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ORIGINAL ARTICLES.

I.—STUDIES IN EDRIOASTEROIDEA. VI. *PYRGOCYSTIS* N.G.

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(Concluded from the January Number, p. 12.)

C. *PYRGOCYSTIS ANSTICEI* n.sp. and others. (Plate III,
Figs. 3–15.)

Previous History.—In 1892 Professor Carl W. S. Aurivillius published his well-known paper “Ueber einige ober-silurische Cirripeden aus Gotland” (Bihang Svenska Vet.-Akad. Handl. Bd 18, Afd. IV, No. 3). Besides the remarkable specimen from the Ludlovian *Pterygotus* bed of Wisby, to which he gave the name *Pollicipes signatus*, and a supposed fragment of a scutum, which he called *P. validus*, Professor Aurivillius described a number of “kurze, mehr oder weniger cylindrische, mit Schuppen bedeckte Bildungen”, which he regarded as the peduncles of a cirripede and referred provisionally, in the absence of any trace of a capitulum, to *Scalpellum*. Though all the specimens (except possibly of *S. cylindricum*) came from a single stratum, bed *c* of Lindström, probably contemporaneous with our Wenlock Shale, and though the majority were found in a single locality, Djupvik in Eksta, still Professor Aurivillius considered that he could with certainty distinguish the following seven species:—

<i>S. sulcatum</i> ,	p. 13, fig. 11,	Bed <i>c</i> ,	Djupvik,	abundant.
<i>S. varium</i> ,	p. 15, figs. 12–14,	“	“	1 specimen.
<i>S. granulatam</i> ,	p. 16, figs. 20–22,	“	“	3 “
<i>S.</i> “ ?	p. 17,	“	Wisby,	some “
<i>S. strobiloides</i> ,	p. 17, figs. 17–19,	“	Mulde,	1 “
<i>S. procerum</i> ,	p. 18, fig. 15,	“	Wisby,	? “
<i>S.</i> “	“	“	Djupvik,	? “
<i>S. fragile</i> ,	p. 19, fig. 10,	“	{ Djupvik, }	3 “
<i>S. cylindricum</i> ,	p. 18, fig. 16,	(horizon not stated),	Wisby,	1 “

In 1906 Colonel [now] Sir J. Arthur Anstice, K.C.B., a son of the Mr. John Anstice of Madeley whose collection was mentioned by Murchison and Prestwich, presented to the British Museum various fossils from the Coalbrookdale district; and among them were 14 specimens of the same character as those described by Aurivillius, and like them coming from the Wenlock Shale. Consequently they were at first placed provisionally among the Cirripedia. When, however, Professor Moberg’s recent memoir (1914) led us to look through our Palæozoic cirripedes, Mr. T. H. Withers directed my attention to these fossils. Immediately close examination under the lens revealed

at the broken edges of the plates the clean crystalline cleavage distinctive of calcite and of echinoderm stereom, but not found in fossil remains of Arthropoda. Their echinoderm nature once recognised, it is further clear that all these fossils represent the stems or turrets of species resembling those from Minnesota and Girvan so far as that portion of the anatomy is concerned, and probably resembling them in the structure of the oral face. It is interesting to note that among the Gotland fossils referred by Aurivillius to *Scalpellum sulcatum*, is one which Hisinger had previously figured as "*Columnæ Crinoidis fragmentum*" (1841, *Lethæa Suecica*, Supplementi Secundi Continuatio, pl. xli, fig. 6). This reference by Hisinger, which, bearing in mind the former extended connotation of the name Crinoidea, now proves perfectly correct, seems to have aroused no suspicions in the mind of Aurivillius. On the contrary, he was quite certain that these fossils represented the stems of some genus of Lepadidæ, and, despite the great extension of geological range involved and the absence of congeners earlier than Cretaceous, he scarcely hesitated to refer them to the characteristically recent genus *Scalpellum*.

