Palæontographical Society, 1920.

A MONOGRAPH

OF THE

BRITISH PALÆOZOIC

ASTEROZOA

BY

W. K. SPENCER, M.A., D.Sc., F.G.S.

PART V.

Pages 197—236; Plates XIV—XVII.

LONDON:
PRINTED FOR THE PALÆONTOGRAPHICAL SOCIETY.
July, 1922.

PRINTED BY ADLARD AND SON AND WEST NEWMAN, LTD., LONDON AND DORKING.

Since I wrote the previous pages my attention has been called to the important work of Petersen and his colleagues (104), which, by its exact information on the feeding habits of recent forms, enables us to judge with more certainty as to the mode of life of their fossil relatives. In particular it helps us to understand the differentiation which has arisen among the forms we are now considering. It always seemed surprising to me that, in the older Palæozoic rocks, the true Asteroid forms (carnivorous) were relatively few in number, and not so much differentiated as the forms which were either Ophiuroidea or transitional towards the Ophiuroidea as judged by the manner of growth of the interradial areas—a feature associated (see above, p. 195) with the mud-eating habit. Petersen's observations show that, even to-day, the mud-eating habit is the general rule among the lower animals which live on the sea-bottom, and that it is plant detritus in the uppermost layer of mud which provides the nourishment. The plant detritus in Danish waters is formed from grass-wrack (*Zostera*) and its attendant microflora living under the water. This plant produces "in leaves alone 8,232,000 kg. annually in the Danish waters east of the Skaw. In course of time these plants of the benthos formation die, or are torn away by the currents or action of the waves, and carried out, in whole pieces or fine particles, into the deeper water, where they are deposited on the bottom in the form of detritus" (1914, p. 46). Here they form an uppermost brown layer of the mud, "especially well suited as nourishment for the animal life of the sea-bottom." The animals which feed on the plant detritus in the brown mud may live either buried in the bottom or not buried in the bottom.

This is well illustrated by the following picture of the mode of life of the Echinodermata given 1914, pp. 61—64:

(1) Those without arms, and living buried in the bottom.

Echinoidea irregularia without masticatory organs (Atelostomata):

Brissopsis lyrifera, Forb. *Echinocardium flavescens*, Müll.
Echinocardium cordatum, Pennant. *Spatangus purpureus*, Müll.

"All these are typical detritus-eaters, feeding directly on the upper layer of the bottom, without any previous sorting of the detritus. As the aquarium observations have shown, they live buried in the bottom, maintaining communication with the surface by means of vertical tubes, and drawing down their food by means of the far-reaching ambulacral feet . . . the *Echinocardium cordatum* frequently devours, together with the bottom detritus, numbers of quite small young bivalves . . ."

(2) Very mobile arms; living buried in the bottom.

Amphiura chiajei, Forb. *Amphiura filiformis*, Müll.

"The *Amphiura* species live, as I have frequently observed in aquaria, buried

deep down in the bottom, only the extremities of some of the arms reaching up over it. These extremities are in constant movement, feeling about over all the small particles in the vicinity, and now and again coiling round and grasping some few of them, the food being then drawn down beneath the surface of the bottom to the mouth. . . . I have examined several hundreds of specimens taken at different places and seasons, without ever finding anything in their stomachs beyond more or less finely sorted bottom detritus, with the micro-organisms and skeletal parts therein contained. . . . Possibly they may, like *Echinocardium cordatum*, accidentally encounter small young molluscs and pass the same into their stomachs together with the detritus of the bottom. . . ."

(3) More or less mobile arms; not living buried in the bottom.

a. Ophiuroidea.

Arms only slightly mobile: *Ophiothrix fragilis*, Abgd., *Ophiopholis aculeata*, Müll.

Arms very mobile: *Ophioglypha* (five species).

"The two first-named species, which in aquaria often sit motionless for days in their hiding-places, are, in conformity with this, mainly detritus-eaters; they can, however, according to Eichelbaum, also devour animal food. This writer has found in the contents of the stomach indubitable remains of worms (soft parts with setæ still attached), crustaceans, remains of small Echinoderms and young bivalves, besides detritus.

"The *Ophioglypha* species, on the other hand, which have very mobile arms, and will in aquaria fling themselves with astonishing rapidity and accuracy upon pieces of meat, small molluscs and similar animal food, are distinctly carnivorous detritus-eaters. They are often found with remains of small molluscs or crustaceans in the stomach; on examining a quantity of specimens, however, a comparatively large number will always be found quite empty. Experience has shown this to be a good sign that the animal in question is carnivorous; the greater the extent to which an animal is constrained to live on prey, the greater will be the percentage found with perfectly empty stomachs, evidently on account of the length of time which frequently elapses between one capture and the next. The *Ophioglypha* species, besides animal food, also eat detritus.

"*O. texturata* lives, for instance, in the Limfjord, where it is found at most places in quantities (up to 71 specimens per 0·1 m^2.) almost entirely on detritus, as a rule with a number of large bottom diatoms. In the Kattegat, on the other hand, the species feeds chiefly on small bivalves such as *Abra alba*, small Crustaceans such as Gammaridæ, Mysidæ and *Diastylis*, the young of *Echinocardium* and winged insects (probably bees)! The last find indicates that they occasionally condescend to feed on carrion. . . . Finally *Ophioglypha* occasionally devours smaller specimens of its own species."

b. Asteroidea. Arms slightly mobile.

Asterias rubens, L. — *Astropecten mülleri*, Müll. et Tr.
Solaster papposus, L. — *Cribrella sanguinolenta*, Müll.
Solaster endeca, L.

" All these animals are distinctly carnivorous." (It is shown that they will live on Mollusca, Gasteropoda, Crustacea, Worms, Bryozoa, *Echinus* and other Echinoderma. No animal is safe from the attacks of *Asterias*, which also devours carrion in large quantity.)

Petersen also shows (1918, p. 14) that " where the sea bottom is level, *i. e.* formed of fine sand, clay or mud without foreign bodies of any considerable size, the animal population is uniform throughout large tracts," which can be compared with the different vegetation tracts on land such as meadowland, moorland, cultivated fields and the like. These uniform populations he calls *animal communities*, and suggests that it is a combination of local physical conditions with the interplay of the various organisms which determines the constitution of these communities. Thus *Echinocardium* is replaced by *Brissopsis* as a sandy bottom passes into clay, and " it is remarkable to note how in those communities where *Amphiura* spread their arms abroad, forming a network in the bottom, extremely few bivalves are found at all. The young will here doubtless as a rule be devoured while still quite small by the *Amphiura*, and only a few individuals of certain species manage to survive " (1918, p. 17).

It seems to me that Petersen might have carried his comparison with the land-flora a stage further, and compared a section across the bottom to that of a section through the soil of a copse, where each layer of soil is being made use of by the plants, the deepest layers being occupied by the roots of trees, the next layers by bulbs, and the surface layers by shallow-seated rhizomes or the roots of grass. I have given here (Text-fig. 139) an imaginary cross-section through an *Echinocardium-Turritella* community, based on Petersen's observations, to show such a comparison. The distinction between the animal and the vegetable communities lies in this, that whereas the plants obtain their salts from their own layer of soil, the animals, with one exception, all obtain their nourishment from the uppermost layer of the mud. Nevertheless it is clear that the occupation of the various levels of the bottom gives greater opportunity for the living together of a mass of organisms, provided that the supply of food be sufficient. We may compare the community with a town population living in flats, all being supplied with food brought from the surrounding country area.

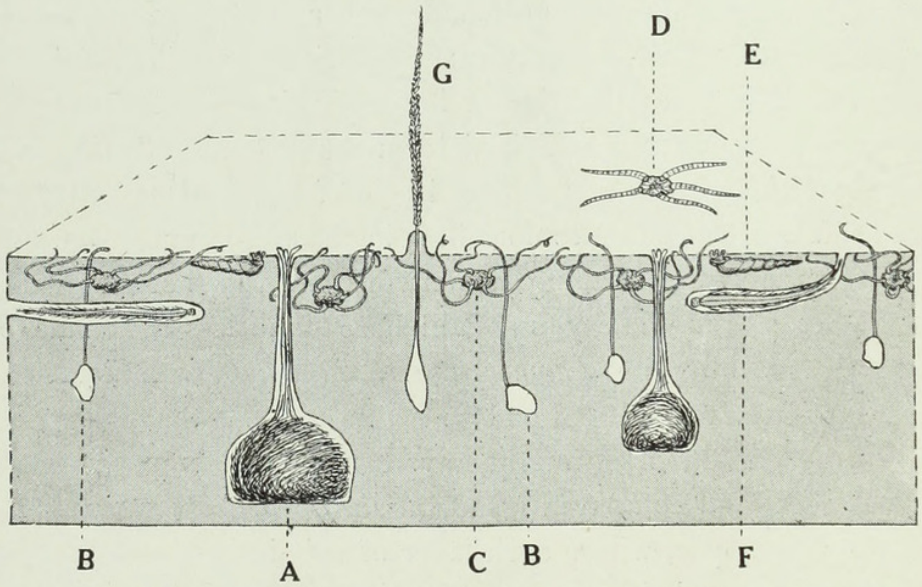
Certain forms seize the detritus as it is falling to the bottom. *Modiola*, *Mytilus edulis* (the edible mussel), so familiar on the supports of piers, have this power. A fauna which consists mostly of organisms of this nature is named by Petersen an *Epifauna*, and it is present (*a*) when the current

is sufficiently strong to wash the stones at the bottom free of mud and so allow attachment of the mussels, etc., or (*b*) where there are rocks or harbour works sticking up in the water. An Epifauna is often rich in Echinodermata. Some Asterozoa, *e. g. Gorgonocephalus*, and, I believe, *Brisinga*, are important characteristic forms.

We can use this material to reconstruct the mode of life of the fossil Asterozoa. Consider first the forms which *lie buried in the mud.*

(1) These probably will be well preserved, since their bodies will not after death be subject to dissolution by the action of currents or by the carrion-eating animals of the surface of the bottom.

(2) They may be expected to die occasionally in some characteristic attitude. The surrounding mud would support the arms and so retain the attitude.

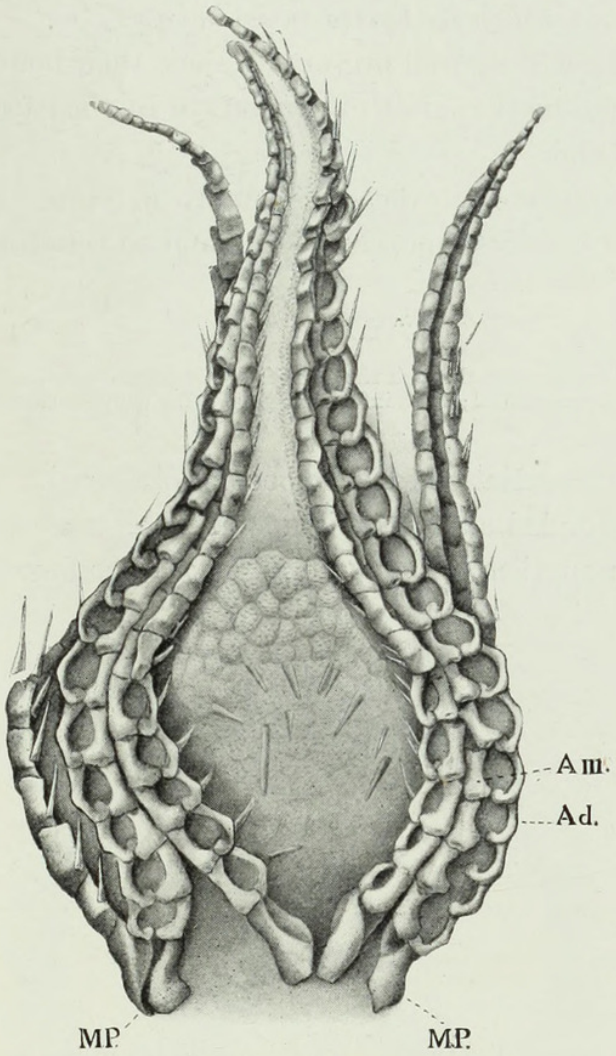


Text-fig. 139.—Drawing of a cross-section through an *Echinocardium-Turritella* community (kindly drawn for me by Magister Blegvad as a modification of a sketch I submitted to him). *A.*, *Echinocardium cordatum* (a burrowing sea urchin); *B.*, *Abra nitida* (a Lamellibranch); *C.*, *Amphiura filiformis* (a burrowing Ophiurid); *D.*, *Ophioglypha texturata* (a surface Ophiurid); *E.*, *Turritella terebra* (a burrowing Gasteropod); *F.*, a worm; *G.*, *Virgularia mirabilis* (an Anthozoan).

The forms of the genus *Protaster* and its allies offer most striking examples of this. They are frequently found, as both Ruedemann (1912, p. 90) and Stürtz (1890, p. 234) have observed, with their arms flexed vertically to the disc (Text-fig. 140). It is clear that it is the same attitude as that described by Petersen (1913, p. 26) for *Amphiura*, which "lies with the body and most of the arms deep down in the clay, but always with the tips of one or more arms stretched out ready to finger any object that comes near and if wanted to draw it down into the clay, where it is swallowed." Petersen also points out that the *Amphiuræ* lie in such quantities that they form a dense net over the sea bottom. The occurrence of *Protaster* or its relations in abundance on the same slab, has been noted by several authors, and we now see the explanation that it was when alive a "detritus"-feeder with the same habits as *Amphiura*. I have noted these facts in advance of

my description of *Protaster*, for I feel that it gives one confidence that we can learn much from the manner in which forms are preserved.

Among the forms with which we are immediately concerned, we may bring to notice *Palasterina* and *Schuchertia*. *Palasterina* is found in crowded masses (Pl. XVII, fig. 3) in a very complete condition, and there can be no doubt that it dug itself into the mud. In support of this we may note that the Devonian form,



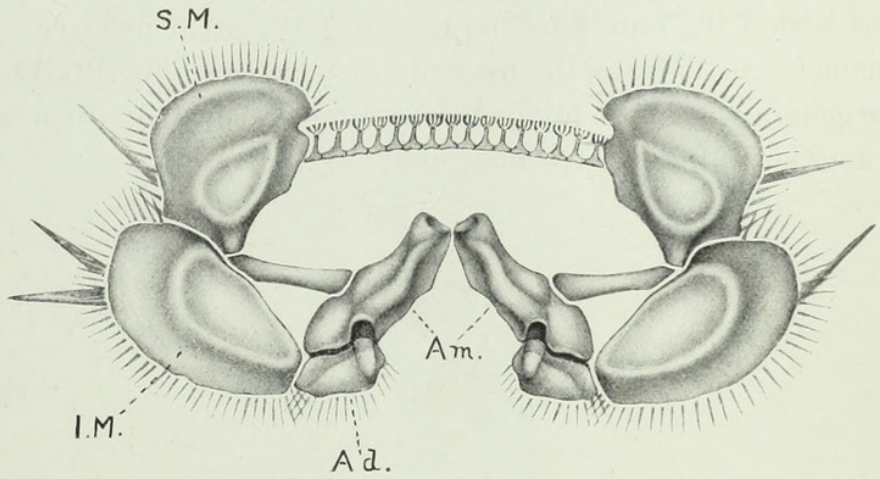
Text-fig. 140.—Drawing of one of the cotypes of *Protaster* (*Tæniaster*) *spinosus*, Billings (Ottawa Mus. no. 1404*b*). *Ad.*, adambulacral; *Am.*, ambulacral; *M.P.*, mouth-angle plate. × 10.

P. follmanni, is found with its arms lightly flexed over its disc (Pl. XVI, figs. 6, 7). *Schuchertia* on the contrary (see p. 210) probably lived buried just beneath the surface.

(c) *Marginal Plates and their Relationship to the Shape of the Arms.*

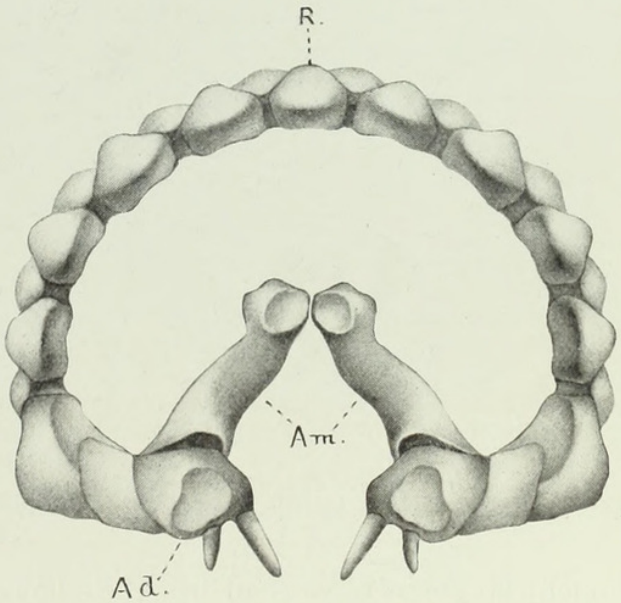
It is useful at this point to examine the exact importance of the presence or absence of differentiated marginalia. It seems to me that such plates in fossil forms are a help in determining the original shape of the arms, but of little value in classification.

If we examine modern genera we find that strongly differentiated marginalia are only found in forms like *Astropecten*, which have an arm almost rectangular in cross-section (Text-fig. 141). When a genus possesses a rounded arm, *e. g. Nardoa*



Text fig. 141.—Cross-section through the arm of a recent *Astropecten*. *Ad.*, adambulacral; *Am.*, ambulacral; *I.M.*, infero-marginal; *S.M.*, supero-marginal.

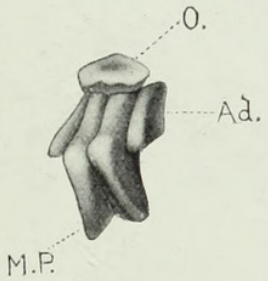
(Text-fig. 142), the differentiation tends to become obscured. This may be explained as follows: In the rounded arm there is no physical reason why any one ossicle should be larger than another, provided that they all commence to be laid down at



Text-fig. 142.—Cross-section through an arm of a recent *Nardoa*. *Ad.*, adambulacral; *Am.*, ambulacral; *R.*, radial.

