higher Collaven railway-bridge, about half a mile east of the Sourton quarry, there are layers of dark chert interbanded with dark and blue flinty rock, probably shale altered by contact with igneous rock (greenstone?) which here comes in. Microscopic sections of the chert show numerous radiolarian casts, which are infilled with cryptocrystalline silica.

Okehampton.—In the railway-cutting on the eastern side of the Meldon¹ viaduct of the L. & S.W. Railway, between two and three miles from Okehampton, a section, about 25 feet in height, of beds dipping N.N.W. is exposed. The rock is principally a black, compact chert, associated with dark, indurated shales. The chert contains radiolaria.

In the railway-cutting about one mile west of the Meldon viaduct, banded dark- and light-bluish flinty rocks, resembling porcellanized shale, are exposed near the band of igneous rock, in the same manner as at the Higher Collaven bridge. Mr. Ussher² has noticed these beds as belonging to the Basement Culm series. It may be mentioned that the dark chert is used for ballast on the railway in this district, and the radiolaria in it can be readily distinguished with a lens.

At the quarry by the public road at the south-western end of Okehampton, beds of limestone alternating with shales are shown, which dip N.N.W. at an angle of 55°. About 300 yards north of this quarry, on the western side of Church Hill, there are thick beds of black chert and shale; the chert has numerous quartz-veins; no radiolaria can be seen in it.

About 4 miles east of Okehampton are the extensive Lower Culm Limestone quarries of *South Tawton*. In the lower part of the quarry at present worked, about 60 feet of dark limestone with shales are exposed. The succession is best seen at the disused quarry, now full of water, nearest the village, where the limestone is seen to be overlain by dark carbonaceous shales, succeeded by pale-grey and buff soft shales, and at the summit by beds of chert and shale which form conspicuous prominences. The chert is compact, bluish, and thickly traversed by veins of quartz; in a microscopic section numerous casts of radiolaria are shown.

Drewsteignton.—At the large limestone-quarries close to this village, a section of about 80 feet in thickness is at present exposed.

¹ 'Elmdon' on the 1-inch Geol. Surv. map.

² Proc. Som. Archæol. & Nat. Hist. Soc. vol. xxxviii. (1892) p. 136.

The beds are mainly of limestone and shales in the lower portion of the quarry; above these, beds of cherty rock several feet in thickness are interbedded with limestone. A microscopic section of the chert showed radiolarian casts in places. According to the late Mr. G. W. Ormerod,¹ *Posidonomya* occurs in one of the lower beds of limestone in this quarry.

Judging by the above-mentioned sections, there seems good reason to suppose that the Radiolarian chert is present along the northern margin of Dartmoor in the same relative position above the *Posidonomya*-limestones and shales as in the other districts described in the present paper. More particularly there is a very close resemblance, both in the character of the chert and its relation to the associated limestones, to the beds exposed at the Wooladon quarry near Launceston (see p. 623).—July 22nd, 1895.]

EXPLANATION OF PLATES XXIII.-XXVIII.

PLATE XXIII.

Geological Sketch-map of Devon, West Somerset, and Cornwall, on the scale of 10 miles to the inch.

PLATE XXIV.

Section of the Radiolarian (Codden Hill) Beds of the Lower Culm Measures at Carzantie Quarry, near Launceston. From a photograph taken in March, 1895.

PLATE XXV.

The specimens figured in the following three Plates are all from the Radiolarian Beds of the Lower Culm Measures.