Students of early Palæozoic fossils know how often it has proved difficult to decide whether isolated plates, or associated fragments, or even whole skeletons, belonged to the Echinoderma or to the Arthropoda; but the criterion of stereom-structure, when it can be applied, ought to prove decisive. Apart from that, in the present instance, Aurivillius himself notes that in the peduncles of Recent Cirripedia the scales are embedded in a thick [uncalcified] chitin, or are only fastened by the base. In other words, the peduncle-valves of the cirripedes are never so closely set or so deeply imbricate as are the plates in these Silurian fossils; and the consequence of this is that up to the present, as Mr. Withers assures me, only two specimens are known in which a scalpelliform peduncle has been preserved in the fossil state with its valves in place,¹ and not a single one has been found apart from its capitulum. What a contrast is provided by the fossils before us, of which over a score have been picked up on a single beach in Gotland and fourteen in one Shropshire lane!

But apart from these fairly obvious considerations, which would have made an ordinary palæontologist hesitate, the general shape of the individual plates might well have raised a doubt in the mind of so high an authority on the recent Crustacea as Professor Aurivillius. The peduncular valves of cirripedes always show growth-lines over the whole outer surface, and definite facets where they abut or overlap; they are clear-cut structures, and in *Scalpellum* at any rate the earlier the species the more characteristic is the shape of the plate. But the plates of these Wenlockian fossils show at the most some minute irregular granules or rugæ, and have no distinct ridges or facets; they are quite unlike any cirripede plates of either Silurian or Recent times.

¹ *Scillelepas carinata* (Phil.), Miocene, Sicily: Seguenza, 1876, *Atti Accad. Pontaniana*, vol. x, pl. viii, fig. 14; and *Pollicipes concinnus* Morris, Oxford Clay, England: Darwin, 1851, *Pal. Soc. Monogr. Foss. Lepadidæ*, p. 50, pl. iii, fig. 1.

Material.—The fourteen specimens presented to the British Museum by Sir Arthur Anstice are registered E 16233 to E 16246, but may for convenience of reference be denoted by the letters *a* to *n*. They are all turrets in various degrees of preservation. Specimen *c* [E 16235] is taken as holotype.

Horizon and Locality.—All are from the Wenlock Shale of Jig House Bank, or, in the local vernacular, "Jiggers Bank." This, says Sir A. Anstice *in litt.*, "is a road that runs from Coalbrookdale up the right hand side of a steep dingle called Lloyd Brook dingle (the main road from Coalbrookdale to Wellington runs up this hill) . . . the road runs up the side of a steep bank, and there is a place called the Loam or Lum hole in the lower part of the dingle."

Detailed Description.—These fossils closely resemble the "*Scalpellum sulcatum*" of Aurivillius, with whose description the following may be compared.

The Turret is slightly curved and increases gradually in diameter from below upwards, frequently expanding rather suddenly at its adoral end, where the plates appear more closely packed.

The plates are arranged in eight columns, which may (as in *c*, Pl. III, Fig. 4) be quite distinct with grooves between, but which may be partly merged so that it is hard to say whether the number is 7 or 8 (e.g. *a*, *b*, *f*, *k*; Pl. III, Fig. 3), or may be clearly not more than 7 (e.g. *d*, *e*; Pl. III, Fig. 5). The vertical seriation is most plain in the middle half of the turret; towards the adoral end there is nearly always an irregularity connected with the expansion of the turret, which is usually more on one side and affects the packing of the plates; towards the lower end, as the turret contracts, the columns inosculate and become reduced in number, so that there may be only 4 or 5 at the base, increasing to 7 or 8 above (e.g. *l*, *m*; Pl. III, Figs. 6, 10). When the irregularity of the upper expansion has come in before the increasing plates of the lower end have taken their positions in definite columns, then the arrangement appears quite irregular (e.g. *j*). In those regions of the turret, or in those individuals, in which the complete arrangement in eight distinct columns has not been attained, the inosculature of the plates frequently appears on the surface as a column of smaller plates between two columns of larger ones; one result is the absence of a groove between the columns and a more even rounding of the surface, as described by Aurivillius for his *S. varium* and *S. strobiloides*.