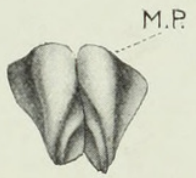
the same moment, for each ossicle has ample room to grow and the rows are not subject to unequal lateral pressures. In an arm with angles at the side, especially when the ossicles are crowded and consequently exercising pressure on one another, the masses of calcite will tend to be pushed into the angles, where larger plates will be built up.

A good example of the artificiality of the use of the marginal plates as a feature of primary importance in classification is seen in the case of the recent family Linkiidæ, which is placed by Sladen among the Cryptozonia, in spite of the fact that the forms within the family belong to one of the great primary groups of the Asteroidea, namely the Valvata, the majority of which are typically Phanerozonate. Almost all the genera within the family have rounded arms, but when, as in *Fromia*, the arms are angular, differentiated marginalia are present.



Text-fig. 143.—Adoral view of a mouth-angle of *Schuchertia wenlocki* (from Royal Scottish Mus. no. 485). *Ad*, first adambulacral; *M.P.*, mouth-angle plate; *O.*, odontophor. × 10.

It is possible that young forms may show differentiated marginalia and that this differentiation may be lost in the older more mature specimens. In consequence of this, Ludwig and others have stated as a general law that all Cryptozonate forms have descended from Phanerozonate stock. Rather would the explanation appear to be, that the so-called differentiated marginalia are the first-formed plates, which obtain a start over the others and for some time remain distinguishable. As the forms become more mature, the other rows of plates,



Text-fig. 144.—Adoral view of a pair of mouth-angle plates (*M.P.*) of *Palasterina primæva* (from specimen in Mus. Pract. Geol.). × 10.

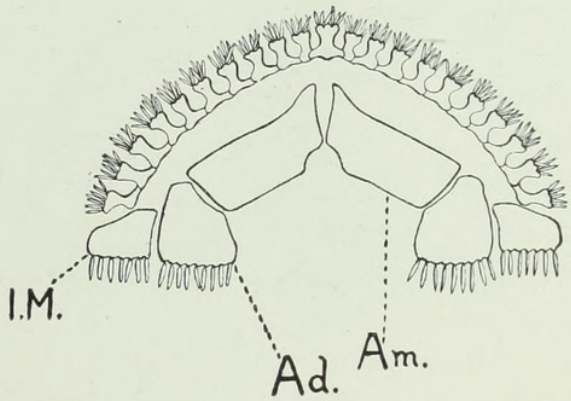
provided that they have room to grow, catch up the early-formed plates, and the distinction is lost.

If the general argument be correct, we can use the changes in the shapes of the marginal (or equivalent) plates to show that the general tendency of evolution in the *Schuchertia*-lineage is to develop a flattish body, while in the *Palasterina*-lineage the arms become progressively rounder.

(d) *The Genera within the Family Eoactinidæ.*

The general features of the Eoactinidæ have been mentioned already (p. 178). Their most obvious characters are the marked Asteroid shape, the broad adambulacralia, and the simple flooring-plate character of the ambulacralia. Although the

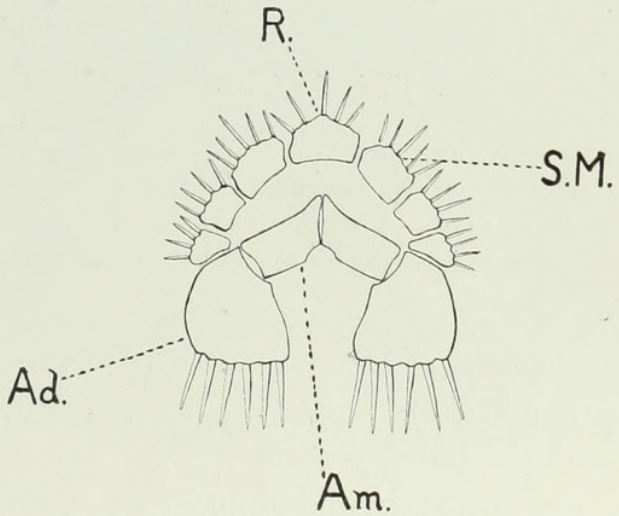
forms are transitional between the early Asterozoa and the true Ophiuroidea, it must not be assumed that any of their descendants became typical Ophiuroidea. Those Eoactinid genera which we know adequately are specialised forms, which go through their own lineage-development and die, without leaving, so far as we can judge, any descendants.



Text-fig. 145.—Diagrammatic cross-section through the arm of *Schuchertia wenlocki*. *Ad.*, adambulacral; *Am.*, ambulacral; *I.M.*, infero-marginal. × 10.

Much material is known of Eoactinidæ. Nearly the whole of this divides into two lineages, each of which can be confined to one genus. These two genera are:

Schuchertia, Gregory, found both in Britain and America, and ranging from the Middle Ordovician to the Middle Silurian.



Text-fig. 146.—Cross-section through the arm of *Palasterina primæva*. *Ad.*, adambulacral; *Am.*, ambulacral; *R.*, radial: *S.M.*, supero-marginal. × 10.

Palasterina, McCoy, found in Britain, Sweden and Germany, and ranging from the Middle Silurian to the Lower Devonian.

A distinctive feature between the two lineages is the shape of the mouth-angle plates, figured in Text-figs. 143 and 144.

In addition, as mentioned above, *Schuchertia* has a flattish arm and well-differentiated infero-marginalia, while in *Palasterina* the arms are much more rounded.

In addition to these two lineages there is a form, known from one specimen only, which I have named *Eoactis*. It is not a *Schuchertia*, and differs from *Palasterina* in certain features which may prove to be only "age" features. At present, however, I am disposed to give these features a somewhat greater value.

A fourth genus is a multi-armed form known only from the Bundenbach slates. It has been placed by Stürtz in several genera and species. I am following Schuchert in only recognising one genus and species, *Palæosolaster gregoryi*, Stürtz. On the whole the affinities of this form are with *Palasterina* rather than *Schuchertia*, but we cannot say at present that it is merely a multi-armed *Palasterina*.

The genera of Eoactinidæ may be defined as follows:

Eoactis, Spencer. Mouth-angle plates rounded; arms straight; a very few flat infero-marginalia in interradial angles.

Schuchertia, Gregory. Mouth-angle plates narrow, high; arms straight and flat; both infero-marginalia and adambulacralia recognisable on oral surface.

Palasterina, McCoy. Mouth-angle plates swollen; arms petaloid and rounded; adambulacralia bounding oral surface.

Palæosolaster, Stürtz. Multi-armed; mouth-angle plates narrow and high; adambulacralia bounding oral surface; arms rounded; lateral and oral surface of arm covered with small well-separated plates, each of which carries a long spine.

Genus **EOACTIS**, Spencer.

1914. *Eoactis*, Spencer, Brit. Palæoz. Asterozoa (Mon. Pal. Soc., vol. for 1913), p. 30.
1915. „ Spencer = ? *Urasterella*, Schuchert, Bull. 88, U.S. Nat. Mus., pp. 173, 178, 186.
1915. „ Bather, Geol. Mag. [6], vol. ii, p. 320.
1916. „ Hudson, New York State Mus. Bull. 187, Twelfth Report of the Director, 1915, p. 135.

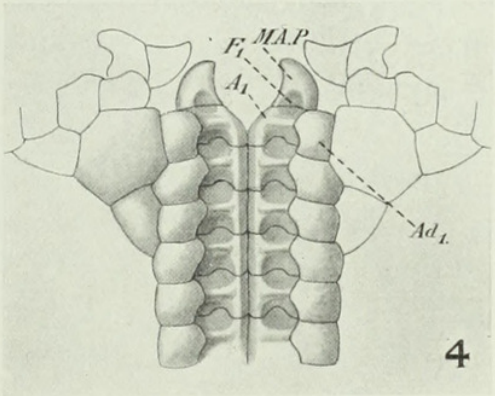
Generic Characters.—See above.

I commence my account of the members of this family by a description of the form which I have named *Eoactis simplex* (see p. 30). It is known only from one specimen and is from a comparatively high geological horizon. It may be the young form of a species not yet recognised. Nevertheless it serves as a convenient starting-point in the discussion of the origin and relationships of the other species.

The form is almost diagrammatically simple. The groove is floored with ambulacralia of the flooring-plate type. Alongside these are stout adambulacralia. The mouth-angle plates have no distinctive shape like those of *Schuchertia* or *Palasterina*. There are a few other skeletal plates visible on the oral surface. In the axils of the arms is a stout polygonal odontophor, and on each side of it a definitely recognisable flat infero-marginal. The apical surface is unknown, but

a lateral view of one of the arms towards the extremity shows that there was a covering of small plates.

The structure of the oral interradial area, inasmuch as only the odontophor and proximal infero-marginalia are present, suggests in a generalised way the structure of a *Urasterella* (compare Text-fig. 86, p. 134). In fact, Schuchert (1915, p. 186), from the very slender account of the species given by me in the Introductory Section to this Monograph, imagined that it might belong to a



Text-fig. 147.—Drawing (somewhat diagrammatic) of *Eoactis simplex* (reproduced from Plate I, fig. 4). A_1, first ambulacral; Ad_1, first adambulacral; F_1, cup for first tube-foot; *M.A.P.*, mouth-angle plate.

Urasterella. I do not know any *Urasterella* which shows such a very definitely differentiated first pair of infero-marginalia, and there is no evidence of the "*Urasterella* paxilla." I regard its generalised features as being those common to very many primitive Asterozoa, and consider that we can most pertinently regard it as illustrating the structure of the basic member of a series which gave rise to *Schuchertia*, *Palasterina* and *Palæosolaster*, each of which tends to depart more and more from the "primitive Asterozoan" appearance as a specialised mode of life is acquired.

1. **Eoactis simplex,** Spencer. Plate I, fig. 4; Plate XV, fig. 8; Text-figs. 147, 148.

1914. *Eoactis simplex*, Spencer, Brit. Palæoz. Asterozoa (Mon. Pal. Soc., vol. for 1913), p. 30, pl. i, fig. 4.

1915. *? Urasterella girvanensis*, Schuchert, Bull. 88, U.S. Nat. Mus., pp. 173, 178, 186.

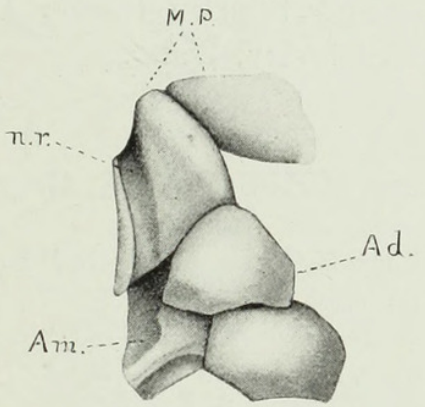
1915. *Eoactis simplex*, Bather, Geol. Mag. [6], vol. ii, p. 320.

Material.—One impression in the British Museum (Nat. Hist.), no. E. 13154, originally no. 657 of the G. H. Morton Collection. The oral surface only is shown.

Specific Characters.—As those for genus.

Description.—Text-fig. 147, which is reproduced from Pl. I, fig. 4, of this Monograph, illustrates most of these characters. The groove is open and shows

ambulacralia which are similar to those of *Schuchertia* (Text-fig. 124, p. 183), except that the overlap of an ossicle on its predecessor is more pronounced. The adambulacralia are broad, with an evenly swollen surface. One can just trace a pustular ornament. The proximal adambulacralia are not differentiated either in size or shape. They fit together so that the suture gives the appearance of a twisted rope, exactly as is described as a generic character for the American form *Schoenaster fimbriatus*, Meek and Worthen. I find that this character also occurs in some species of *Aspidosoma*. The odontophor is large and prominent with a swollen unornamented surface. It terminates proximally in a point which does not quite reach the mouth-angle plates. A small ossicle intervenes here exactly as is figured by Hudson (33, for *Hudsonaster narrawayi*, reproduced in this Monograph, Pl. I, fig. 5). This small plate is not shown in the text-figure.



Text-fig. 148.—Drawing of the mouth-region of *Eoactis simplex*. *Ad.*, adambulacral; *Am.*, ambulacral; *M.P.*, mouth-angle plate; *n r.*, groove for nerve-ring. × 20.

An infero-marginal fits on each side of the odontophor. Beyond this the infero-marginal series disappears on to the apical surface. The extremity of the arm pointing west in the photograph (Pl. XV, fig. 8) shows one or two stout plates in apical view which probably belong to this series.

Dr. Bather (*loc. cit.*) makes the following remarks about my original description of the mouth-frame: "As an example of a very primitive mouth-frame, Mr. Spencer (1914, p. 30) takes the fossil which he names *Eoactis simplex*. His drawing (Pl. I, fig. 4) shows a simple series of ambulacrals and adambulacrals. At the proximal end of the groove the ambulacrals diverge, and the series is there terminated on each side by a curved subtriangular plate, which Mr. Spencer designates 'mouth-angle plate.' It is, however, clear from his drawing, no less than from the specimen itself, that this plate continues the ambulacral series and not the adambulacral, and this is further emphasised by the fact that the depression for the first podium lies equally on this plate and on the adjacent ambulacral. Further examination of other interradii in the fossil showed that this ambulacral mouth-angle plate was actually overlaid by a paired adambulacral element, though only the empty space that might have been occupied by such a

plate is shown in the drawing. It follows from this that the plates marked by Mr. Spencer as A_1 and Ad_1 were really A_2 and Ad_2, and that the true proximal ambulacral and its corresponding adambulacral had not yet fused to form a mouth-angle plate."

I have introduced a new drawing (Text-fig. 148) which shows the mouth-angle plate in one of the interradii mentioned by Dr. Bather as showing the plate in two pieces. It will be seen that the plate is in one piece and has precisely the same structure as the mouth-angle plate of the recent *Astropecten* figured in Text-fig. 137, p. 195. The suture which Dr. Bather thought that he could distinguish separating two elements is obviously the groove for the nerve-ring. Dr. Bather allows me to say that he accepts this explanation.

Measurements.—R : r : : 7 mm. : 3·1 mm.

Horizon and Locality.—Upper Silurian (Lower Ludlow) or Middle Silurian (Upper Wenlock); Hafod, Llandovery, Wales.

Genus **SCHUCHERTIA**, Gregory.

1858. *Palasterina*, Billings (part, not McCoy or Salter), Geol. Surv. Canada, Canad. Organic Rem., dec. iii, p. 76, pl. ix, fig. 1.
1862. *Palasterina*, Wright (part), Mon. Brit. Foss. Echinod., Oolitic, vol. ii (Mon. Pal. Soc., vol. for 1861), p. 26, fig. 16 *b*.
1899. *Schuchertia*, Gregory, Geol. Mag. [4], vol. vi, p. 351.
1900. *Trentonaster*, Stürtz, Verhandl. Naturh. Ver. preuss. Rheinl., Jahrg. 56, pp. 224, 225 (based on the same genoholotype as *Schuchertia*).
1914. *Schuchertia*, Schuchert, Fossilium Catalogus, Animalia, pt. 3, pp. 5, 8, 30, 38, 43.
1915. „ Schuchert, Bull. 88, U.S. Nat. Mus., pp. 51, 140, 152, 194, 195, 252.

Generic Characters.—See p. 205.

The genoholotype of *Schuchertia* is *S. stellata*, which was described more than fifty years ago by Billings as *Palasterina stellata*. The species is found in the Trenton (M. Ordovician) of Canada. Both Gregory and Stürtz, about 1899, recognised that the species was not a true *Palasterina*. Gregory gave the name *Schuchertia*. Stürtz, who published a little later, suggested the name *Trentonaster*.

In 1915 Schuchert described two new species, *S. laxata* and *S. ordinaria*, found respectively in the Upper Ordovician and basal Silurian of the United States. I am now able to show that *S. laxata* is found in the Upper Ordovician of Scotland, and that a fourth species, *S. wenlocki*, n. sp., occurs in the Middle Silurian of Scotland. This extends the range of the species both geographically and in horizon. It seems very probable, judging by the way the species succeed each other in the ascending order of the strata, that they are descendants of one another.

The oral surface of *Schuchertia* (Text-fig. 154, p. 216) may be derived from that of a form like *Eoactis*—(1) by the further differentiation of the infero-marginalia

which brings about a superficial resemblance to the oral surface of *Hudsonaster*, (2) by an outgrowth of the interradial areas which carries the madreporite oralwards. The latter character we have learnt to associate with "*débris* feeding." The former character is probably associated with the flattening of the body, for which a cause is suggested by the progressive changes of the apical surface detailed below.

The apical surface of the earliest species, *S. stellata* (Text-fig. 149), is quite dissimilar from that of a *Hudsonaster*, and even at this early stage shows a general resemblance in its numerous columns, sometimes twisted, to the same surface of recent members of the Paxillosa (compare the text-figure with Verrill, 1914, pl. ciii, fig. 2, *Luidia foliolata*). Progressive changes heighten this resemblance and make it more exact. Schuchert noted that the apical plates in *S. stellata* were only

Text-fig. 149.—Camera lucida drawing of the apical surface of *Schuchertia stellata* (after Schuchert). × 8.

tumid, while in a later species, *S. ordinaria*, they become spicular. The account given below of the latest form, *S. wenlocki*, shows that by the Middle Silurian very definite paxillæ have developed. The recent Paxillosa, as suggested by the name, are characterised by paxillæ, and a study of their mode of life suggests a physiological reason for their presence. The forms live, when at rest, just below the surface of the sand, and clearly might be expected to find some difficulty in respiration. Their breathing organs are papulæ, naked protruding patches of skin, which are found between the ossicles. The spines of the paxillæ act like an umbrella and keep the particles of sand away from the sensitive skin and loosen the sand, so as to allow the ready ingress of streams of freshly aërated water.

It is possible that the sunk valleys between the infero-marginalia of *S. wenlocki* (Text-fig. 124, p. 183) were occupied by specialised spines carrying cilia

and so producing respiratory currents, exactly as Cuenot has shown to be the case in the recent *Astropecten* and *Luidia*. (These ridges on the infero-marginalia in *Astropecten* are shown in Text-fig. 141, p. 202.) We appear therefore to be able to trace progressive changes in *Schuchertia*, associated with a habit of retiring on occasion, if not altogether, beneath the surface of the bottom. It is probable that the animals did not go very deep. The recent *Luidia* when at rest is so near the surface that the respiratory currents form "star-like impressions agreeing with the starfish in size and form." The fragmentary condition in which *S. laxata* is found both in Europe and America (see p. 212) suggests that it could not have been deeply buried at death, but that slight current-action could displace the ossicles when no longer held together by living tissue.