- Figs. 1 a-1 g. *Sphærozoum*, sp. Detached spicules of various forms. From the Lower Culm Radiolarian rocks at Swiubridge, Heddon, and Kent's Hill, North Devon; Carzantie, near Launceston; Ramshorn Down; Winstow Lodge, near Chudleigh. ×200 diameters.
- Fig. 2. *Cenosphæra pachyderma*, Rüst. Ramshorn Down, near Bovey Tracey, South-east Devon. ×200.
3. *Cenosphæra*, sp. a. From near Ashbrittle, Wellington, West Somerset. ×200.
 4. *Carposphæra*, sp. a. Ramshorn Down, South quarry. ×200.
 5. *Carposphæra*, sp. b. Artiscombe quarry, near Tavistock. ×200.
 6. *Carposphæra*, sp. c. From a boulder of radiolarian chert at Tavistock. ×200.
 7. *Carposphæra*, sp. d. Ramshorn Down, South quarry. ×200.
 8. *Thecosphæra*, sp. a. From hedge-section, Lawell House, Chudleigh. ×200.
 9. *Xiphosphæra*, sp. a. Ramshorn Down, North quarry. ×200.
 10. *Xiphosphæra*, sp. b. Ramshorn Down, North quarry. ×200.
 11. *Xiphostylus*, sp. a. Ramshorn Down. ×200.
 12. *Xiphostylus*, sp. b. Showing traces of the lattice-structure, Ramshorn Down. ×200.
 13. *Xiphostylus*?, sp. c. Ramshorn Down. ×200.
 14. *Staurolonche*?, sp. a. Hedge-section, Lawell House, near Chudleigh. ×200.
 15. *Stylosphæra*, sp. a. Ramshorn Down. ×200.
 16. *Cenellipsis*, sp. d. Ramshorn Down. ×200.
 17. *Druppula*, sp. a. Ramshorn Down. ×200.

¹ Trans. Devon. Assoc. vol. ii. (1867-68) p. 124.

PLATE XXVI.

- Fig. 1. *Cenellipsis*, sp. a. Carzantic Quarry, near Launceston. $\times 200$.
 2. *Cenellipsis*, sp. b. Codden Hill Quarry, near Barnstaple. $\times 200$.
 3. *Theodiscus aculeatus*, sp. nov. Ramshorn Down, near Bovey Tracey. $\times 100$.
 4. *Lithocyelia devoniensis*, sp. nov. Ramshorn Down. $\times 200$.
 5. *Dorysphaera*, sp. b. Ashbrittle, near Wellington, West Somerset. $\times 100$.
 6. *Acanthosphaera laxa*, sp. nov. Ramshorn Down. $\times 100$.
 7. *Druppula*, sp. b. Carzantic Quarry, near Launceston. $\times 200$.
 8. *Cenellipsis*, sp. b. Codden Hill Quarry. $\times 200$.
 9. *Dorysphaera*, sp. a. Ramshorn Down. $\times 100$.
 10. *Elvipsoziphus*, sp. a. Tregear Down, near Launceston. $\times 100$.
 11. *Trigonocyelia*, sp. a. Ramshorn Down. $\times 100$.
 12. *Trigonocyelia*, sp. b. Ramshorn Down. $\times 100$.
 13. *Sethodiscus chudleighensis*, sp. nov. Hedge-section, Lawell House, Chudleigh. $\times 200$.

PLATE XXVII.

- Fig. 1. *Porodiscus percinctus*, sp. nov. Ramshorn Down. $\times 200$.
 Figs. 2, 3. *Porodiscus brevis*, sp. nov. Hedge-section, Lawell House, Chudleigh. $\times 200$.
 Fig. 4. *Porodiscus clathratus*, sp. nov. Ramshorn Down. $\times 200$.
 5. *Amphibrachium*, sp. b. Carzantic Quarry, near Launceston. $\times 100$.
 6. *Rhopalastrum ingens*, sp. nov. Ramshorn Down. $\times 75$.
 7. *Amphibrachium*, sp. a. Carzantic Quarry, near Launceston. $\times 100$.
 8. *Rhopalastrum*, sp. a. Ramshorn Down. $\times 75$.
 9. *Rhopalastrum clavatum*, sp. nov. Ramshorn Down. $\times 75$.
 10. *Porodiscus lens*, sp. nov. Hedge section, Lawell House, Chudleigh. $\times 200$.
 11. *Porodiscus percinctus*, sp. nov. Ramshorn Down. $\times 200$.
 12. *Porodiscus clathratus*, sp. nov. Ramshorn Down. $\times 200$.
 13. *Porodiscus*, sp. a. Ramshorn Down. $\times 200$.
 14. *Stichocapsa*, sp. a. Ramshorn Down. $\times 200$.
 15. *Lithocampe*, sp. a. Ramshorn Down. $\times 200$.
 16. *Lithostrobus*, sp. a. Heddon Quarry, near Barnstaple. $\times 200$.
 17. *Sethocapsa*, sp. a. Carzantic Quarry, near Launceston. $\times 100$.