The shape of the visible portion of each plate varies with the extent to which it is exposed, and with the greater or less distinctness of the columns. The shape of the whole plate is given in Pl. III, Figs. 14, 15; and the only variation of this seems to be in the greater or less relative width, producing a more obtuse or more acute angle. The sides of the upper half of the plate form a somewhat parabolic curve, the whole of which may be exposed; but however little be exposed it can never be likened to the segment of a circle. In the lower half of the plate the sides become more straight and vertical, or even converge slightly. Of course it is only at the distal end of the turret that the plates are ever fully exposed, and it is probable that the

relative height is greater there. The measurements of such plates in millimetres are :—

	<i>a</i>	<i>c</i>	<i>e</i>	<i>j</i>
Height	2.9	1.8	2.75	2.7
Greatest width	2.0	1.6	1.8	1.6
Depth of portion exposed	.6	.4 or less	.5	.2 in column, 1.5 when alternating.

Thus the ratio of width to height varies from .88 to .59 in different individuals, when plates of the same character are compared.

The number of plates in a column is 21 in *a* with a total height of 8.2 mm., 18 in *c* with a total height of 7 mm., about 16 in *e* where the portion preserved has a height of 5.6 mm., about 23 in *g*, with an approximate height of 8 mm. These numbers seem to imply that the plates are closer than in *S. sulcatum*, according to the measurement given by Aurivillius, who says 20 plates in 10 mm. But that measurement does not seem to take into account the more crowded plates at the two ends. His figure 11 suggests that there were in that specimen 27 plates in a height of about 10 mm. Probably there was no difference in this respect between individuals of the two species with clearly marked columns.

The amount of overlap is gauged by the proportion of depth of a plate exposed, and this in vertical series is somewhere about one-fifth. Aurivillius says of *S. sulcatum* "eine Schuppe nur die Hälfte oder oft nur $\frac{1}{3}$ der nächststehenden freilässt", but later on he gives the actual measurements for the middle region of the turret as .5 in a length of 2.5 mm., i.e. one-fifth.

As regards the mutual relations of the plates in a tier, Aurivillius says: "Was die Anordnung in die Quere betrifft, stehen die Schuppen jeder zweiten Reihe auf derselben Höhe." If we letter the plates in a tier *a* to *h*, reading from right to left, then this sentence conveys the impression that the arrangement is as follows—

h g f e d c b a

It will be observed that a repetition of this order in successive tiers would produce a line of the same letters ascending in spiral from right to left, *a* overlapping *b*, *b* overlapping *c*, and so on—

and a similar line descending from right to left, *b* overlapping *a*, and so on. This spiral arrangement is not conspicuous when the plates overlap closely, as in Aurivillius' fig. 11, and in those of our specimens that have clear vertical columns; but it is very plain when the overlap is less, though the alternation remains regular, as in Aurivillius' figs. 12, 15, 16, assigned by him to other species.

The slope of the plates towards the axis of the turret appears to be much as represented in Aurivillius' fig. 13, i.e. nearer the vertical below, and nearer the horizontal above.

In *c* the lumen at the lower end has diameters of 1.4 and 1.1 mm. The diameter of the turret at the top of the first tier of plates is 3.2 and 2.9 mm. (Pl. III, Fig. 8). This is the only specimen that shows a definite lumen at the distal end. In other cases the lumen is filled with plates (Pl. III, Fig. 7), or with plates and secondary calcite (Pl. III, Fig. 9), or it may be quite covered over with plates in a more horizontal position. Grinding down *n* at the distal end displays a section with diameters about 1.3 mm. and 2.9 mm. Aurivillius gives for *S. sulcatum* a lumen-diameter of barely 1 mm. and a turret-diameter [? same specimen and level] 3.5 mm. This indicates a relatively smaller lumen, but he says that the width increases towards the imagined capitulum. The section which he figures of *S. varium* (fig. 13) represents a different set of proportions; here the lumen does not increase upwards, but the contrary if anything, and at its lower end it is more than half the diameter of the turret, at its upper end a little less than one-third. In *S. strobiloides* the diameter of the lumen is said to be three times that of the wall; i.e. three-fifths the diameter of the turret. It is very doubtful whether the width of the lumen increased upwards in our Shropshire species; in the fossils at any rate it is filled with the more horizontally disposed and crowded plates, whose position cannot entirely be due to post-mortem shifting (Pl. III, Figs. 11, 12, 13).