The cross-section given (Text-fig. 145) shows that only infero-marginalia are present. We can interpret this as meaning either that supero-marginalia have been lost, as in the recent *Luidia*, or that like *Urasterella* (p. 130) the form has not yet acquired supero-marginalia. Schuchert takes the first view, and regards the general resemblance of the oral surface to that of *Hudsonaster* as being due to a descent from that Asteroid.

I do not think Schuchert is correct, for, apart from the possible descent of *Schuchertia* from a form similar to *Eoactis*, an examination of *S. stellata* does not show the markedly defined infero-marginalia characteristic of the later species, but a far greater resemblance to their less distinct appearance in *Urasterella*. It is the very prominent infero-marginalia, far more apparent in the later than in the earlier species, which make the form so very like *Hudsonaster*; and if the above argument be correct, the resemblance arises secondarily and is not a primitive character. Personally I should be inclined to assign the presence of the differentiated infero-marginalia to a progressive flattening of the body, which causes a sharp edge to the disc (see p. 202).

A progressive diminution in the comparative size of the adambulacralia is dealt with on p. 185.

An exceedingly interesting feature is the constancy in shape of the mouth-angle plates (Text-fig. 143, p. 203) throughout the life-history of the genus. They are long, narrow, and sharply bent at the junction of the oral and adoral surfaces. We shall see that *Palasterina* also has very characteristic mouth-angle plates recognisable through a considerable geological period.

As the species make so interesting a series, I give a full description whether or no they are known in British rocks. The following table gives their diagnostic characters:

S. stellata.—Small form with short arms. R equals in larger specimen 9 mm. and is approximately twice r. Adambulacralia about as broad as the infero-marginalia. Apical plates closely fitting and slightly tumid. Middle Ordovician.

S. laxata.—Larger form with longer arms. Apparently R may be over 30 mm. and nearly three times r. Adambulacralia as broad as the infero-marginalia. Apical plates rather irregular and slightly tumid. Upper Ordovician.

S. ordinaria.—Form imperfectly known. Apical plates more spicular. Basal Silurian.

S. wenlocki.—General form and size very similar to *S. laxata*. Adambulacralia much less prominent than the infero-marginalia. Apical plates have become paxillæ. Middle Silurian.

A madreporite has not been identified in specimens of the first three species. In *S. wenlocki* it is large and on the oral surface (Text-fig. 154, p. 216).

1. **Schuchertia stellata** (Billings). Plate XVI, fig. 8; Text-fig. 149.

1857. *Palasterina stellata*, Billings, Geol. Surv. Canada, Rep. Progress for 1853—1856, p. 209.
1858. „ „ Billings, Geol. Surv. Canada, Canad. Organic Rem., dec. iii, p. 76, pl. ix, figs. 1 *a*, 1 *b*.
1862. „ „ Wright, Mon. Brit. Foss. Echinoderm., Oolitic, vol. ii (Mon. Pal. Soc., vol. for 1861), pp. 26, 27, fig. 16 *b*.
1876. „ „ Quenstedt, Petrefaktenkunde Deutschlands, vol. iv, p. 74, pl. xcii, fig. 34.
1900. *Trentonaster stellata*, Stürtz, Verhandl. Naturh. Ver. preuss. Rheinl., Jahrg. 56, pp. 217, 224, 225.
1914. *Schuchertia stellata*, Schuchert, Fossilium Catalogus, Animalia, pt. 3, pp. 32, 43.
1915. „ „ Schuchert, Bull. 88, U.S. Nat. Mus., pp. 196—198, pl. xxxii, fig. 2; pl. xxxiii, fig. 1.

Material.—The holotype, which shows the oral surface, was found by E. Billings, and is preserved in the Canadian Geological Survey Collection (no. 1399) at Ottawa. A second specimen in the same collection shows the apical surface. It was found on Governor General Bay, near New Edinburgh, Canada.

Specific Characters.—See p. 210.

Description.—The following description is given by Schuchert:

"Abactinal area composed of a series of plates which are more or less closely adjoining, and on the rays are arranged in distinct but twisted columns. This twisting is due to the insertion of new columns of plates, always on the right side, crowding the older ones to the left. The plates on the rays are subquadrangular to elongate subquadrangular, increasing in size proximally, and on the disc are largest and generally subcircular in outline, or faintly stellate. The plates appear to be smooth. At the apex of the ray are two somewhat larger plates followed by three columns, and on each side of this there are two other columns of ossicles. Near the beginning of the interbrachial arcs the rays have from seven to eight columns of plates.

"Madreporite not distinguished among the abactinal plates.

"Actinally the most conspicuous columns are the adambulacrals bounding the

very narrow ambulacral grooves. These ossicles are subquadrangular in outline near the base of the column, but become wider than long distally; there are about 15 in a column, terminating proximally in two larger, prominent, wedge-shaped plates of the oral armature. Interradially upon each pair of oral pieces is placed a large, single, pentagonal plate (holds the position of axillary interbrachials), against which rest two diverging inframarginal columns, each with 13 or 14 ossicles, and these columns continue adjoining the adambulacrals. Before attaining the distal ends of the rays they gradually become smaller and pass over to the abactinal side. Other actinal disc plates are also present, but apparently are arranged in quincunx, and are smooth like those of the abactinal side.

"Ambulacrals unknown."

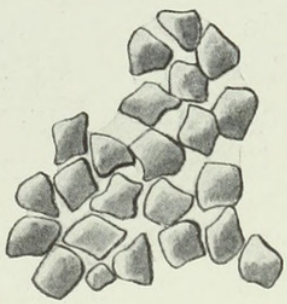
Measurements.—The holotype gives R : r : : 6 mm. : 3 mm. The second specimen gives R : r : : 9 mm. : 4 mm.

Horizon and Locality.—Middle Ordovician (Trenton Limestone); Canada.

2. **Schuchertia laxata,** Schuchert. Plate XV, fig. 1; Text-figs. 150—153.

1914. *Schuchertia laxata*, Schuchert, Fossilium Catalogus, Animalia, pt. 3, p. 38.
1915. „ „ Schuchert, Bull. 88, U.S. Nat. Mus., pp. 198—9, pl. xxxii, fig. 3; pl. xxxiii, figs. 2, 3.

Material.—Four moulds in Mrs. Gray's Collection from the Starfish Bed of Thraive Glen (nos. D. 283, D. 330—D. 332), all fragmentary. D. 283 shows a portion of the apical surface of an arm. The apical ossicles have fallen away, exposing the ambulacralia (Text-fig. 126, p. 186). D. 330 shows the apical surface



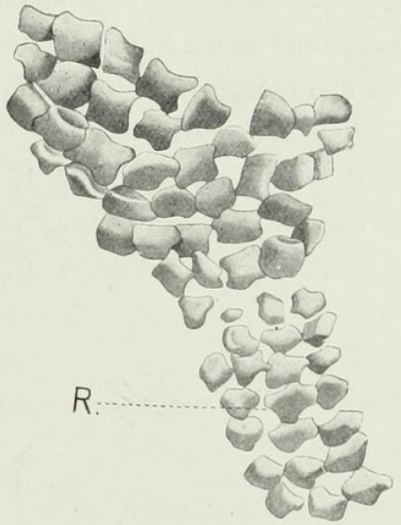
Text-fig. 150.—Apical plates of *Schuchertia laxata* (after Schuchert). × 8.

of a portion of two arms and is figured Pl. XV, fig. 1, and Text-fig. 151. Views of portions of the oral surface are given by D. 331 and D. 332. The plates are much displaced in the former specimen. The latter shows only portions of two arms but they are in good condition.

Schuchert notes that in America "six specimens are known, four of which are poorly preserved and but a jumble of plates. The specific name is given to indicate the generally separated condition of the plates." The British material repeats this condition.

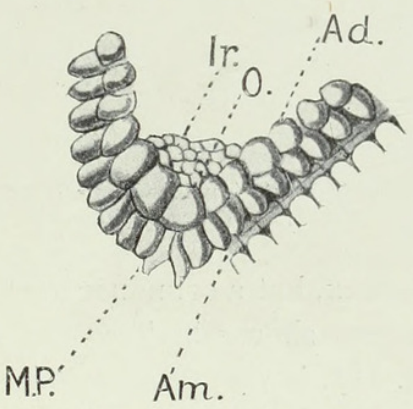
Specific Characters.—See p. 211.

Oral Surface (Text-figs. 152, 153).—For comparison with the British specimens I have reproduced Schuchert's original figure, in which both the odontophor and the proximal infero-marginalia are very distinct. The mouth-angle plates are



Text-fig. 151.—Drawing of a portion of the apical surface of *Schuchertia laxata*? *R.*, radialia. × 6.

drawn with a wide gape, and are apparently preserved much in the same position as they are in the specimen of *S. wenlocki*, figured Pl. XV, fig. 3. D. 331 shows a pair of similar mouth-angle plates, but here the muscle occupying the gape had contracted before death, and the gape is scarcely visible. The odontophor is as in the American specimen. The interradial area in the American specimen is

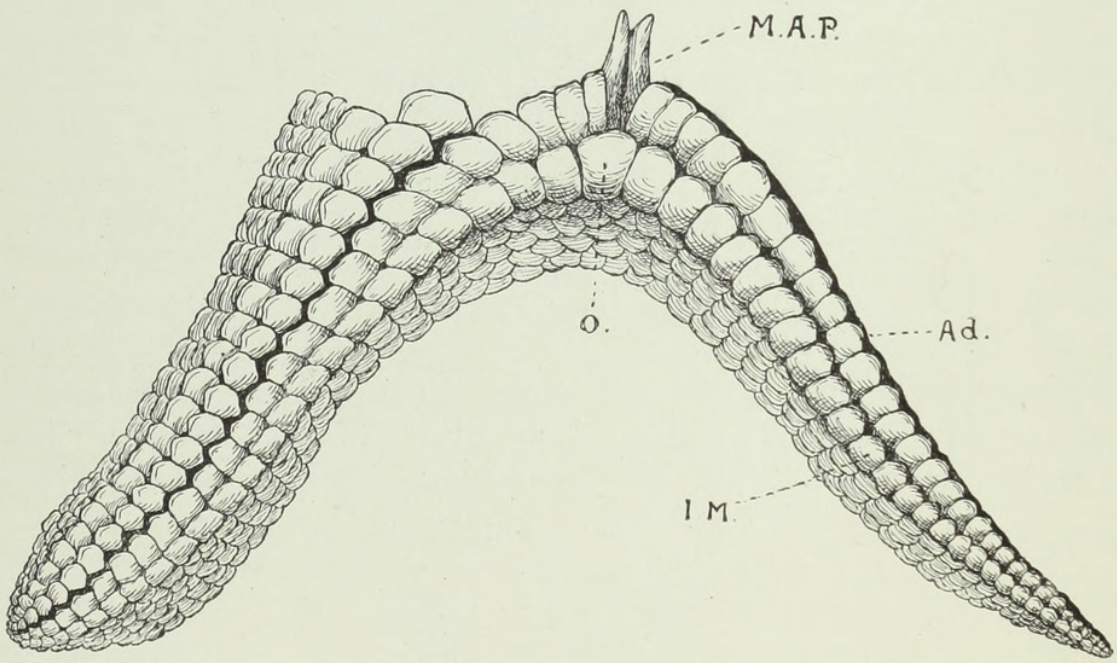


Text-fig. 152.—An interradial area and the ambulacral groove of *Schuchertia laxata* (after Schuchert). *Ad.*, adambulacral; *Am.*, ambulacral; *Ir.*, interradial plates; *M.P.*, mouth-angle plate; *O.*, odontophor. × 4.

occupied by numerous small plates described by Schuchert as "smallest in the inner axillary areas and thence increasing rapidly to a size maintained throughout the interbrachial areas. In form they are either diamond-shaped or subquadrate, centrally tumid, and each plate seems to have borne one central and two or three lateral spines." D. 332 shows similar plates perhaps just a little larger than in the American figured specimen. They merge gradually into the apical skeleton.

Schuchert's drawing shows the adambulacralia not meeting above the radial line. In D. 331 and D. 332 the adambulacralia meet across this line and completely close the groove. This may be simply due to a greater contraction of the walls of the groove at the time of entombment, or it may have some slight specific value (see below). The adambulacralia of the American species are said to be very convex. Those of the British form are rounded but not strikingly convex. The inner sides of the adambulacralia are stated by Schuchert to bear tufts of short blunt spines.

Apical Surface (Pl. XV, fig. 1 ; Text-figs. 150, 151).—The American form has "abactinal areas of rays and disc composed of very numerous, small but irregularly sized, sub-quadrate or diamond shaped, slightly pustulose plates. The



Text-fig. 153.—Line-drawing of *Schuchertia laxata* (combined from D. 331 and D. 332). *Ad.*, adambulacralia; *I.M.*, infero-marginalia; *M.A.P.*, mouth-angle plates; *O.*, odontophor. × 5.

arrangement is mainly in quincunx, but a columnar arrangement is also noticeable." Isolated plates of this form are shown in Text-fig 150. The drawing of the British form given, Text-fig. 151, is very good evidence of the identity of the two sets of material. The ossicles are distinctly more irregular than those of *S. stellata*. The distal portion of the arm in the drawing shows only three rows of plates. At least two more were undoubtedly present originally, but are now represented only by scattered plates. The median row shows a tendency to differentiate into breast-plate-shaped radialia.

Measurements.—D. 332 gives the following approximate measurements: R : r : : 17 mm. : 6 mm. The other specimens were probably of approximately the same size.

Schuchert states that the best American specimen " measures : R = 18 mm.,

r = 6 mm., R = 3 r. The University of Chicago individual : R = 23 mm., r = about 8 mm., R = 2·8 r. Other specimens indicate a growth twice as long as the former one."

Horizon and Locality.—Upper Ordovician (Ashgillian); Girvan, Ayrshire, Scotland. The American species is from the Upper Ordovician (Richmond Formation) of Ohio.

3. **Schuchertia ordinaria,** Schuchert.

1915. *Schuchertia ordinaria*, Schuchert, Bull. 88, U.S. Nat. Mus., p. 199 (not figured).

Material.—One specimen in the Gurley Collection of the University of Chicago (no. 10992). Schuchert remarks—" The specimen cannot be freed of the adhering clay sufficiently to make an instructive photograph, and is therefore not illustrated."

Specific Characters.—See p. 211.

Description.—" The species is most closely related to *S. laxata*, but is smaller and with a comparatively larger disc. Therefore the rays do not protrude beyond the disc so far as in the latter form. Abactinal skeleton consists of minute tumid ossicles that are more cut along their edges than in *S. laxata* and therefore more spicular " (Schuchert, *loc. cit.* p. 199).

Measurements.—R = 11 mm, r = about 6·3 mm.

Horizon and Locality.—The basal Silurian Girardeau Limestone ; Alexander County, Illinois, U.S.A.

4. **Schuchertia wenlocki,** n. sp. Plate XIV, figs. 5, 6 ; Plate XV, figs. 2—4; Text-figures 124 (p. 183), 127 (p. 187), 143 (p. 203), 145 (p. 204), 154—156.

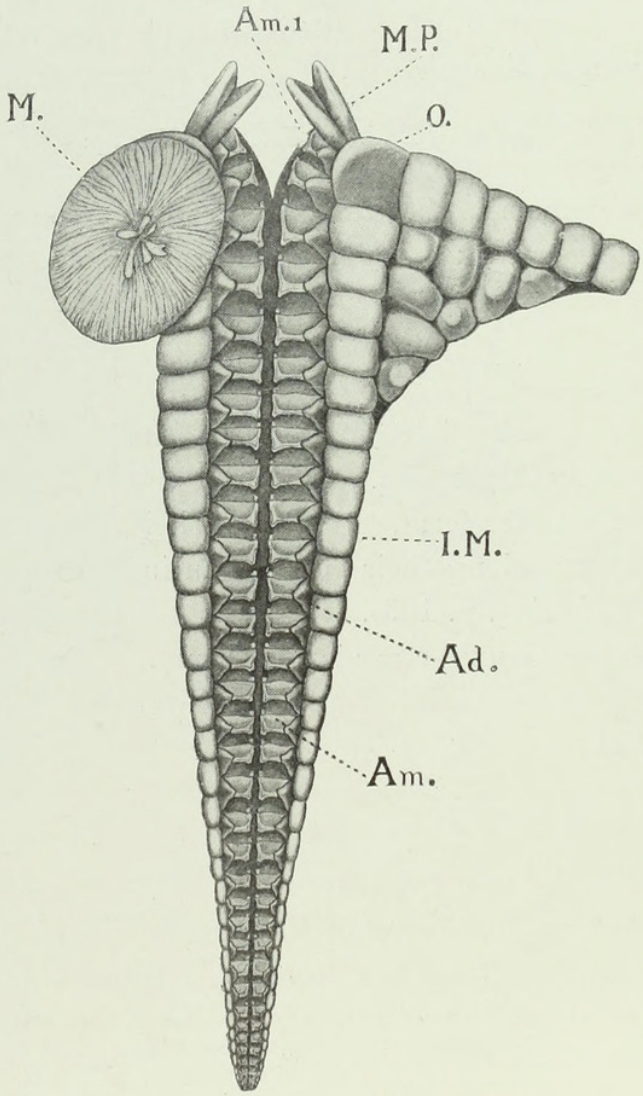
1916. *Schuchertia*, n. sp., Spencer, British Palæoz. Asterozoa (Mon. Pal. Soc., vol. for 1915), p. 67.

Material.—Eleven specimens of the species are known, all moulds in sandstone from the Starfish Bed of Gutterford Burn. They are in the Royal Scottish Museum (nos. 1897, 32/475, 477, 478, 480, 482, 484, 485, 486, 487, 490, 491). Specimen no. 485, a cast of which is photographed in Pl. XIV, fig. 5, is taken as the holotype of the species.