PLATE XXVIII.

The specimens figured in this Plate are all from the Radiolarian Beds of the Lower Culm Measures in North Devon.

- Figs. 1, 1 a. *Phillipsia Leei*, H. Woodw. Glabella, enlarged 4 diameters, and detached cheek, enlarged 2 diameters. From Hannaford Quarry, near Barnstaple.
 Fig. 2. *Phillipsia minor*, H. Woodw. Pygidium, enlarged 3 diameters. Hannaford Quarry.
 3. *Phillipsia Cliffordi*, H. Woodw. A small imperfect specimen showing the head and tail. Enlarged 4 diameters. Combe Wood Quarry, Codden Hill, near Barnstaple.
 3 a. *Phillipsia Cliffordi*, H. Woodw. A pygidium, enlarged 3 diameters. Hannaford Quarry, near Barnstaple.
 4. *Phillipsia*, sp. Larval form. Enlarged 4 diameters. Hannaford Quarry.
 Figs. 5, 5 a. *Griffithides acanthiceps*, H. Woodw. Detached free cheek, natural size. The eye of the same, enlarged 7 diameters. Hannaford Quarry. Collected by Mr. G. F. Tregelles.
 Fig. 6. *Griffithides longispinus*, Portlock. Natural size. Codden Hill Quarry, near Barnstaple. Collected by Mr. J. G. Hamling, F.G.S.
 Figs. 7, 7 a. *Proetus*, sp. a. Body-segments and pygidium, enlarged 4 diameters; and detached pygidium, enlarged 3 diameters. Codden Hill Quarry, near Barnstaple. Coll. Mr. J. G. Hamling.

- Fig. 8. *Proetus*, sp. *b*. An imperfect specimen, enlarged 3 diameters. Combe Wood Quarry, near Barnstaple.
- Figs. 9, 9 *a*. *Productus concentricus*, Sarres. Cast of the ventral valve. Natural size, and enlarged 2 diameters. Hannaford Quarry.
- Fig. 9 *b*. *Productus concentricus*, Sarres. A specially wide form. Natural size. Hannaford Quarry.
- Figs. 10, 10 *a*. *Productus plicatus*, Sarres. Cast showing traces of spines. Natural size, and enlarged 2 diameters. Hannaford Quarry.
- Fig. 10 *b*. *Productus plicatus*, Sarres. Cast of the ventral valve, enlarged 2 diameters. Hannaford Quarry.
- Figs. 11, 11 *a*. *Productus*, cf. *levipunctatus*, Sarres. Internal cast of the ventral valve. Natural size, and enlarged 2 diameters. Hannaford Quarry.
- Figs. 12, 12 *a*. *Chonetes rectispina*, von Koenen. Natural size, and enlarged 2 diameters. Hannaford Quarry.
- Fig. 12 *b*. *Chonetes rectispina*, von Koenen. Cast of the dorsal valve, enlarged 2 diameters. Hannaford Quarry.
- Figs. 13, 13 *a*. *Chonetes Laguessiana*, de Koninck. Cast of the ventral valve. Natural size, and enlarged 2 diameters. Hannaford Quarry.
- 14, 14 *a*. *Leptæna anuloja*, Phill. Cast of valve. Natural size, and enlarged 2 diameters. Hannaford Quarry.
- 15, 15 *a*. *Orthis tetes crenistria*, Phill., sp. Cast of the brachial valve. Natural size, and enlarged 2 diameters. Hannaford Quarry.
- 16, 16 *a*. *Spirifer*, sp. Internal casts of the dorsal or brachial valve. Natural size. Hannaford Quarry.
- 17, 17 *a*. *Athyris*, sp. Casts of the interior and exterior of the ventral valve. Natural size. Hannaford Quarry.
- Fig. 18. *Pleurodictyum Dechenianum*, Kayser. Cast of a small specimen. Natural size. Hannaford Quarry.
- 18 *a*. The same. Cast of the basal portion of a larger specimen, showing the arrangement of the corallites. Natural size. Hannaford Quarry.
- 18 *b*. The same. Some of the corallites, enlarged 3 diameters, showing the disposition of the connecting pores.
- Figs. 19, 19 *a*. *Cladochonus Michelinii*, M.-Edw. & Haime. Cast of a single corallite and pedicel, showing vertical rows of pores in the calice. Natural size, and enlarged 3 diameters. Hannaford Quarry.
- Fig. 20. *Petraia*, sp. Cast of the interior of the calice. Natural size. Hannaford Quarry.
- 20 *a*. The same. The base of the cast, showing the disposition of the septa and the rows of minute pores on either side of them. Enlarged 3 diameters.