The plates, when well preserved, are covered externally with fine anastomosing rugæ, showing a tendency to radiate towards the curved margins. Since these are developed equally on the exposed and unexposed portions of the plate, they must be regarded not as superficial ornament, but as an expression of stereom structure.

The plates are frequently broken on their free margins, so that either the tops are truncate or great pieces are, as it were, bitten out leaving jagged points conforming to the lines of crystalline cleavage (Pl. III, Fig. 3). This frequently gives the turret sides quite a peculiar appearance, as though they belonged to an entirely distinct species. The tops of the plates seem to be broken in the specimen of *S. strobiloides* shown in Aurivillius' fig. 17, which reminds one of the appearances in the Minnesota fossils.

There is no trace of any spines or spinules. But in *b* at the distal end, which is rounded, the ordinary large turret-plates seem to be covered by a number of very small plates the meaning of which is obscure.

Not a single specimen shows any trace of the oral face.

Measurements in millimetres are as follows:—

	<i>a</i>	<i>c</i>	<i>g</i>	<i>h</i>
Greatest length of turret	8.2	7	8.1	5.3
Diameter at adoral end .	4.0 × 4.4	4.9	5.1 × 5.7	2.2 × 3.5
Diameter at distal end .	ca. 3.0	3.2	ca. 3.6	1.5 × 2.8

Distinctions between the Wenlockian Species.—In spite of the variation as regards number and distinctness of vertical columns, there are good reasons for regarding all the Coalbrookdale specimens as belonging to a single species. First, the variations themselves merge into one another, and do so in such a way as to suggest that they represent stages of development, from fewer to more columns, and from alternation to seriation of plates. Secondly, there is little or no variation in the shape of the individual plates and in the nature of their ornament; and it is by characters such as these, little influenced by the cruder forces of the environment, that genetic differences are usually distinguished.

If now we apply the conclusions drawn from these Shropshire fossils to their contemporaries from Gotland, we find that the differences relied on by Aurivillius to distinguish his species are for the most part those which appear to us as simple growth-variations. So far as figures and descriptions allow one to judge, there seems no good reason why *S. sulcatum*, *S. varium*, and *S. fragile* should not all belong to a single species, for which the name *Pyrgocystis sulcata* would most naturally be adopted. *S. strobiloides*, represented only by the sole fragment found at Mulde, is probably no more than a slight variation, owing much of its different appearance to difference of preservation. *S. granulatum* seems to be distinguished by the nature of its ornament, but this again may only be due to better preservation; we have seen in *P. ansticei* that no weight can be attached to the difference in the direction of the plates at the distal end. Of the two long, cylindrical forms, *S. cylindricum*, known only from a single specimen, has plates of more pointed shape, and, since its horizon is possibly different, it may perhaps be left in its independence. The other, *S. procerum*, may also be distinct, but is more likely to consist merely of elongate individuals of *S. sulcatum*. It must be borne in mind that none of these specimens is really complete.

So much for the supposed differences between these Gotland forms. On the other hand, all, with the sole exception of the unique *S. cylindricum*, have plates of the same shape, namely, with the visible portion forming, in the words of Aurivillius, a segment of a circle. This fact, while confirming the view that they represent but a single species, sufficiently distinguishes them from the Shropshire specimens, in which the outline is consistently parabolic.

In the absence of any evidence to the contrary, such as might conceivably have been furnished by the oral face, these Wenlockian species must be referred to the genus *Pyrgocystis*.

The Relationships of Pyrgocystis.—It is clear that *Pyrgocystis* is an Edrioasteroid, but it is not clear whether it is to be referred to the Agelacrinidæ or the Edrioasteridæ. We need not consider either the Cyathocystidæ or the Steganoblastidæ in this connection.