Specific Characters.—See p. 211.

Oral Surface (Pl. XIV, figs. 5, 6 ; Pl. XV, figs. 2, 3 ; Text-fig. 154).—Excellent oral views can be obtained from casts of 475, 484, 485, which show almost the whole of the original specimens. Casts from 486, 487 and 491 show the same surface but are more fragmentary. The reconstruction (Text-fig. 154), is based mostly on a cast from 485, although details are added from other

material. The odontophor is a very prominent flat plate, shaped somewhat like a kite. Its proximal edges are convex and its distal edges slightly concave. Each proximal edge carries a mouth-angle plate and two adambulacralia. The mouth-angle plates are high, narrow, and project well into the mouth-cavity (see Text-fig. 143, p. 203). Proximally the triangular depression for the inter-dental muscle shows as a deep depression. If this muscle be relaxed, as in some



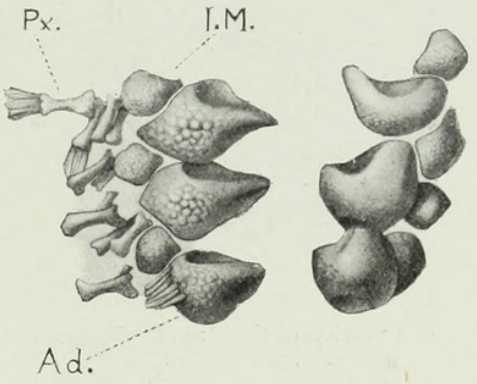
Text-fig. 154.—Slightly reconstructed view of an arm and a portion of the disc of *Schuchertia wenlocki*. *Ad.*, adambulacral; *Am.*, ambulacral; *I.M.*, infero-marginal; *M.*, madreporite; *M.P.*, mouth-angle plate; *O.*, odontophor. × 6.

specimens, the mouth-angle plates appear strongly divergent (Pl. XV, fig. 3). A fringe of slender spines projects from the mouth-angle plate into the mouth-cavity. The first two pairs of ambulacralia are small. By inference we may suppose that the proximal tube-feet were also small.

These proximal pairs of ambulacralia do not meet across the middle line but form divergent arms of a V. The first two pairs of adambulacralia are also

smaller than the immediately succeeding ossicles, which are almost constant in size for some distance along the arm. In consequence the proximal region of the arm is straight, not petaloid as in *Palasterina* (see below, p. 225).

The proximal infero-marginalia are broader than long, with a weakly concave upper surface (Text-fig. 124, p. 183). About a third of the way down the arm they become longer than broad and much more swollen. Finally they become almost globular and pass over to the apical surface. Text-fig. 155 shows these small, globular infero-marginalia clearly distinguishable from the apical paxillæ. I have made a suggestion above (p. 209) that some of the infero-marginalia may have been modified for respiratory purposes. The infero-marginalia are approximately equal in number and more or less alternate with the adambulacralia—characters which appear to be constant in the genus. The interradial plates of the disc are not arranged in a constant manner and also vary in number. They are polygonal, with distinctly swollen central areas.



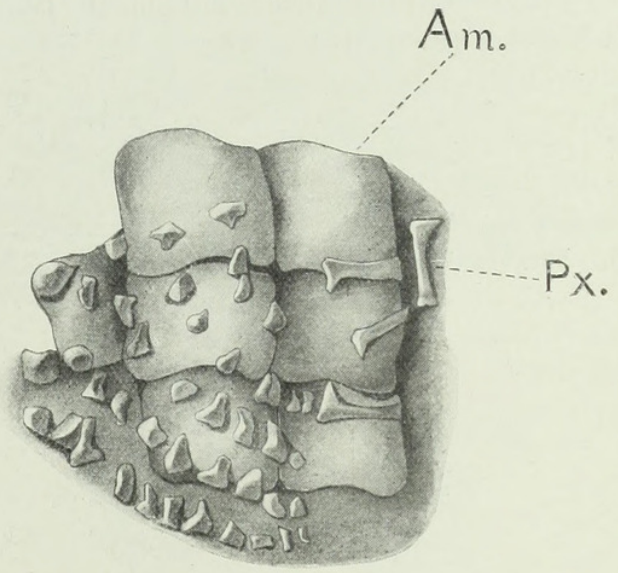
Text-fig. 155.—Wash-drawing of the end of an arm of *Schuchertia wenlocki*. *Ad.*, adambulacral; *I.M.*, infero-marginal; *Px.*, paxilla displaced from apical surface. × 30.

The madreporite is a large oval plate seen in all the three more perfect specimens. It overlaps the other plates of the interradial area, suggesting, as in *Palasterina primæva* (p. 223), that it was embedded in a skin which covered the interradial ossicles. Details of the minute structure of the groove have already been given (p. 182).

Apical Surface (Pl. XV, fig. 4; Text-figs. 127 and 156).—It is extremely difficult to get a really good view of the apical covering, as the plates are usually much displaced. The arrangement of the ossicles can only be seen in a rather indistinct specimen (no. 490). Casts from this and other specimens (nos. 477, 478, 480, 482) show that the apical covering was composed of numerous small plates, arranged in rows but not showing differentiation into radialia, adradialia and supero-marginalia. Favourable views of the plates show them to be paxilliform (see Text-fig. 145, p. 204, and Text-fig. 156, p. 218). Each paxilla possesses a flat top, a long shaft and a spreading base. Spines can be distinguished on some of the paxillæ in specially good casts.

It is extremely difficult to get a good cast of a paxilla unless it is end on, for the air inside a vertical hollow in the mould has no method of escape and so keeps the rubber out (*cf.* p. 151). If the holes are at an angle the rubber enters more readily.

Oral Surface (Text-fig. 120).—The displacement of the apical covering, alluded to above, allows one to obtain good views of the ossicles of the oral surface as seen



Text-fig. 156.—Apical view of a portion of the arm of *Schuchertia wenlocki*. *Am.*, ambulacral; *Px.*, paxilla. × 12.

from above. Text-fig. 127 (p. 187) gives such a view in the region of the mouth. The odontophor is almost flat, but one can see a suggestion of the **Y** so conspicuous in *Stellaster*. The arrangement of the proximal ambulacralia is somewhat as in the Platanasteridæ (p. 177). The first ambulacral is small. Although it is displaced it is seen, like the second ambulacral, to lie on one edge. Neither of these ossicles meets its pair across the median line of the arm. The more distal ambulacralia have slightly advanced in structure from those of the Ordovician species (Text-fig. 126, p. 186). The longitudinal muscle-depressions are well marked, and there is a distinct beginning of a ball and socket. The inner edges of the plates are slightly raised for the attachment of the dorsal transverse muscles.

Measurements.—Specimen no. 490—R : r : : 21 mm. : 6·5 mm. Specimen no. 485—R : r : : 20 mm. : 7 mm.

Horizon and Locality.—Wenlockian (the Starfish Bed); Gutterford Burn, Pentland Hills.

Genus **PALASTERINA**, McCoy.

1848. *Uraster*, Forbes (pars), Mem. Geol. Surv. Gt. Brit., vol. ii, pt. ii, p. 463.
1849. ,, Forbes (pars), Mem. Geol. Surv. United Kingdom, dec. i, p. 2.
1851. *Palasterina*, McCoy, Brit. Palæoz. Foss., p. 59.
1857. ,, Salter, Ann. Mag. Nat. Hist. [2], vol. xx, pp. 324, 327.
1858. ,, Billings (pars), Canad. Organic Rem., vol. iii, p. 76.
1859. ,, Salter (pars), in Murchison, Siluria, 3rd edit., p. 248.
1879. ,, Zittel, Handb. Palæont., vol. i, p. 453.
1884. ,, La Touche (pars), Handb. Geol. Shropshire, p. 34.
1890. *Palasterina*, Stürtz (pars), Palæontographica, vol. xxvi, p. 246.
1893. ,, Stürtz (pars), Verhandl. Naturh. Ver. preuss. Rheinl., Jahrg. 50, pp. 43, 60.
1899. *Palæasterina*, Gregory, Geol. Mag. [4], vol. vi, p. 349.
1899. *Lindstromaster*, Gregory, *loc. cit.*, [4], vol. vi, pp. 344, 346.
1900. *Hisingeraster*, Stürtz, Verhandl. Naturh. Ver. preuss. Rheinl., Jahrg. 56, pp. 224, 225.
1900. *Pseudopalasterina*, Stürtz, *loc. cit.*, Jahrg. 56, pp. 219, 224.
1910. *Palasterina*, Schöndorf, Jahrb. Nassau. Ver. Naturk., vol. lxiii, p. 220.
1914. ,, Schuchert, Fossilium Catalogus, Animalia, pt. 3, pp. 5, 7, 29, 30.
1914. *Lindströmaster*, Schuchert, *loc. cit.*, pt. 3, pp. 5, 7, 21, 23.
1914. *Pseudopalasterina*, Schuchert, *loc. cit.*, pt. 3, pp. 5, 7, 36.
1915. *Palasterina*, Schuchert, Bull. 88, U.S. Nat. Mus., pp. 49, 130, 138, 140, 150, 154, 156, 196.
1915. *Lindströmaster*, Schuchert, *loc. cit.*, pp. 138, 140, 148, 154, 156.
1915. *Pseudopalasterina*, Schuchert, *loc. cit.*, pp. 138, 156.
1915. *Lindstromaster*, Bather, Geol. Mag. [6], vol. ii, p. 318.

Generic Characters.—Groove with an open ambulacral channel. Bases of arms separated by strongly calcified disc area. Mouth-angle plates swollen with rounded sides. Odontophor in adult either absent or recognisable with difficulty. Adambulacralia bound the oral surface of the arm, and frequently have a ridge bearing stout spines (see p. 205).

The name *Palasterina* was suggested by McCoy, who in 1851 (when writing about the three species named by Forbes *Uraster ruthveni*, *U. hirudo* and *U. primævus*) stated: "Before I was aware Professor Forbes had described them, it seemed to me that the *U. ruthveni* and *U. hirudo*, as well as the similar American species *Urasterella pulchella*, might be easily separated from the great starfishes forming the recent genus *Uraster* by their small size and much more simple skeletons, and I had named the genus *Urasterella* in my manuscript. The *U. primævus* I thought generically distinct from the other two, as the rays were not contracted at base, etc.; and I had named it *Palasterina*, from its resemblance to the recent genus *Asterina*." McCoy then went on to publish the descriptions given by Forbes.

Salter in 1857 definitely accepted McCoy's name with the same genotype, *P. primæva*. He defines the genus as follows: "Pentagonal, depressed, the arms

a little produced, with three or five principal rows of tubercles above, combined with a plated disc which fills up the angles; ambulacra rather shallow, of subquadrate or slightly transverse ossicles, bordered by a single row of squarish large plates, the lowest of which (ad-oral adambulacral plates, Huxley; angle ossicula, Forbes) are large and triangular, bearing combs of spines (Upper Silurian)."

Unfortunately the specimen examined and described by Salter was not *P. primæva*, but the form described later by Gregory as "*P. bonneyi*." Neither Gregory nor later authors appear to have noticed this, and in consequence there has been some confusion.

I have placed in the genus several forms which some previous observers have separated rather widely. These include "*Lindstromaster*" *antiquus*, Hisinger, from the Wenlock (Middle Silurian) of Gotland, *P. primæva*, Forbes, and "*P. bonneyi*" from the Ludlow (Upper Silurian) of England, and "*Pseudopalasterina*" *follmanni*, Stürtz, from the Bundenbach (Lower Devonian) of Germany. I am also able to describe a little new material from the Wenlock horizon of both England and Scotland. All these forms possess one characteristic type of mouth-angle plate (Text-fig. 144, p. 203), and agree in the rounded shape of the arm and other general characters.

The new form from the Wenlock of Scotland appears to be a young specimen. In many respects, particularly in the shape of its odontophor, it recalls *Eoactis* (see p. 205).

For the reasons stated below I think that we can limit the species as follows:

(1) A Wenlock species, *P. antiqua*, Hisinger, present also in the Ludlow Beds and passing directly into—

(2) The Devonian *P. follmanni*, Stürtz.

(3) A Ludlow species, *P. primæva*, Forbes, which seems to be characteristic of its own horizon and locality (passage beds between Lower and Upper Ludlow in Lake District).

The following table gives the diagnostic characters of these species:

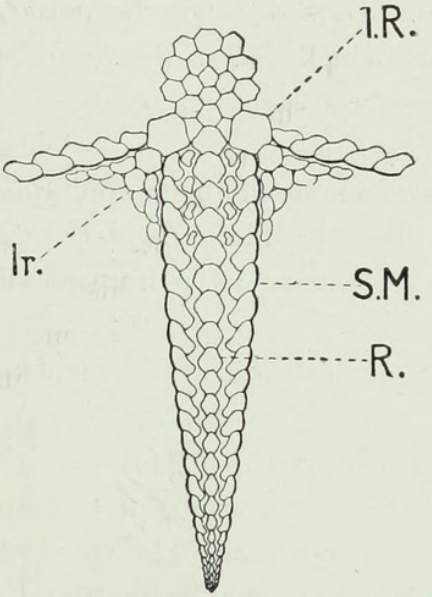
P. primæva.—Form of medium size; R may be 18 mm. A comparatively small number of ossicles in the interradii. Radialia and marginalia can be identified.

P. antiqua.—Form of medium size; R may be 17 mm. A large number of ossicles in the interradii. Radialia and marginalia can be identified.

P. follmanni.—Large form; R may be 113 mm. Arm much swollen with numerous similar rows of apical ossicles, which may be squeezed by post-mortem distortion into oral surface forming large interradii.

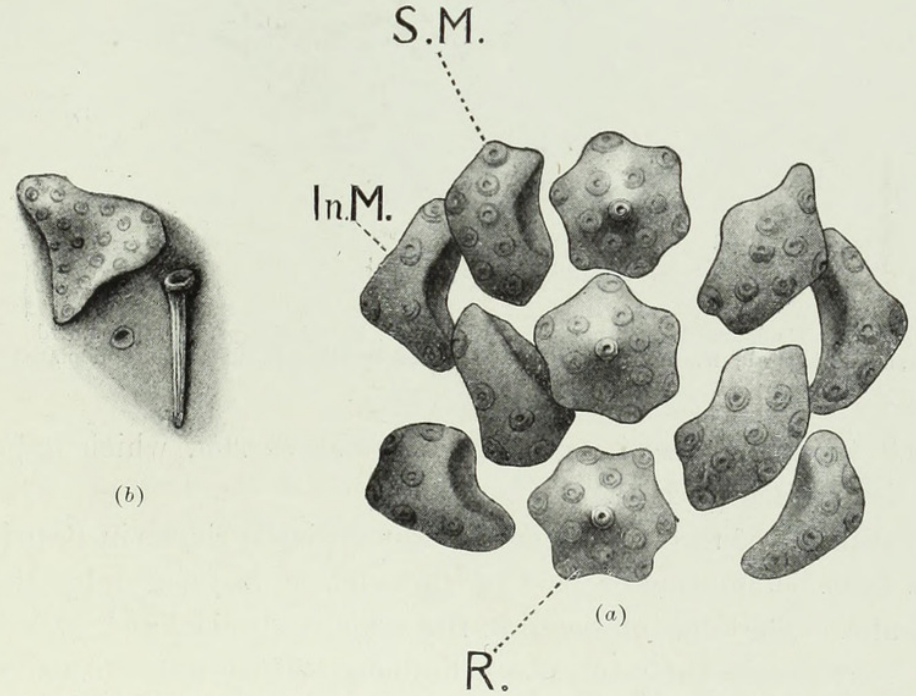
The characters of the apical surface can be understood most clearly if we commence with a study of *P. primæva*. In this form both radialia and marginalia are differentiated (Text-fig. 146, p. 204, and Text-fig. 157). The

earlier observers, who had not noted the oral position of the madreporite, classified the form, in consequence, among the Phanerozonate Asteroidea. The apical



Text-fig. 157.—Plan of ossicles on the apical surface of *Palasterina primæva*. *I.R.*, primary interradial; *Ir.*, intermarginalia; *R.*, radial; *S.M.*, supero-marginal. × 5.

plates are covered with pustules, which are shown slightly exaggerated in Text-fig. 158.

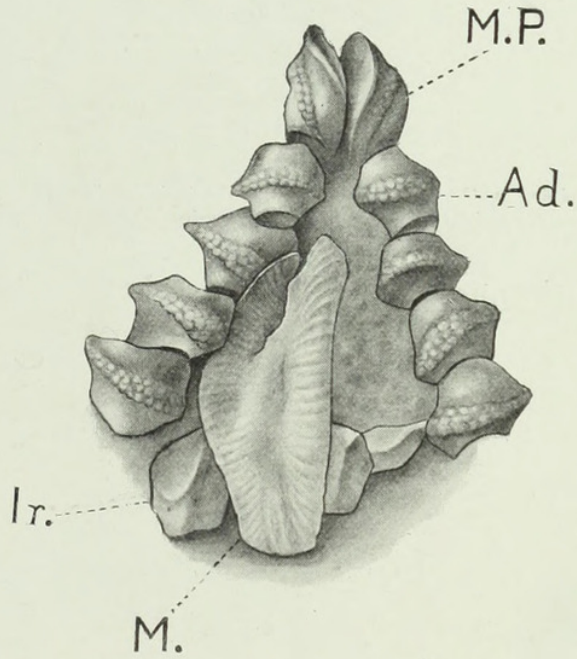


Text-fig. 158.—(*a*) Wash-drawing of ossicles across the apical surface of a somewhat compressed specimen of *Palasterina primæva*. *In.M.*, infero-marginal; *R.*, radial; *S.M.*, supero-marginal. × 30. (*b*) On left an isolated ossicle with detached spine from a specimen of *P. antiqua* (Brit. Mus. no. 40301).

The faint ornament suggests that the spines fitting on these pustules were slender and easily destroyed, and they are usually missing in the specimens. If present there is only one to a plate (Text-fig. 158 *b*), and one may surmise that this was

a central spine stouter than the remainder. This ornament must have been very similar to that in *Palæosolaster* (p. 239). The arm in *P. follmanni* shows no differentiation of marginalia. It was clearly more rounded and flexible (Pl. XVI). The position of the arms in Pl. XVI, figs. 6, 7, proves that they had the power of bending upwards over the disc. Fig. 6 shows only the base of the arms in oral view. The other side of the specimen has been cleared of the matrix and shows the remaining portions of the arms folded over the disc. The upward flexure is very clear in the specimen photographed in fig. 7.