DISCUSSION

The CHAIRMAN (Mr. W. H. HUDLESTON) remarked that such a paper as this proved that the subject of British geology was by no means exhausted. Notwithstanding the attention which had been paid to the several members of the Carboniferous system in Devonshire, the existence of a thick series, mainly of organic origin, on the horizon of the 'Codden Hill Grits' had hitherto been unsuspected. The correlation of these with the Millstone Grit had long ago been considered doubtful by him, but it had the sanction of authority. Besides the palæontological importance of a discovery like this, such a well-marked horizon might be useful in determining boundary-lines in areas where the Carboniferous and Devonian were much mixed up, as in the Tavistock district.

The Rev. G. F. WHIDBORNE said that he had listened to the paper with interest, as he had visited the Codden Hill quarries last summer with Mr. J. G. Hamling, and had collected a number of fossils from

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them. The new facts brought to light by the Authors had an important bearing upon the succession in some Devonian areas which he was now examining.

Mr. J. G. HAMLING expressed his pleasure at being present on the occasion of the reading of this interesting paper—especially interesting to him, living as he did at the foot of Coddan Hill. He entirely agreed with the conclusions arrived at by the Authors, and consequently had no criticism to offer. He might mention that he had himself traced the Radiolarian Beds from Dulverton to Fremington.

Dr. HICKS said that he had visited the quarries near Dulverton last year with Mr. Whidborne, chiefly to notice the gradual change in the deposits in ascending from the Pilton Beds. They subsequently visited South Pembrokeshire for the purpose of comparing the sections there with those in North Devon. There they found more calcareous matter, but also chert-bands, and the succession seemed to show a gradual passage from the Old Red to the Lower Culm Measures. They made a large collection of fossils from these rocks in Pembrokeshire, and they hoped ere long to bring the results before the Society. The paper by the Authors was, in Dr. Hicks's opinion, a most important one in its bearing on the succession in North Devon.

Mr. J. H. COLLINS congratulated the Authors on their very important discoveries, and had little doubt as to the justice of their conclusions, although he had no very intimate knowledge of the Culm Measures, his own work having been mostly among the much older rocks of the centre and west of Cornwall.

Sir HENRY HOWORTH also spoke; and Dr. G. J. HINDE replied, thanking the Fellows for the reception accorded to his and Mr. Fox's paper.

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Section of the Radiolarian (Cudden Hill) Beds of the Lower Culm Measures, at Carzantic Quarry, near Launceston, Cornwall.

(From a photograph taken in March 1895.)

A.T. Hollick del. et lith.

Mintern Bros. imp.

RADIOLARIA FROM THE LOWER CULM MEASURES.

A. T. Hollick del. et lith.

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RADIOLARIA FROM THE LOWER CULM MEASURES.

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RADIOLARIA FROM THE LOWER CULM MEASURES.

A.T. Hollick del. et lith.

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TRILOBITES, BRACHIOPODS AND CORALS FROM THE
RADIOLARIAN BEDS OF THE LOWER CULM MEASURES.