According to the definitions given by me in 1899 and 1900 ("Treatise on Zoology," pp. 207–208), it would go more readily with the Agelacriniæ; but in those definitions the differences in the subvective skeleton were not sufficiently taken into account.

In Studies I, II, IV, and V, the subvective skeleton of four Edrioasterid genera has been described in detail, and shown to consist of floor-plates and cover-plates, both disposed in alternating series, with pores between the floor-plates.

The evidence adduced by C. F. Roemer (1851), F. B. Meek (1873), Miller & Faber (1892), O. Jaekel (1899), J. M. Clarke (1901), and W. K. Spencer (1904) proves that in *Agelacrinus* (sensu lato) and *Hemicystis* among Agelacriniæ, the subvective skeleton likewise consists of floor-plates and cover-plates, but that the floor-plates form a single series stretching right across the groove, and show no trace of pores. There is also a difference in the cover-plates, for normally in these two genera, as also in *Cystaster* and *Streptaster*, they are boot-shaped, with the sole of the boot adoral (= proximal) and the toe of the boot admedian, and in consequence of this shape they cannot close in the groove so completely as do the symmetrical cover-plates of the Edrioasteridæ. In some species of *Agelacrinus*, as shown in J. Hall's well-known figure of *A. cincinnatiensis* (1871), there are small additional cover-plates along the median line, much as may occur exceptionally in *Edrioaster* (Study IV, text-fig. 2). These additional plates, however, involve no departure from the essential plan of either group.

These two plans do not, I believe, exhaust the actual constructions employed in the Edrioasteroidea. Setting aside *Cyathocystis* and *Stromatocystis*, in which the structure is still not fully known, we may note *Lebetodiscus* (Study III), in which the cover-plates appear to be minute and to lie over the sutures between the floor-plates. The specimen figured by Jaekel (1899, *Stammesges. d. Pelmatoz.*, pl. ii, fig. 2) as *Agelacrinus Dicksoni* Billings, presents notches along the sides of its supposed cover-plates, and in other specimens I have observed these notches to be very distinct and regular: so that in such forms, it has seemed to me, there may have been minute cover-plates resting in the notches, and the larger visible plates may really be floor-plates.

The specimens of *Pyrgocystis*, so far as one can judge from the obscure evidence, do not display either cover-plates or floor-plates of the typical Edrioasterid or Agelacriniid plan. It is, however, conceivable that the plates observed correspond to the notched plates of the third plan of structure. Appearances that may possibly represent notches have been mentioned in the description of *P. grayæ*, and indications that the plates may perhaps not be cover-plates have been given in the description of *P. sardesoni*.

Those species which seem to me to have this supposed third plan of subvective structure, appear in all other points more closely allied to the Agelacriniæ than to the Edrioasteridæ. In those same points it is with the Agelacriniæ that *Pyrgocystis* also agrees. Therefore this genus may for the present be left in that Family. Although *Steganoblastus* is the genus of Edrioasteroidea that has the

most pronounced stem, and that manifests in its thecal structure the most pronounced reaction to such a mode of fixation, still it differs greatly from *Pyrgocystis* in the crinoid-like nature of that stem, in the solidity of the theca, and in the Edrioasterid character of the subvective skeleton. *Cyathocystis* again, especially in its more elongate individuals, presents a subvective system of straight grooves mounted on a turret of much the same proportions as in *P. sardesoni*. But the turret in *Cyathocystis* is a solid tube, and the structure of the whole oral face is totally different.

Among the Agelacriniæ are some genera that approach *Pyrgocystis*. *Cystaster granulatus* as defined by J. Hall (October, 1871), from which Jaekel has attempted to separate some specimens as *Thecocystis sacculus* (1899), has straight rays surmounting an elevated sac-like body composed of minute plates or granules. In *Hemicystis* also the rays are straight, and Hall (October, 1871) specially mentions that *H. parasitica* and *H. stellata* have "the sides more abruptly elevated than the ordinary forms of *Agelacrinus*". The theca in *Hemicystis* is composed of minute squamiform plates. *Agelacrinus pileus* is said by Hall to have a "globular bell-shaped" theca when well preserved, and he figures a specimen in which many of the interradian plates "have a rounded node near the centre", possibly a spiniferous tubercle. In this species, as in all "*Agelacrinus*", the rays are curved.