The fact that the arms are preserved in this condition, and the general good state of preservation of the specimens, suggest to me that the form lived buried in the mud with the tips of its arms flexed and searching for food at the surface of

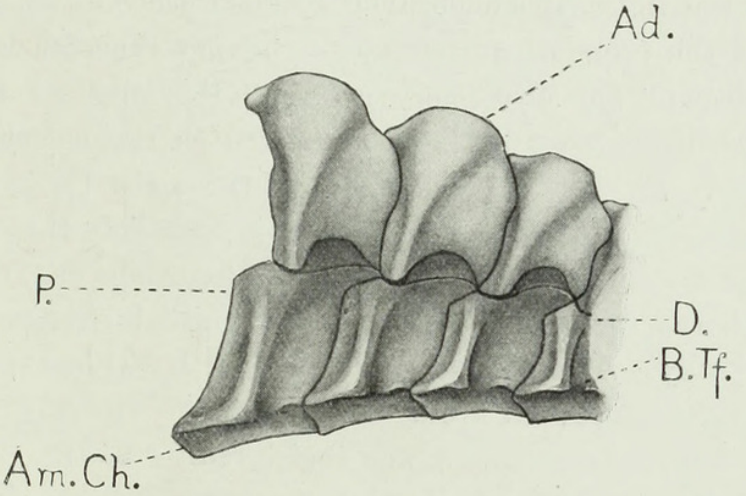


Text-fig. 159.—Wash-drawing of an angle of the disc of *Palasterina primæva* (from Sedgwick Mus.). *Ad.*, adambulacral; *Ir.*, interradial plate; *M.*, madreporite; *M.P.*, mouth-angle plate. × 15.

the bottom. In this respect it contrasts with *Schuchertia*, which appears to have lived near the surface (p. 210).

The constitution of the oral surface is most typically shown in *P. primæva* (Text-fig. 161, p. 225). The greater part of the surface is formed by the prominent adambulacralia. The oral interradii in the various species, and even in individual specimens, vary considerably in extent. Those of *P. primæva* usually contain but a few plates. In both *P. follmanni* and *P. antiqua* these areas may be quite extensive (see, *e.g.*, Text-fig. 165, p. 229, and Text-fig. 168, p. 232). The photographs on Pl. XVI give the explanation of these discrepancies. When the arms are high and the body swollen, post-mortem compression may cause the extensive lateral surfaces in the interradii to be forced oralwards and so make the form look as if it had a large flat disc.

The madreporite is a large thin plate. It presents features which I do not understand. Text-fig. 159 has an appearance which suggests that it is embedded in a membrane overlying the interradial plates. Its inner proximal surface overrides the adambulacralia in an obviously unnatural position. The whole appearance indicates that the madreporite overlaid a large vesicle which projected oralwards and collapsed after death. The thin madreporite was forced down on to the adambulacralia and became slightly fractured during this process.



Text-fig. 160.—Wash-drawing of the floor and inner wall of the ambulacral groove of *Palasterina primæva* (from Sedgwick Mus.). *Ad.*, adambulacral; *Am.Ch.*, ambulacral channel; *B.Tf.*, channel for the branch of the radial water-vascular canal to the tube-foot; *P.*, proximal direction; *D.*, distal direction. × 30.

The simple flooring-plate character of the ambulacralia is shown in Text-fig. 160. The same ossicles in apical view are shown in Text-fig. 164, p. 227. The ambulacralia near the mouth are but little differentiated (Text-fig. 163, p. 227).

1. **Palasterina primæva** (Forbes). Plate XV, figs. 5—7; Plate XVII, fig. 3; Text-figs. 30 (p. 37), 138 (p. 195), 157—164.

1848. *Uraster primævus*, Forbes, Mem. Geol. Surv. Gt. Brit., vol. ii, pt. 2, p. 463.
1849. „ „ Forbes, Mem. Geol. Surv. United Kingdom, dec. i, p. 2, pl. i, figs. 2 *a*, 2 *b*.
1851. „ „ Forbes in McCoy, Brit. Palæoz. Foss., p. 60.
1851. *Palasterina primæva*, McCoy, *loc. cit.*, p. 59.
1854. *Uraster primævus*, Murchison, Siluria, p. 221, fig. 39.
1876. „ „ Quenstedt, Petrefakt. Deutschl., 1, iv, p. 74, pl. xcii, fig. 35.
1893. *Palasterina primæva*, Stürtz, Verhandl. Naturhist. Ver. preuss. Rheinl., Jahrg. 50, p. 44.
1899. „ „ Stürtz, *loc. cit.*, Jahrg. 56, pp. 214, 224.
1899. *Palæasterina primæva*, Gregory, Geol. Mag. [4], vol. vi, p. 349.
1910. *Palasterina primæva*, Schöndorf, Jahrb. Nassau. Ver. Naturk., vol. lxiii, pp. 220, 243, 250.
1913. *Palæasterina primæva*, Spencer, Introductory Section to this Monograph, pp. 37, 38, Text-fig. 30.
1914. *Palasterina primæva*, Schuchert, Fossilium Catalogus, Animalia, pt. 3, pp. 31, 44.
1915. „ „ Schuchert, Bull. 88, U.S. Nat. Mus., pp. 149, 151, 152, 153.

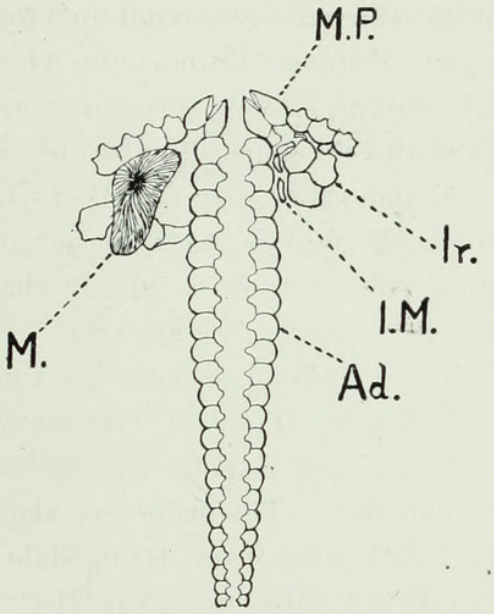
Material.—There are many specimens in various museums, nearly all impressions in sandstone. Individuals are often crowded together on the same slab, suggesting that, like many Ophiuroidea, the form occurred in swarms. The most extensive collection is in the Sedgwick Museum, Cambridge, where there are twelve slabs, with another slab which contains two impressions associated with *Urasterella ruthveni* (see p. 140). Six of the slabs are stated to be from the Bannisdale Slates, High Thorns, Underbarrow, and are registered as *a*/517. A note is attached to the label that Forbes' original figures were based on this material. I have identified one of the impressions (slab *d*) as giving the cast from which Forbes' fig. 2 *a* was drawn, but I cannot recognise the original of fig. 2 *b*. The specimen on slab *d* is therefore hereby selected as the holotype of the species. It is figured here, Pl. XV, fig. 5. Four of the slabs (*f*, *g*, *h*, *k*) are labelled Bannisdale Slates, nr. Kendal, and a note is attached that these were in a Kirkby Lonsdale drawer unlabelled. The other two slabs are from the Bannisdale Slates, High Thorns (no. 146*), and from Bannisdale Slates (?), Underbarrow (no. 48), respectively. The British Museum (Nat. Hist.) has specimens registered as E. 61, E. 4990—4993, all from Underbarrow. Specimens in the Museum of Practical Geology, Jermyn St., are registered as 25349, 25350 and 25375. The locality of the first is near Kendal, the other two are from Underbarrow. The following specimens are in the Kendal Museum: no. 9 from the "Asterias bed," Bannisdale Slates, Underbarrow; nos. 7, 34, from the Bannisdale Slates, High Thorns, Underbarrow. It seems clear that all the specimens are from the same horizon and locality (see also p. 142).

Specific Characters.—See p. 220.

Oral Surface (Pl. XV, fig. 7; Text-figs. 161, 162).—The adambulacralia are very prominent indeed, and it is their shape and disposition which give the arm its distinctive appearance. They margin the arm, and the largest lie about the base of the free portion of the arm, with the result that it has a distinctly petaloid appearance.

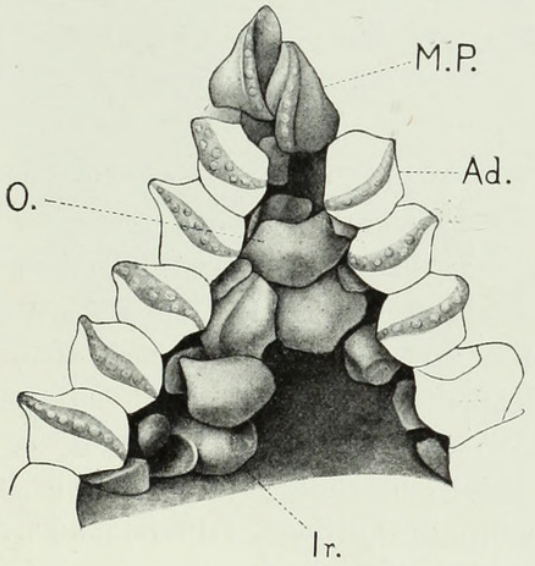
Each adambulacral has a characteristic shape. It only meets its neighbours along a comparatively slender articulation (Text-fig. 162). The surface above the line of contact is much swollen. The nose, which is, as usual, on the proximal portion of the ossicle, is continued into a ridge, which at first starts backwards, and then runs along the middle of the ossicle. The ridge possesses pustular elevations which carried long spines. Text-fig. 160, p. 223, gives a view of the ossicle of the groove as seen from within (corresponding to the aspects figured Text-figs. 124, 125, pp. 183, 184). The adambulacralia look as if they were tipped away from the mouth. This is due to slight distortion in the rubber cast from which the drawing was made. Really they tip, as is usual, towards the mouth. The groove is deep, and the adambulacralia form a steep wall just as in *Urasterella* (see p. 133). The ambulacralia have the same general character as those of *Schuchertia* (Text-fig. 124, p. 183). The median ridge as figured appears to be thicker and more rounded than

in *Schuchertia*, but the ossicles on the other side of the groove of the same arm as figured show a thin ridge.



Text-fig. 161.—Plan of the ossicles on the oral surface of *Palasterina primæva*. *Ad.*, adambulacra *I.M.*, infero-marginal; *Ir.*, interradial plate; *M.*, madreporite; *M.P.*, mouth-angle plate. × 5.

A very good view of the groove in the region of the mouth was obtained by bending rubber casts of specimen *k* from the Sedgwick Museum while still



Text-fig. 162.—Wash-drawing of an angle of the disc of *Palasterina primæva* (from Sedgwick Mus.). Lettering as in Text-fig. 159. *O*, plate which corresponds in position with the odontophor of related species. × 12.

soft. The groove was thus forced open with but little distortion of the ossicles (Text-fig. 138, p. 195). The mouth-angle plate is large. On its inner side it is hollowed to lodge the first tube-foot. There is a distinct apophysis. Between the apophysis and the oral surface of the plate runs the groove for the nerve-ring. Behind the apophysis is the groove for the circular water-vascular ring. The hollow

for the fitting of the first adambulacral is also shown. It is rather larger in the drawing than in reality because of the slight distortion of the cast. The great general resemblance between this mouth-angle plate and the same plate in a recent Asteroid has already been remarked (p. 196).

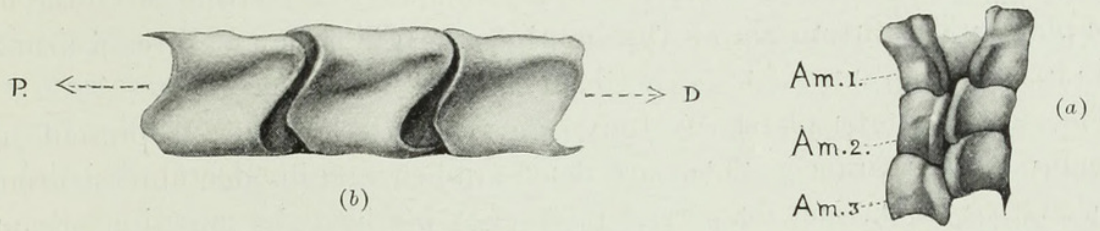
The first ambulacral has moved a little from its exact fitting on to the mouth-angle plate. The fitting shows that a peg-and-socket joint ensures a firm fitting of the two ossicles.

The mouth-angle plates in full oral view (Text-fig. 162) present a very characteristic appearance. They are much swollen, and divided almost throughout their length by a distinct deep triangular cleft bordered by two thin ornamented ridges. This same drawing also shows the interradial ossicles. One long ossicle, which may represent the odontophor, occupies the whole space between the second adambulacralia of neighbouring arms. Proximal to this ossicle are two smaller ossicles, and behind it four ossicles of various sizes. All these ossicles have swollen surfaces and appear to imbricate in the direction of the mouth. There appears to be some variation on this arrangement in the various specimens, possibly due to the degree of compression to which the form has been subjected. It is evident that increased compression would result in an apparent increase of the interradial areas due to a forcing downwards of a portion of the apical surface.

The madreporite is very large. As shown in Text-fig. 159, p. 222, it may overlie other interradial plates. The plate figured has slightly split in its anterior region, and the split shows that the plate is very thin. It is possible that it was also slightly flexible. Specimen no. 25349 shows the madreporite sticking close to the curve of the interradial region. The direction of the grooves on the madreporite suggests that the opening of the pore canal was at the edge of the disc—that is, in the primitive Ophiuroid position (see pp. 37, 181).

Apical Surface (Pl. XV, figs. 5, 6; Text-figs. 157, 158, 163, 164).—The arrangement of the ossicles is seen very clearly in casts from two impressions in the Sedgwick Museum (48 and *a*/517 A). The plan given (Text-fig. 157, p. 221) is drawn from these two specimens. It is strongly reminiscent of that met with in *Mesopalæaster primus* (Text-fig. 46, p. 86). The centre of the disc is occupied by a number of small plates, arranged approximately in two circles. Outside this is a circle of ten plates, five primary radialia and five primary interradialia. The primary interradialia are a little larger than the primary radialia. As stated above, the madreporite is not associated with a primary interradial as in the true Asteroidea, but is oral in position. Distal (and oral) to the primary interradialia are a number of plates (*Ir.*) occupying the same position as do the intermarginalia in *Mesopalæaster*. The radialia are hexagonal plates alternating in the proximal region of the arm with the supero-marginalia, and separated from these latter plates at the very base of the arm by a few adradialia. Just below the supero-marginalia, and except in compressed specimens only showing in side view, are two rows of

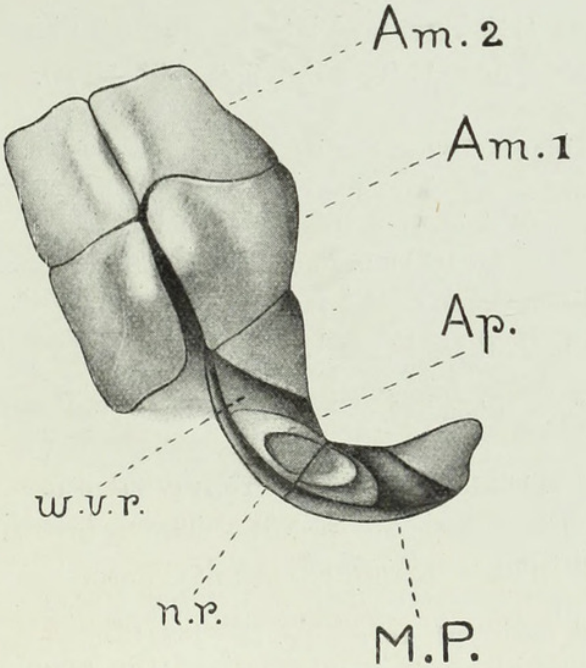
distinct large plates (infero-marginalia), which are again succeeded by the small accessory plates (only seen in side or oral view). A drawing is given (Text-fig. 158, p. 221) to show the shape and ornament of these plates. The supero-marginalia overlap and are what I have called "bent finger" shaped. The series outer to



TEXT-FIG. 163.—(*a*) On right. Wash-drawing of the apical surface of the proximal ambulacralia of *Palasterina primæva* (from Sedgwick Mus.). $Am._1$, first ambulacral; $Am._2$, second ambulacral; $Am._3$, third ambulacral. × 10. (*b*) On left. Lateral view of apical surface of adambulacralia. *P.*, proximal; *D.*, distal direction. × 18.

this are very similar. If seen in position in side view they appear V-shaped. Probably the shapes of both series may be derived from what I have called the half-moon shape in the case of *Uranaster* (see p. 110).

The ornament on the plates is very distinct from that of *Schuchertia*. On each ossicle is a central eminence which carried a long spine. Small pustules, which



TEXT-FIG. 164.—Adoral view of the mouth-frame of *Palasterina primæva* (from Sedgwick Mus., no. 344). $Am._{1, 2}$, first and second ambulacralia; *Ap.*, apophysis; *M.P.*, mouth-angle plate; *n.r.*, groove for nerve ring; *w.v.r.*, groove for water-vascular ring. × 18.

doubtless carried small spines, are scattered around this. A somewhat similar ornament is figured by Schuchert for *Promopalæaster bellulus* and *P. spinulosus* (1915, pl. xv, fig. 7; pl. xviii, fig. 8).

Several specimens have the apical covering displaced and show the upper surface of the ambulacralia. Text-fig. 163 gives such a view in the region of the

mouth. The first ambulacralia are somewhat long and touch only at their distal ends. Each of the succeeding ossicles has a high median ridge (for the attachment of the dorsal transverse muscle) and a lateral swelling. The line of junction of successive ossicles is very close, and it appears as if the dorsal longitudinal muscles were of small importance.

An excellent apical view of the mouth-frame (Text-fig. 164) was obtained by dissolving an embedded calcite specimen and taking casts as the process proceeded. The arrangement of the various exposed parts is exactly as in Text-fig. 133, p. 191, except that (*a*) the first ambulacralia do not dip so steeply, and (*b*) the basal portion of the mouth-angle plate does not project so far into the mouth-cavity, (*c*) the interradial faces of the apophyses show depressions for the adductor muscles, but the adradial faces are smooth, suggesting that abductor muscles were absent (see p. 192).

Measurements.—The species varies in size between the following limits : largest specimen on slab *a*, Sedgwick Museum, R : r :: 18 mm. : 5 mm. ; smallest specimen on slab *a*, Sedgwick Museum, R : r :: 8 mm. : 3 mm.

Horizon and Locality.—Upper Silurian (Ludlow) ; Westmoreland.

2. **Palasterina antiqua** (Hisinger). Plate IV, fig. 6; Plate XV, fig. 9; Plate XVI, figs. 1, 2; Text-figs. 165—170.

1837. *Asterias antiqua*, Hisinger, Lethea Suecica, p. 89, pl. xxvi, fig. 6.
1857. *Palasterina primævus*, Salter, Ann. Mag. Nat. Hist. [2], vol. xx, p. 327, pl. ix, figs. 2 *a*—*c*.
1862. „ „ Wright, Mon. Brit. Foss. Echin., Oolitic, vol. ii, pt. 1 (Palæontogr. Soc. for 1861), p. 26, fig. 16 *a*.
1899. *Lindstromaster antiqua*, Gregory, Geol. Mag. [4], vol. vi, pp. 343, 347, pl. xvi, figs. 1 *a*, 1 *b*.
1899. *Palasterina bonneyi*, Gregory, *loc. cit.* [4], vol. vi, pp. 349, 350, pl. xvi, figs. 2 *a*, *b*; text-figs. 1—3.
1910. *Lindströmaster antiqua*, Schöndorf, Jahrb. Nassauisch. Ver. Naturk., Wiesbaden, vol. lxiii, p. 225.
1910. *Palasterina bonneyi*, Schöndorf, *loc. cit.*, vol. lxiii, pp. 223, 250.
1914. *Lindströmaster antiquus*, Schuchert, Fossilium Catalogus, Animalia, pt. 3, p. 23.
1914. *Palasterina bonneyi*, Schuchert, *loc. cit.*, Animalia, pt. 3, p. 31.
1915. *Lindströmaster antiquus*, Schuchert, Bull. 88, U.S. Nat. Mus., pp. 149, 153.
1915. *Palasterina bonneyi*, Schuchert, *loc. cit.*, pp. 15 , 152, 153.
1916. „ *primæva*, Spencer, this Monograph, pl. iv, fig. 6.

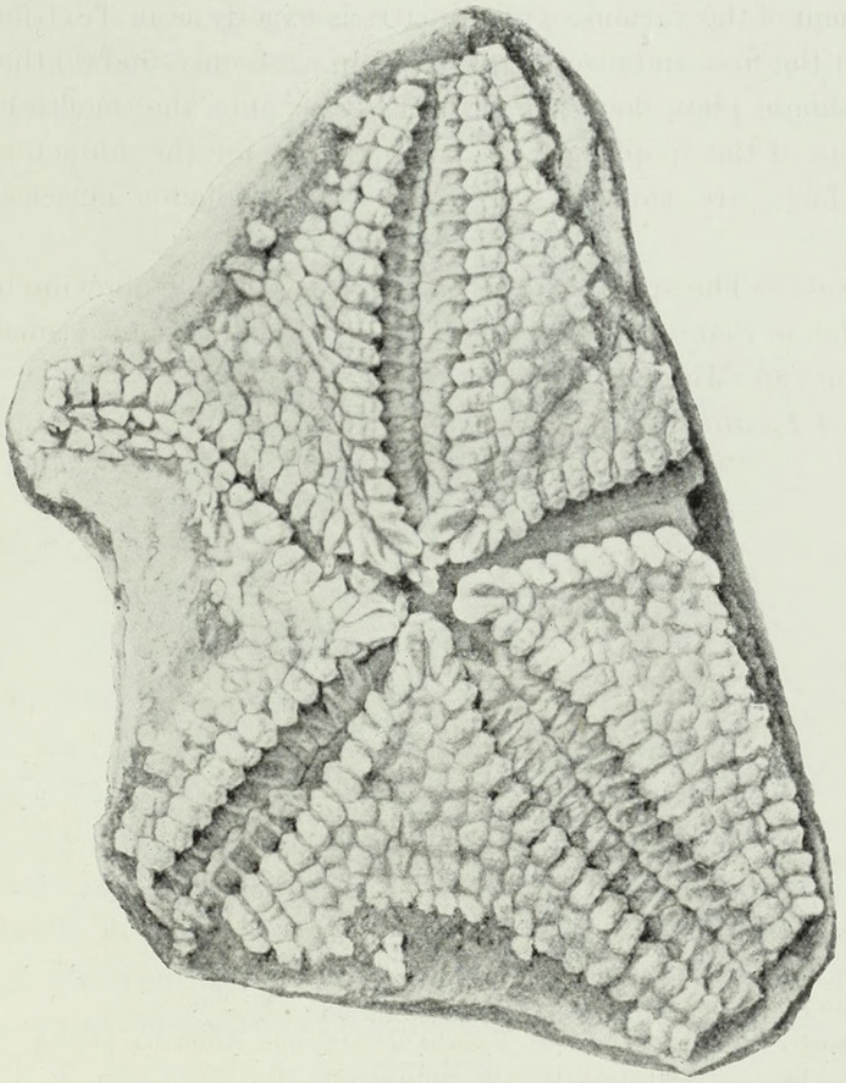
Material.—I have placed in this species five specimens showing the oral surface, two being from the same horizon :

(1) The type of *Lindströmaster antiquus*, in the Angelin Collection of the Mineralogical Museum, Copenhagen (no. 306), from the Ludlow of Gotland.

(2) A new specimen from the Wenlock of Dudley, in Sir Charles Holcroft's collection at the museum of the University of Birmingham (no. 1).

(3) A new specimen from the Wenlock of Gutterford Burn, in the Royal Scottish Museum, Edinburgh.

The fourth and fifth specimens are from a slightly higher horizon, the Lower Ludlow of Church Hill quarries, Leintwardine, and are in the British Museum (Nat. Hist.). One of these is the type of Gregory's species *P.* "*bonneyi*," and shows both oral and apical surfaces (no. 40299). The second specimen shows only the apical surface (no. 40301).



Text-fig. 165.—Liljevall's original drawing of *Palasterina antiqua* (reproduced from 'Geol. Mag.,' 1899, pl. xvi, fig. 1 *b*). × 4.

Although there are differences between the specimens I think that they can be best explained as due either to the age of the individual animal, accidents in preservation, or slight differences in the geological horizon.

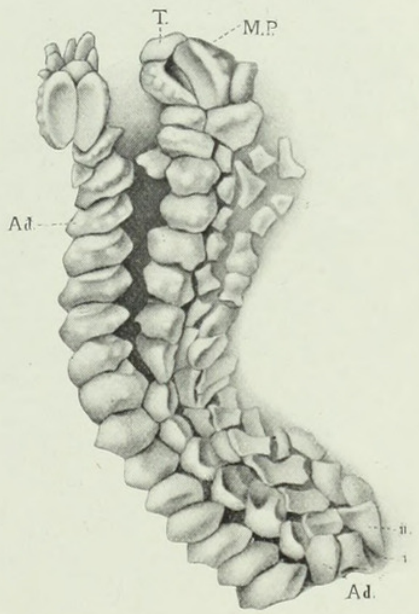
Specific Characters.—See p. 220.

(1) *Description of Type-Specimen from Gotland* (*Text-fig.* 165).

If we turn to the illustration (Text-fig. 165), we observe that at first sight there are, apparently, infero-marginalia at both sides of the arms pointing S.E. and

N., that is, we seemingly have a pentagonal form with large ventral interradial areas bounded by infero-marginalia, many of which have fallen away. It was this appearance which led Gregory to place the form among the Phanerozonate Asteroidea. Gregory stated that "both supero- and infero-marginals are present." I cannot see any trace of supero-marginals.

Schuchert (1915, p 149), in his remarks on this species, stated that "it is probable that the marginals in *Lindströmaster* which Gregory thinks are both supra- and infra-marginals lying directly superposed are only infra-marginals." He also states that "when more material is obtained and the genus is re-studied, comparisons should also be made with *Palasterina primæva*, as the two forms



Text-fig. 166.—Drawing of an arm of *Palasterina antiqua* (type-specimen). *Ad.*, adambulacral; *M.P.*, mouth-angle plate; *T.*, torus. × 5.

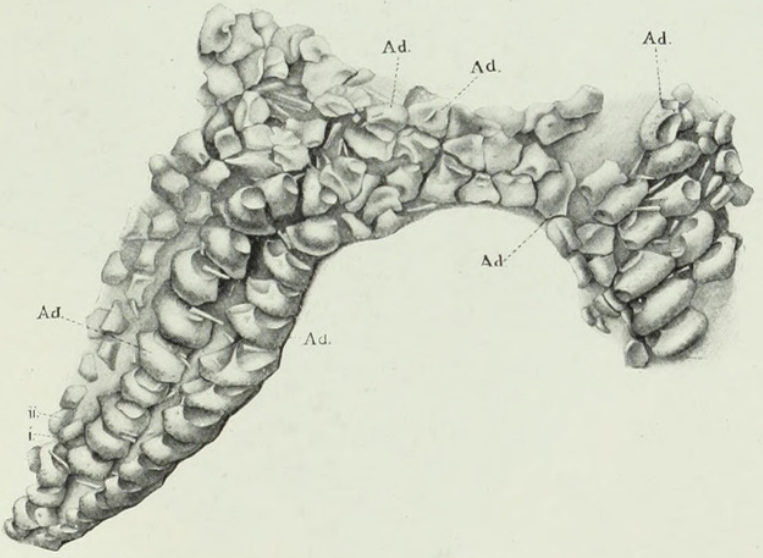
appear to have much in common." Prof. Lindström, who lent the specimen to Gregory, referred the form to *Palasterina*.

If the form belonged to *Palasterina*, many of the ossicles in the interradii must be really ossicles from the lateral surfaces squeezed into their present position by post-mortem distortion. Both the original drawing and an electrotype of the specimen in the collection of the British Museum (Nat. Hist.) suggested that this was the case, and in order to clear the matter up I applied to the authorities of the Copenhagen Museum for permission to re-examine the specimen. By the courtesy of Dr. Ravn this was granted.

The arm pointing east was cleared of matrix and turns out to be a long cylinder stretching to within a short distance of the odontophor. The plates in the interradius are therefore those squeezed over from the neighbouring arm. A drawing has been made of the first-mentioned arm (Text-fig. 166), and it illustrates well the cylindrical structure and the typical *Palasterina* appearance. The mouth-angle plates are almost exactly similar to those of *P. primæva*, and the adambula-

cralia are stout with a coarse, pustulose ornament. Alongside the adambulacralia are the small accessory plates seen in the type species. These are succeeded by almost oblong infero-marginalia. At the extremity of the arm are a few swollen apical plates similar to those figured in Text-fig. 158, p. 221.

The mouth-angle plates carry a torus with stout flat spines. The oral surfaces of the adambulacralia are not so rounded as in *P. primæva* but almost identical with the same surfaces in *P. follmanni*. The groove in this arm is closed over but is open in other arms (Text-fig. 165). The ambulacralia are closely similar to those in *P. primæva*, except that they have a slight thickening where they overlap the preceding plate. An odontophor is visible in the interradial angle. The arms are distinctly petaloid.



TEXT-FIG. 167.—Drawing of an arm and the base of a second arm of *Palasterina antiqua* (from specimen in University of Birmingham Museum). *Ad.* indicates rows of adambulacralia. × 5.

Measurements.—None of the arms is visible in full length, although it is probable that the arm pointing east is nearly so. This possesses seventeen adambulacralia and has R = 16·5 mm., r = approximately 6 mm.

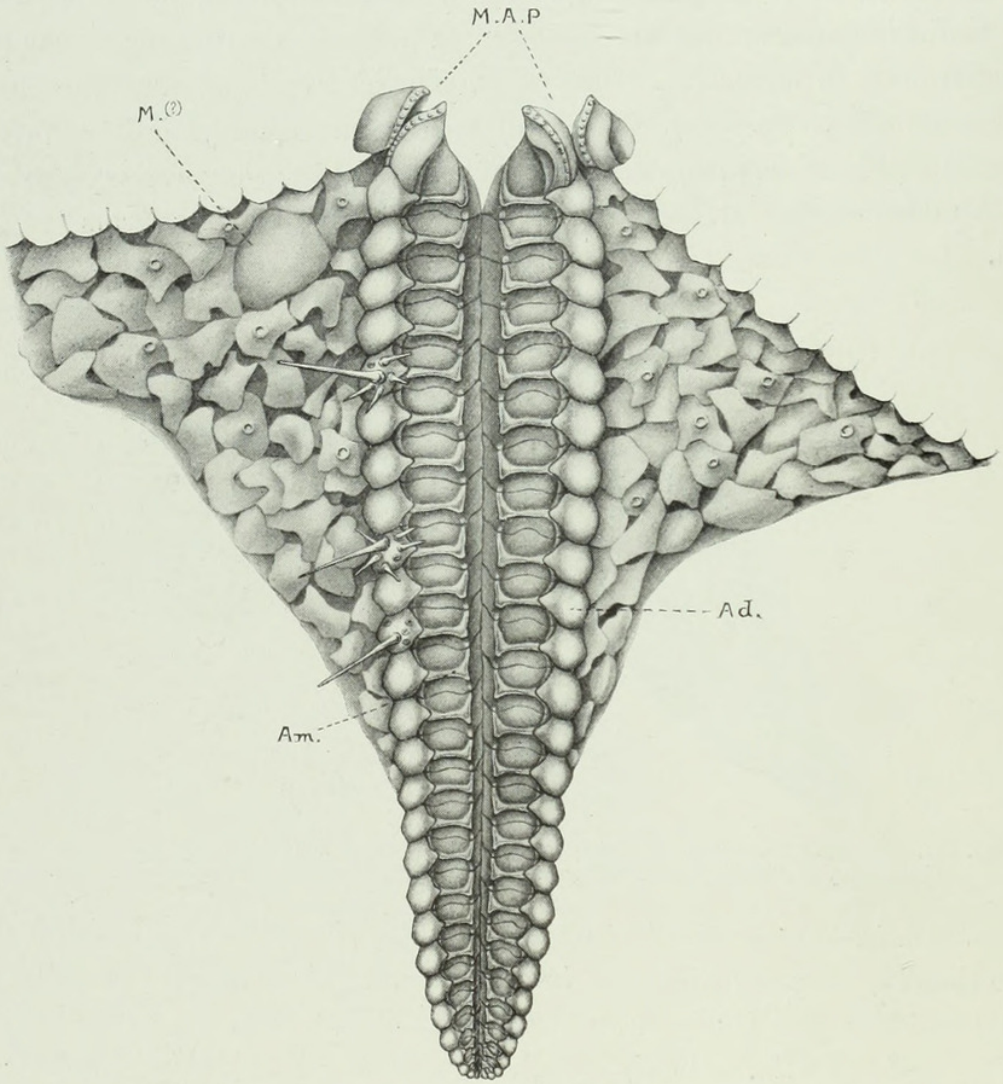
Horizon and Locality.—Originally given as Lower Wenlockian (Bed C), but the Hamra Limestone is now correlated with Upper Ludlow ; S. Udde, Gotland.

(2) *Description of the Specimen from the Wenlock Limestone of Dudley* (*Text-fig.* 167)·

The mouth-region of the specimen seems to be imperfect and mouth-angle plates are not recognisable. In spite of this, there can be no hesitation in referring the specimen to *Palasterina*. The general form of the arm and the stout, swollen adambulacralia are exactly similar to those of *P. primæva*, except that they do not seem to show a ridge. The first few adambulacralia are rather irregular in form and remind one of the proximal adambulacralia in *Lepidactis wenlocki* (see p. 115). The stout adambulacral spines are preserved. Alongside the adambulacralia is the usual row of accessory plates. Beyond these again is a row of swollen infero-marginalia. The plates filling up the interradial areas are rather irregular in shape.

Measurements.—The specimen is of almost exactly the same size as the type of the species. R. is approximately 17 mm. and there were apparently about 18 adambulacralia on each side of an arm; r. is approximately 6 mm.

Horizon and Locality.—Wenlock Limestone; Dudley, Worcestershire.



Text-fig. 168.—Drawing of an arm and the neighbouring interradii of *Palasterina antiqua* (specimen previously referred to *Palasterina bonneyi*, Gregory). *Ad.*, Adambulacralia; *Am.*, ambulacralia; *M.* (*?*), madreporite?; *M.A.P.*, mouth-angle plate. × 10.

Remarks.—The specimen differs from the type in the swollen nature of the adambulacralia and the greater irregularity of the interradial plates. These do not seem to me to warrant specific distinction. In the absence of more material I do not think it is advisable to name the variety.

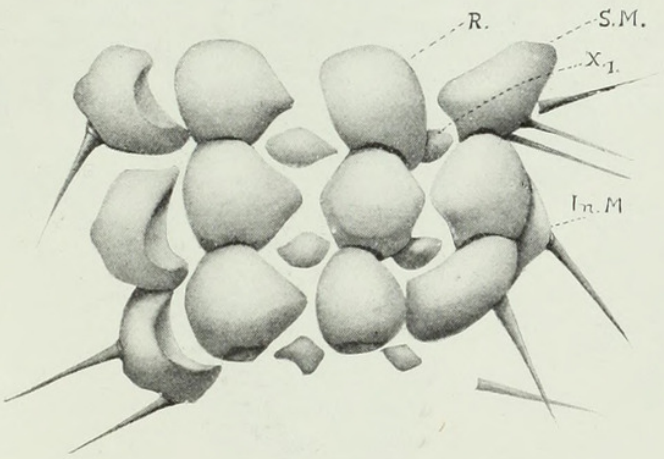
(3) *Description of* "Palæasterina bonneyi" (*Pl. XVI, fig.* 2; *Text-fig.* 168).