The occurrence of spines in Pelmatozoa was probably more common than is generally supposed, but their preservation is certainly rare. Had specimen *a* of *P. sardesoni* not been found, nobody would have supposed that any species of *Pyrgocystis* bore spines; and the fact that they are not known in the other species is no proof that they were not present. No stress should be laid on the appearance of vertical rods on the cup-plates of *P. grayæ*, since they may be merely strengthening ridges. Meek (1873, Rep. Geol. Surv. Ohio, vol. i, pt. 2, p. 56) mentions ridges on the inner surface of marginal plates in an *Agelacrinus cincinnatiensis* (?).

Bionomics of Pyrgocystis.—The three formations from which specimens of this genus are known are of different lithological character.

P. sardesoni is found in a thin-bedded limestone, intercalated in soft green shales, and composed of numerous small fossils and fragments, but mainly of bryozoan skeletons, especially of branching bifoliate forms. This seems to suggest pure, relatively shallow water, crowded with animal life. The skeletons afforded a firm base of attachment for the Edrioasteroid's turret, which was under no necessity to be lofty since there was abundance of food and of aerating currents. There is no indication that the turret was fixed in other than a vertical position. The spines might conceivably be ascribed to some innate acanthogenous agency, or (less mystically) to an excess of lime in the water; but, whatever the contributory causes, we may suppose that the longer spines on the oral face were useful as a defence against worms and other predatory foes, while the spinules on the turret may have protected the soft stroma from parasitic organisms.

P. grayæ is preserved in a sandstone from which, as generally found, the calcareous constituents have been leached. This also was

a shallow-water formation, but not so rich in life as the *Stictoporella* bed, and especially poor in sedentary organisms. No firm base was afforded for the turret, which therefore seems to have tapered off to a pointed end thrust in the soft sand, while upwards it grew out of the reach of a bombardment by sand-grains (cf. "Caradocian Cystidea from Girvan", § 558). By the domed elevation of the oral face, the accumulation of sand-grains over the subvective system was prevented. The water was not so rich in lime, and parasitic enemies were not so numerous, wherefore it is probable that the reason why spines have not been preserved is because they never were developed in this species.

The Wenlock Shale of Shropshire, like the contemporaneous Bed *c* in Gotland, is a very fine-grained shale, apparently deposited in calm waters, in which lived a fairly numerous but rather dwarfed fauna, rich in ostracods and in small brachiopods and trilobites. There was no good fixation for the turrets, which seem therefore to have been rounded off at the distal end, and presumably stuck in the ooze, but may possibly have been attached to seaweeds. Frequently, it seems, they did not stand upright, and therefore grew in a slight curve. As a rule, relative want of lime made their plates thin and of a loose texture as now manifested in their dark colour. This also did not encourage the production of spines, which probably were absent. The differences between the various Wenlockian species do not seem to be of much physiological importance.

The results of the present Study may now be summarised in the following *Diagnoses*.

*PYRGOCYSTIS*¹ n.g.

An Agelacrinid with a subvective system of five broad straight rays mounted on a subcylindrical turret of adorally imbricate thin wide plates, which are not markedly different from those of the interradial areas of the oral face.

Range.—Lower Ordovician to Middle Silurian.

Genotype.—*P. sardesoni*.

P. SARDESONI n.sp.

A *Pyrgocystis* with diameter of turret equal all the way up, and about two-thirds its height, which is about 14 mm.; turret-plates in about 48 tiers of 11 plates in each, irregularly alternating and nowhere forming the complete 22 columns; each plate is from two to three times as wide as high, and is shaped like a segment of a flat ring. Not more than one-third of each plate is exposed. At the distal end of the turret the plates are almost horizontal; towards the proximal end they gradually approach the vertical, and finally merge into the interradial plates of the oral face, which is approximately horizontal. Spines are borne by all plates, those on the turret-plates being minute and not readily preserved.

Holotype.—Brit. Mus., Geol. Dept., E 16232.

¹ πύργος, a tower.

Horizon.—Stictoporella bed, Decorah shales, Lower Ordovician.

Locality.—St. Paul, Minnesota, U.S.A.

P. GRAYAE n.sp.

A *Pyrgocystis* with turret markedly tapering distalwards, its diameter in the proximal region about one-fifth its total height, which is about 20 mm.; turret-plates in about 80 tiers of about 5 plates in each, which in the proximal region alternate regularly so as to form about 10 columns; each plate appears to be probably wider than high, and to have an outer margin shaped like a flattened arc of a circle; the amount exposed is uncertain. The turret-plates seem to be laid at a steep pitch throughout; at the proximal end they form a distinct, almost vertical-walled, kind of cup, from which springs the high-domed oral face. Spines not observed.

Holotype.—Collection of Mrs. Robert Gray, Edinburgh, K 8.

Horizon.—Starfish bed, Drummuck series, Upper Ordovician.

Locality.—Thraive Glen, Girvan, Ayrshire, Scotland.

P. ANSTICEI n.sp.

A *Pyrgocystis* with turret slightly tapering distalwards, its diameter in the proximal region about one-half to two-thirds its total height, which is about 8 mm.; turret-plates in about 50 (or fewer) tiers of not more than 4 plates in each, which in the middle region alternate regularly, often forming 8 distinct columns separated by grooves; the width of each plate is from six-tenths to nine-tenths of its height; amount exposed about one-fifth, its margin a parabolic curve. The slope of the turret-plates in the fossils is nearer the vertical at the distal end, nearer the horizontal at the proximal end. Oral face and spines not observed.

Holotype.—Brit. Mus., Geol. Dept., E 16235.

Horizon.—Wenlock Shale, Middle Silurian.

Locality.—Jig House Bank near Coalbrookdale, Shropshire, England.

P. SULCATA Aurivillius sp.

Scalpellum sulcatum Auriv. 1892, p. 13.

Scalpellum varium Auriv. 1892, p. 15.

Scalpellum fragile Auriv. 1892, p. 19.

? *Scalpellum strobiloides* Auriv. 1892, p. 17.

? *Scalpellum granulatum* Auriv. 1892, p. 16.

A *Pyrgocystis* with turret slightly tapering distalwards, its diameter in the proximal region about half (or a little less) of its total height, which is about 11 mm.; turret-plates in about 50 (or fewer) tiers of not more than 4 plates in each, which alternate regularly, often forming 8 distinct columns, separated by grooves; the width of each plate appears [from Aurivillius' drawings; no measurements are given] to be greater than its height; amount exposed about one-fifth, its margin an arc of a circle. The slope of the turret-plates in the fossils is nearer the vertical towards the

distal end, nearer the horizontal at the proximal end, but they may be compressed and flattened at the extreme distal end. Oral face and spines not observed.

Holotype.—The original of Aurivillius' plate-fig. 11 is hereby selected. It is in the Riksmuseum, Stockholm. The holotype of *Scalpellum varium* is the unique original of Aurivillius' plate-fig. 12. The original of Aurivillius' plate-fig. 10 is hereby selected as holotype of *S. fragile*; it is not the specimen measured. The holotype of *S. strobiloides* is the unique original of Aurivillius' plate-fig. 17. The specimen measured by Aurivillius (p. 16) is hereby selected as holotype of *S. granulatum*; the figures may or may not be taken from this. All these specimens also are in the Riksmuseum, Stockholm.

Horizon.—Bed *c* (= Wenlock Shale), Middle Silurian.

Locality.—Djupvik in Eksta, also at Mulde and near Wisby, Gotland, Sweden.

P. PROCERA Aurivillius sp.

Scalpellum procerum Auriv. 1892, p. 18.

A *Pyrgocystis* with turret almost cylindrical, its diameter in the proximal region about one-third of its total height, which is not less than 10 mm.; turret-plates in at least 25 tiers of 4 plates in each, which alternate regularly, forming 8 columns separated by faint grooves; the width of each plate appears to be greater than its height; amount exposed fully one-half, its margin an arc of a circle; each plate is slightly bent on its vertical axis. The slope of the turret-plates approaches the vertical in all the portion preserved. Oral face and spines not observed.