Material.—Two imprints, one with counterpart, in the British Museum (Nat. Hist.), nos. 40299 and 40301 respectively. The former is the specimen described by Salter as *P. primævus* in 1857. Gregory later described it as a new species,

P. bonneyi, but neither he nor other authors appear to have recognised that the specimen was the "*P. primævus*" of Salter. The form has been somewhat distorted by post-mortem pressure. Specimen 40301 shows the apical surface only.

Oral Surface (Pl. XVI, fig. 2; Text-fig. 168).—The groove has been forced widely open and in consequence appears to be shallow. The ambulacralia are exposed in full length. They are opposite or slightly alternating in the proximal region, distinctly alternating distally, and have the usual structure associated with these primitive forms. The small size of the adambulacralia makes their ornament difficult to determine. So far as one can see, there was no distinct adambulacral ridge, but the spines seem to have been distributed all over the face of the ossicle. The majority of the spines appear to have been long.

The mouth-angle plates look like poorly preserved smaller editions of the corresponding structures in *P. primæva*.



TEXT-FIG. 169.—Drawing of a small portion of the apical surface of an arm of *Palasterina antiqua* (=*P. bonneyi*). *In.M.*, inter-marginalia; *R.*, radial; *S.M.*, supero-marginal; x_1, adradial. × 20.

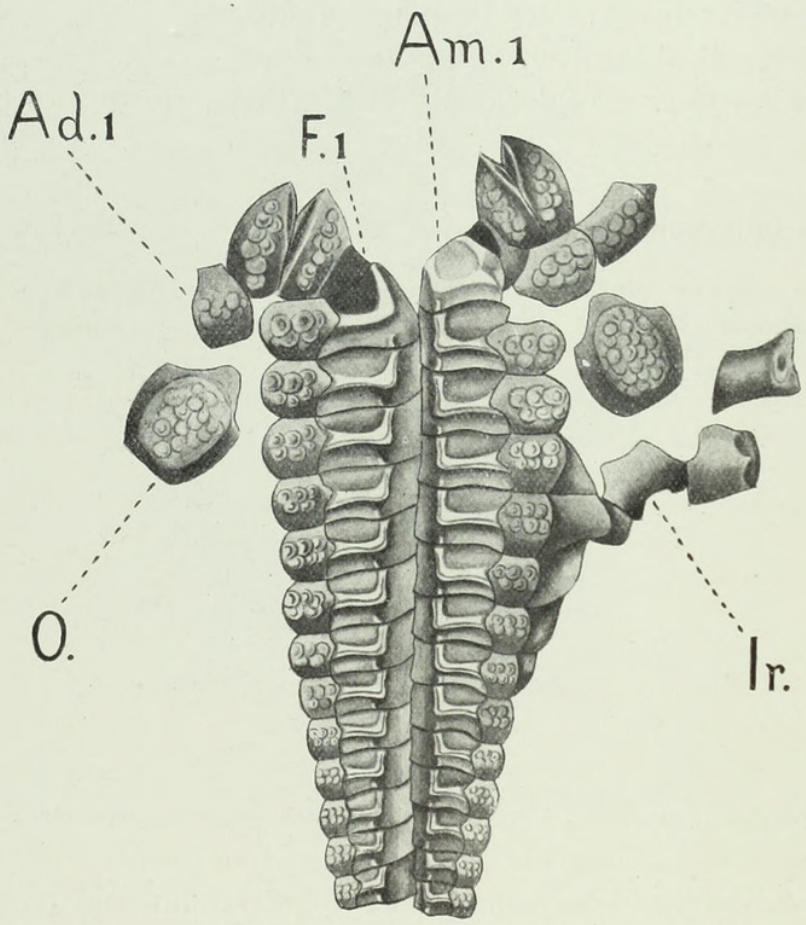
The interradial areas are much more extensive than in *P. primæva*, but the extent varies so much in the different radii (Pl. XVI, fig. 2) that one can only suppose that the body was considerably swollen during life, and that the plates now seen on the oral surface once formed the lateral interradial walls of the disc. The plates are not pavement-like, as in Gregory's figures, but rounded. Some show rounded articulations for spines. A plate shaded in the figure may represent the madreporite, but one cannot be certain of the madreporiform markings.

Apical Surface (Pl. XVI, fig. 1; Text-fig. 169).—The apical surface is so very like that of *P. primæva* that I do not consider it necessary to figure it in detail. One must note, however, that certain of the plates in the centre of the disc which are visible in the photograph, and have been previously figured as disc plates, are really the mouth-angle plates pushed through the apical covering after death. Adradialia are more numerous than is usual in *P. primæva*, but this one would expect because of the swollen nature of the arms.

Measurements.—R is 13·5 mm.; r varies from 5 mm. to 6·5 mm.

Horizon and Locality.—Upper Silurian (Lower Ludlow); Church Hill Quarry, Leintwardine, Salop.

Remarks.—The presence in the fossils of large areas in some of the interradii gives a very strong resemblance to the type. The interradial plates are more irregular than in the type. The adambulacral spines appear to be longer than is usual in other specimens of *Palasterina*.



Text-fig. 170.—Oral view of a portion of the disc and arm of *Palasterina antiqua* (specimen in Royal Scottish Mus.). *Ad.*$_1$, first adambulacral; *Am.*$_1$, first ambulacral; *F.*$_1$, the cup for the first tube-foot; *Ir.*, interradial plates; *O.*, odontophor. × 25.

(4) *Description of the Small Form from Gutterford Burn* (Pl. XV, fig. 9; Text-fig. 170).

Material.—One mould in sandstone in the Royal Scottish Museum, Edinburgh. The oral surface only is shown, and that rather imperfectly.

Description.—Text-fig. 170 gives a portion of one arm and the neighbouring interradii. The mouth-angle plates are of the usual *Palasterina* type, swollen, with a wide gape and showing the inner coarsely ornamented area. The groove is widely open and has obviously suffered somewhat from post-mortem distortion. The ambulacralia are as in "*P. bonneyi*." The adambulacralia also are much as in that form. The ornament is very conspicuous and there is no ridge.

The first adambulacral is the largest. The arm must have been uniformly tapering, not petaloid.

The interradii may extend to about the fourth or fifth adambulacral. There is considerable variation in the different interradii. Some show no ossicles except the odontophor. This latter plate has considerable resemblance in general form to that in *Eoactis*, and suggests that *Palasterina* descended from a form with a conspicuous odontophor. It differs from the odontophor in *Eoactis* in being more swollen and in possessing a coarse pustulose ornament.

Measurements.—R : r :: 4 mm. (approx.) : 2 mm.

Horizon and Locality.—Wenlockian (Starfish Bed); Gutterford Burn, Pentland Hills.

3. **Palasterina follmanni,** Stürtz. Plate XVI, figs. 3—7; Text-fig. 171.

1890. *Palasterina follmanni*, Stürtz, Palæontographica, vol. xxxvi, p. 226, pl. xxix, figs. 29—31 *a*.
1900. *Pseudopalasterina follmanni*, Stürtz, Verhandl. naturhist. Ver. preuss. Rheinl., vol. lvi, pp. 219, 224.
1914. *Pseudopalasterina follmanni*, Schuchert, Fossilium Catalogus, Animalia, pt. 3, p. 36.
1915. *Pseudopalasterina follmanni*, Schuchert, Bull. 88, U.S. Nat. Mus., pp. 156, 157.

Material.—There are nine specimens of this species in the British Museum (Nat. Hist.), three figured by Stürtz (nos. E. 3469, fig. 29; E. 3470, figs. 30, 30 *a*; E. 3471, fig. 31), the remaining six registered as E. 5004 (specimen mentioned by Stürtz, p. 224), E. 13625, E. 13626, E. 13629, E. 13635 and E. 13636.

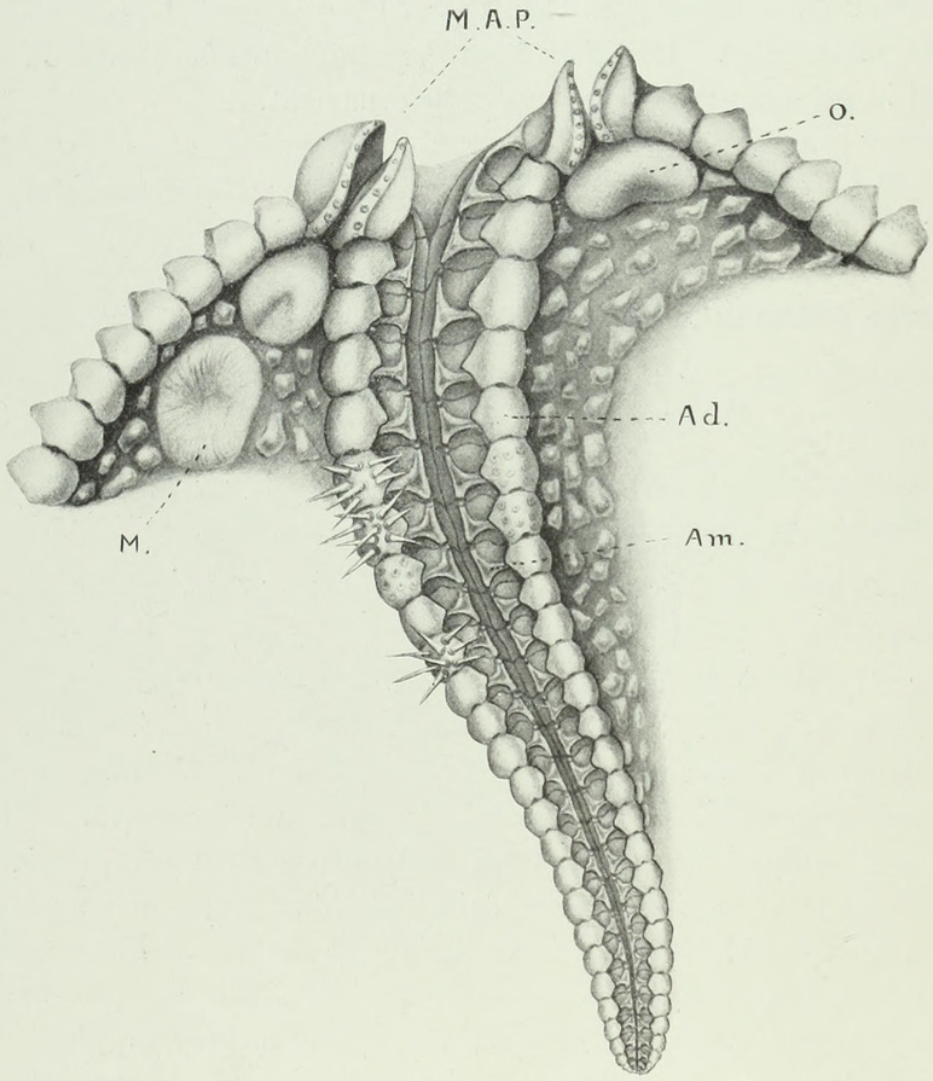
The photographs given on Pl. XVI are designed to show the somewhat varying appearances due to differences in fulness of growth. The smaller specimens are compact in appearance, and post-mortem compression has not greatly changed their outline. Age in the individual seems to have been accompanied by a considerable increase in the height of the arm. The general surface of the body becomes, in consequence, more slightly built, and post-mortem compression causes considerable distortion. The specimen photographed in Pl. XVI, fig. 4, has had its arms distorted by lateral compression, but the ossicles remain for the greater part in their original apical position. That photographed in fig. 7 has been subject to dorso-ventral compression, and the apical ossicles are forced into some of the oral interradial areas. The series is valuable in supporting the view that in other species of *Palasterina*, in which the material is not nearly so complete, the large interradial areas are produced secondarily and were not a feature of the living form.

In several of the specimens the distal half of one or more arms is bent back, so that, if only the oral surface be seen, the arms appear to be much foreshortened.

This is noticeably the case in E. 13629 (Pl. XVI, fig. 6), where all the arms have been preserved in this way.

Specific Characters.—See p. 220.

Oral Surface (Pl. XVI, figs. 3—7 ; Text-fig. 171).—The text-figure is drawn from one of the smaller individuals (R = 36 mm.). The mouth-angle plates are of the typical *Palasterina* type. Immediately behind them is a stout odontophor as in *P. scotiæ*, but it is not swollen or ornamented as in that form. Behind the odontophor in the left interradius is a large madreporite of the same form as that



Text-fig. 171.—Drawing of an arm and the neighbouring interradii of *Palasterina follmanni*. *Ad.*, adambulacralia ; *Am.*, ambulacralia ; *M.*, madreporite ; *M.A.P.*, mouth-angle plates ; *O.*, odontophor. × 2.

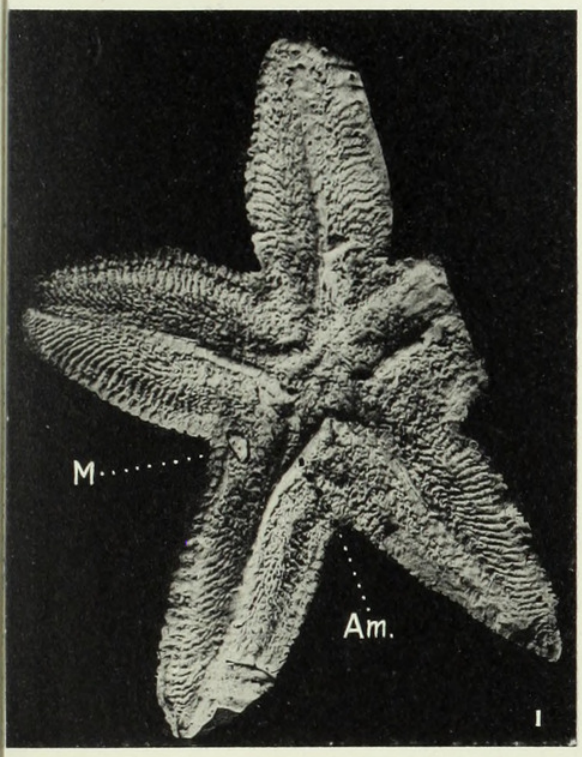
in *P. primæva*. The remaining plates in the interradii are small and identical in shape and ornament with those on the apical surface.

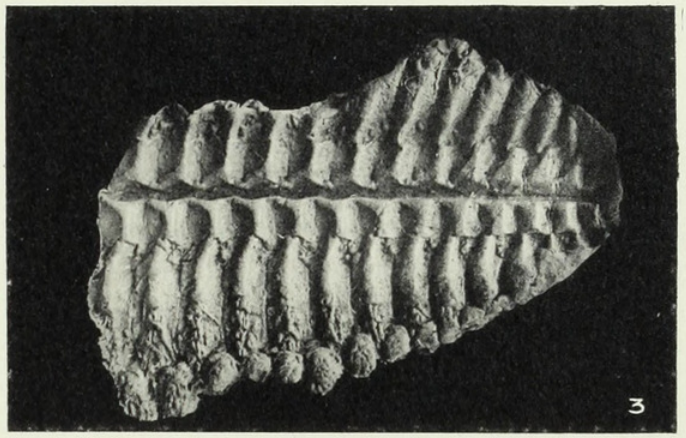
The groove is widely open and the ambulacralia are seen clearly. They are of the primitive type found in the forms of this lineage. They seem to be opposite throughout the length of the arm drawn. This is the condition in three of the arms of the specimen. In the other two arms the ambulacralia alternate in the distal region. The adambulacralia are only slightly swollen on their ornamented surface. The ornament consists of three groove-spines and stout sub-ambulacral spines distributed uniformly over the plate.

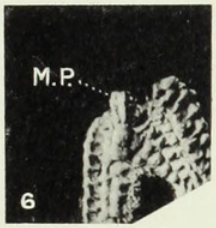
PLATE XIV.

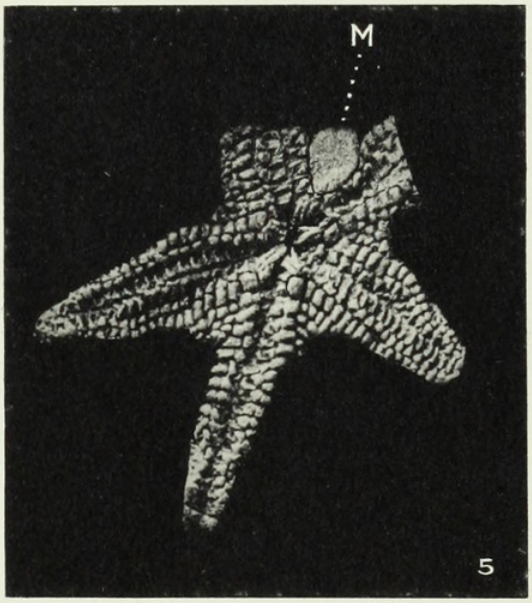
Fig.		Page.
1.	*Platanaster ordovicus*, n. sp.; photograph of the apical surface, nat. size.—Upper Ordovician (Caradocian); Cound, Madeley, Salop. Museum of Practical Geology, Jermyn St., no. 8238.	171.
2.	Ditto; photograph of the oral surface of the counterpart of the same specimen, nat. size. Museum of Practical Geology, Jermyn St., no. 25347.	171.
3.	Ditto; photograph of a portion of oral surface of the arm of the same specimen, × 4.	171.
4.	*Palasteriscus devonicus* (Stürtz); photograph of the apical surface, two-thirds nat. size.—Lower Devonian; Bundenbach, Germany. British Museum (Nat. Hist.), no. E. 5026.	176.
5.	*Schuchertia wenlocki*, n. sp.; photograph of the oral surface, × 2.—Middle Silurian (Wenlock); Gutterford Burn, Pentland Hills. Royal Scottish Museum, no. 32/485.	215.
6.	Ditto; photograph of a portion of the oral surface of another individual, × 2.—Ibid. Royal Scottish Museum, no. 32/484.	215.