Holotype.—The original of Aurivillius' plate-fig. 15 is hereby selected; it appears to be the specimen measured (p. 18). It is in the Riksmuseum, Stockholm.

Horizon.—Bed *c* (= Wenlock Shale), Middle Silurian.

Locality.—Aurivillius gives *a*) near Wisby, *b*) Djupvik in Eksta. I do not know from which of these the holotype came.

P. CYLINDRICA Aurivillius sp.

Scalpellum cylindricum Auriv. 1892, p. 18.

A *Pyrgocystis* with turret almost cylindrical, its diameter not more than one-third of its total height, which is not less than 9 mm.; turret-plates in at least 12 tiers of 4 plates in each, which alternate regularly, forming 8 columns, which are not separated but closely inosculate; the width of each plate is very little (if at all) greater than its height; amount exposed about two-thirds, its margin a pointed arch. The slope of the turret-plates approaches the vertical in all the portion preserved. Oral face and spines not observed.

Holotype.—The unique original of Aurivillius' plate-fig. 16, in the Riksmuseum, Stockholm.

Horizon.—Silurian, precise bed unknown.

Locality.—Near Wisby, Gotland, Sweden.

EXPLANATION OF PLATE III.

Pyrgocystis grayae.

- FIG. 1. The holotype seen in three-quarter view from above, so as to show the oral face.
 „ 2. The holotype seen from the side.
 Both these figures are photographs from a squeeze of the original. $\times 3$ diam.

Pyrgocystis ansticei.

- „ 3. Specimen *a*. Side view. Note the irregular shape of the plates, due to fracture.
 „ 4. Specimen *c*. Holotype, side view. Note the regular plates arranged in columns.
 „ 5. Specimen *e*. Side view. Note the slightly irregular columns, of which there are only 7.
 „ 6. Specimen *l*. Side view. Note the small number of columns at the distal end, with new ones coming in above.
 „ 7. Specimen *g*. View of distal end. Since the turret is much curved, its side is also visible, though out of focus. There is no trace of a lumen.
 „ 8. Specimen *c*. Holotype, view of distal end. The turret is slightly curved. There is a small distinct lumen.
 „ 9. Specimen *e*. View of distal end. The position of the lumen is filled with a solid mass of plates and secondary mineral matter.
 „ 10. Specimen *m*. Side view. Note the irregularity of the columns near the tapering distal end.
 „ 11. Specimen *a*. View of adoral end. Note the approach to horizontality of the plates, and how they stretch across the lumen.
 „ 12. Specimen *c*. Holotype, view of adoral end, as in Fig. 11.
 „ 13. Specimen *i*. View of adoral end. Traces of the lumen are seen filled with matrix.

All the preceding figures, 3-13, are from photographs, taken and worked up by the author. $\times 3$ diam., the same scale as Aurivillius' figures.

- „ 14. Specimen *c*. Holotype. A plate at the distal end. $\times 7.5$ diam.
 „ 15. Specimen *j*. A plate at the distal end. $\times 7.5$ diam.

Unfortunately it has not proved possible to obtain for comparison similar drawings of the plates in the Swedish species.

II.—RADIO-ACTIVITY AND THE EARTH'S THERMAL HISTORY.

By ARTHUR HOLMES, A.R.C.S., D.I.C., B.Sc., F.G.S.

PART I.

The Concentration of the Radio-active Elements in the Earth's Crust.

1. INTRODUCTION.

TWO years ago, in discussing the thermal energy of the earth,¹ I suggested that while it had become impossible to deduce the earth's age from its thermal condition alone, Kelvin's problem might profitably be reversed by accepting the earth's age as a known factor, and deducing with its help the thermal history of the earth. This paper is a first attempt to attack the new problem then suggested. For geological purposes, one of the most fundamental aspects of the

The Age of the Earth, p. 135, 1913.

London Stereoscopic Co., imp.