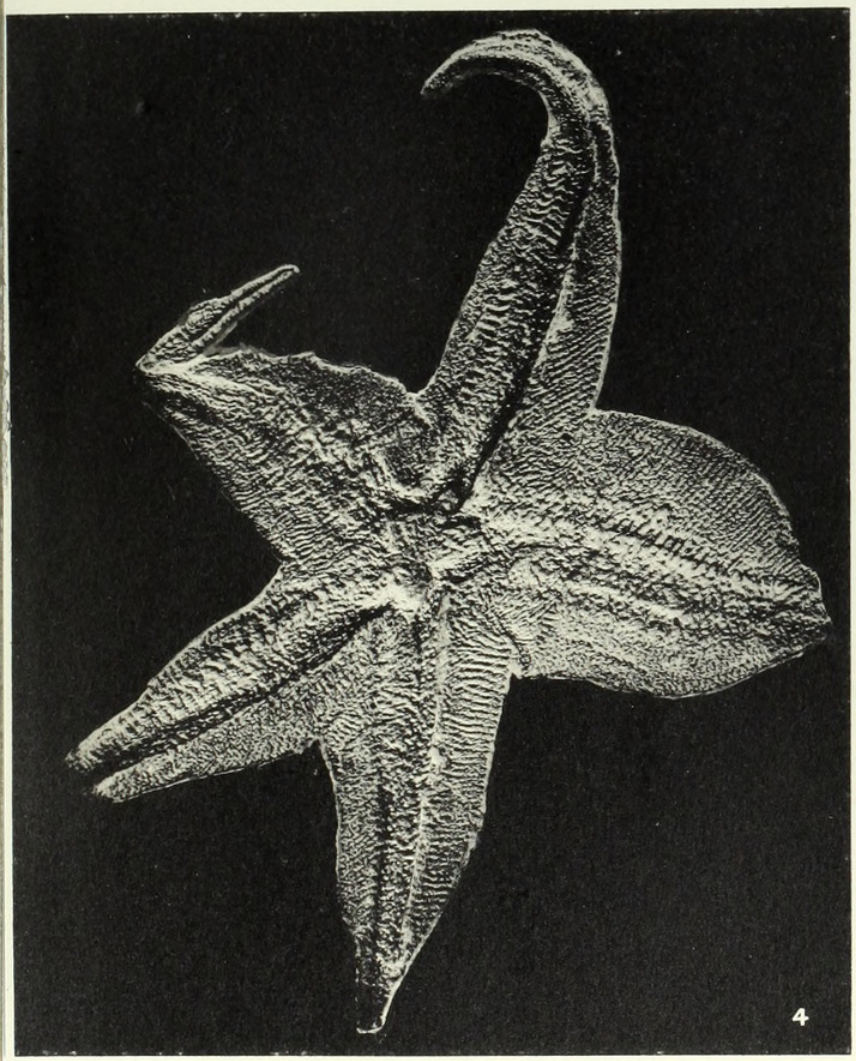
M. = madreporite; M.P. = mouth-angle plate.


M
Am.
1


3


M.P.
6


M
5


4

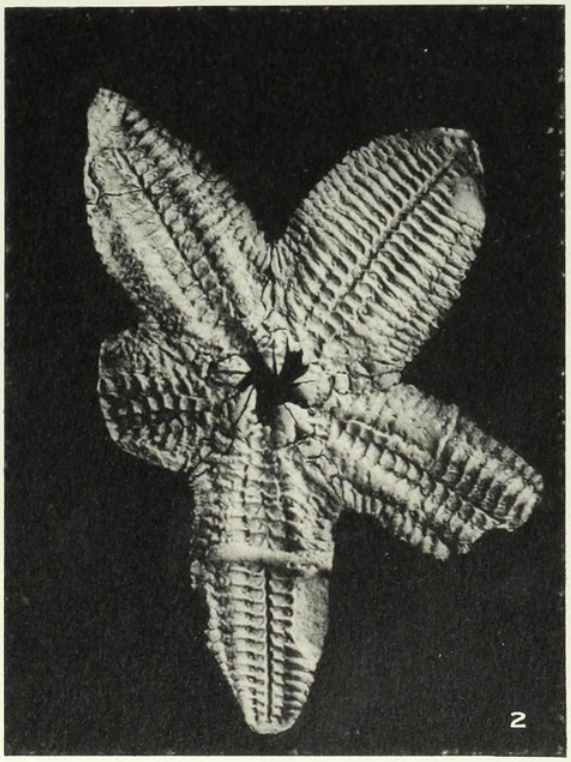
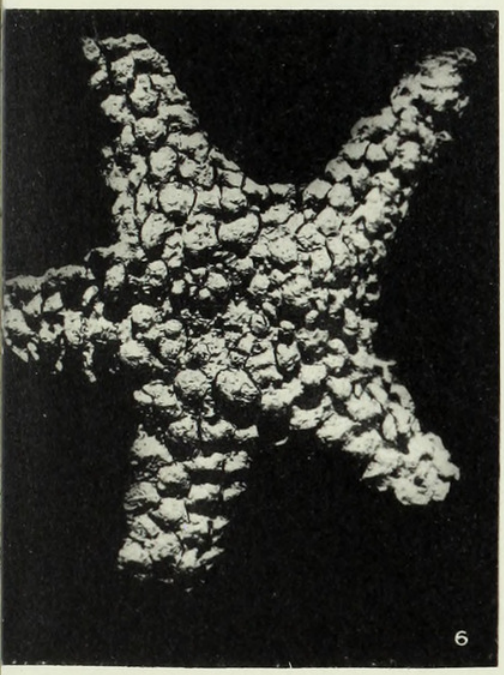
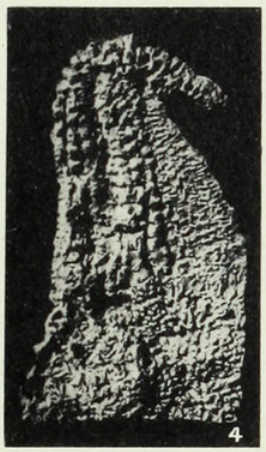

2

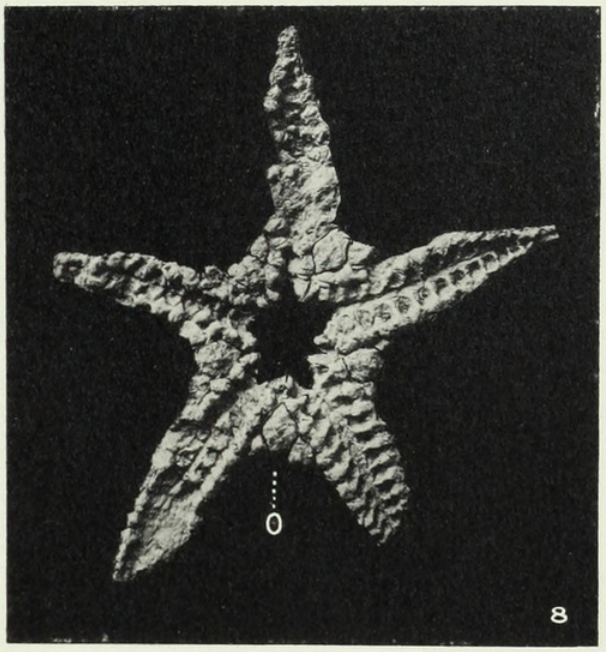
PLATE XV.

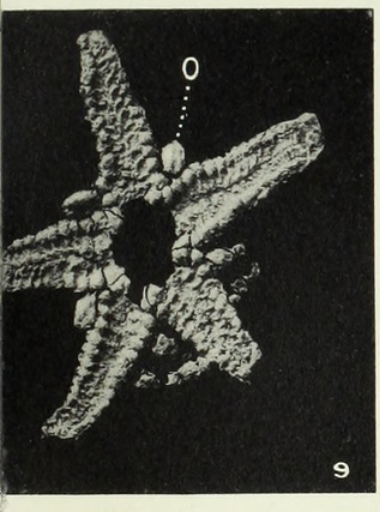
Fig.		Page.
1.	*Schuchertia laxata*, Schuchert; photograph of the apical surface, × 2.—Upper Ordovician (Ashgillian); Thraive Glen, Ayrshire. Mrs. Gray's Collection, no. D. 330.	212.
2.	*Schuchertia wenlocki*, n. sp.; photograph of a portion of the oral surface to show detailed structure of the ambulacral groove, × 10.—Middle Silurian (Wenlock); Gutterford Burn, Pentland Hills. Royal Scottish Museum, no. 32/484.	215.
3.	Ditto; photograph of an interradial angle of the specimen figured Pl. XIV, fig. 5, × 3.	215.
4.	Ditto; photograph of a portion of the apical surface, × 2.—Ibid. Royal Scottish Museum, no. 32/480.	215.
5.	*Palasterina primæva* (Forbes); photograph of the apical surface of one of Forbes' types, × 3.—Upper Silurian (Lower Ludlow, Bannisdale Slates); High Thorns, Underbarrow, Westmoreland. Sedgwick Museum, Cambridge, no. a/517 (slab d).	223.
6.	Ditto; photograph of the apical surface of another individual, × $4\frac{1}{2}$.—Bannisdale Slates; ? Underbarrow. Sedgwick Museum, Cambridge, no. 48.	223.
7.	Ditto; photograph of the oral surface of another individual, × $4\frac{1}{2}$.—Ibid. British Museum (Nat. Hist.), no. E. 4991.	223.
8.	*Eoactis simplex*, Spencer; photograph of the oral surface, × $4\frac{1}{2}$.—Lower Ludlow or Upper Wenlock; Hafod, Llandovery. British Museum (Nat. Hist.), no. E. 13154.	206.
9.	*Palasterina antiqua* (Hisinger); photograph of the oral surface of young individual, × $4\frac{1}{2}$.—Middle Silurian (Wenlock); Gutterford Burn, Pentland Hills. Royal Scottish Museum, no. 32/463.	228.

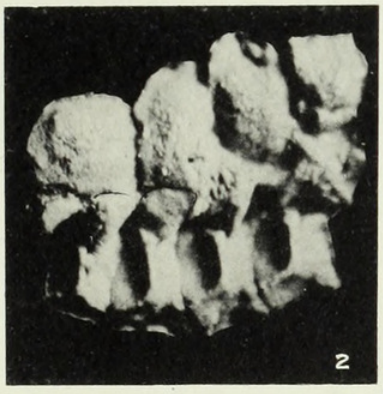
M. = madreporite; M.P. = mouth-angle plate; O. = odontophor.

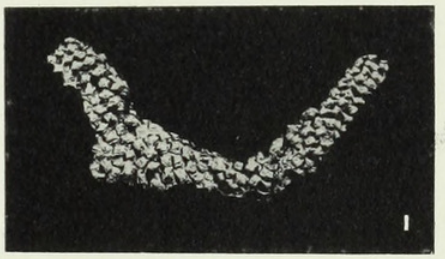


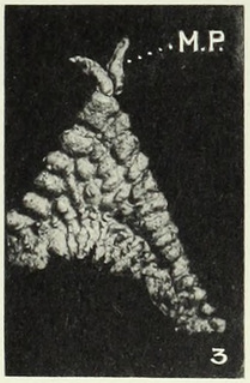


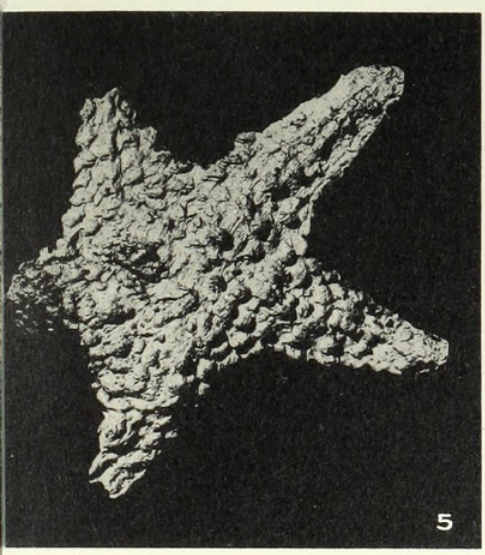


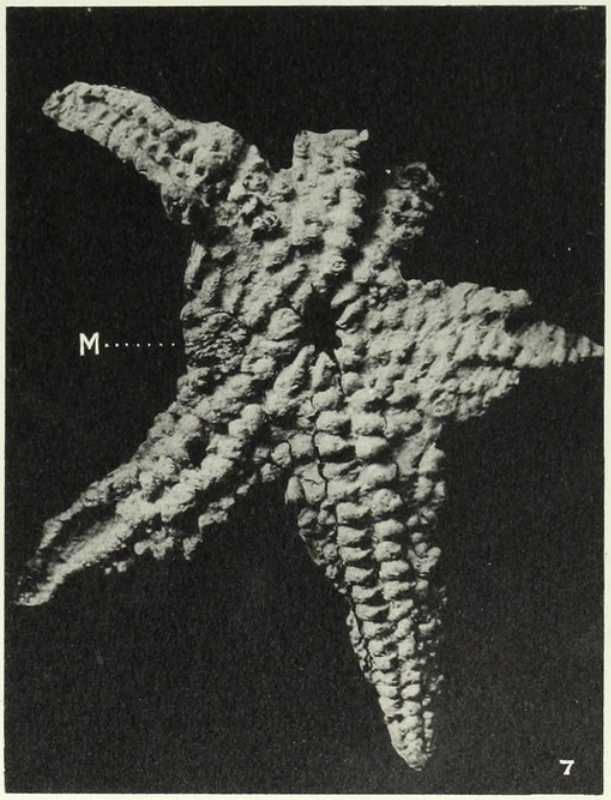










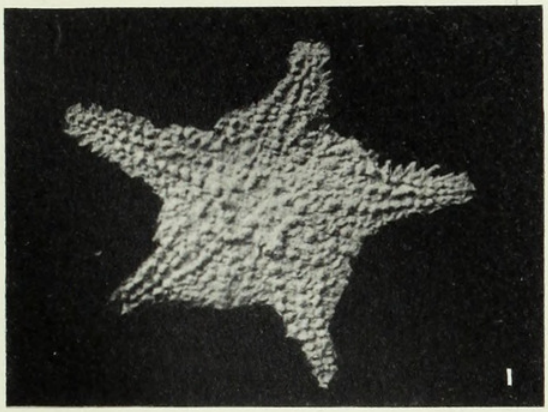


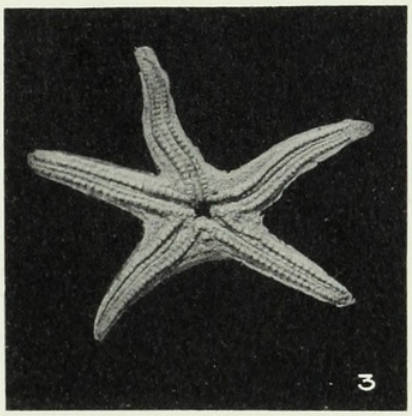
London Stereoscopic Co. Imp.

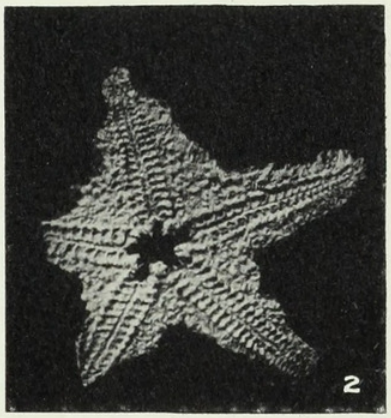
PLATE XVI.

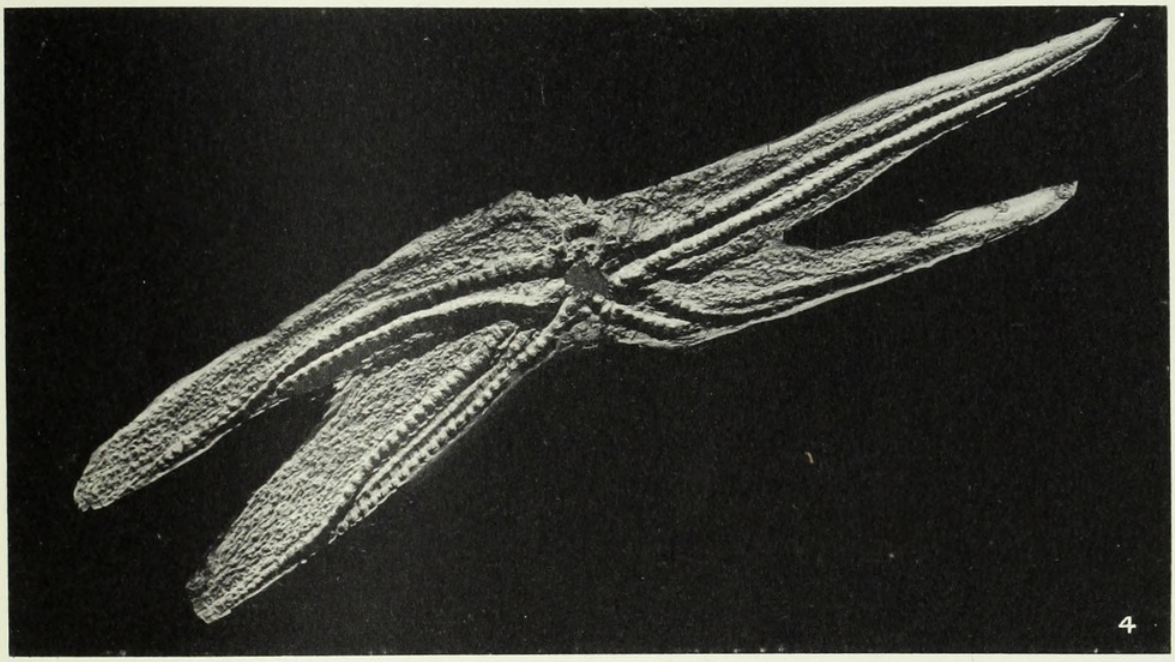
Fig.		Page.
1.	*Palasterina antiqua* (Hisinger); photograph of the apical surface, × 2.—Upper Silurian (Lower Ludlow); Leintwardine, Herefordshire. British Museum (Nat. Hist.), no. 40299.	228.
2.	Ditto; photograph of the oral surface, the counterpart of the specimen photographed in fig. 1, × 2.	228.
3.	*Palasterina follmanni*, Stürtz; photograph of the oral surface, × $\frac{3}{5}$.—Lower Devonian; Bundenbach, Germany. British Museum (Nat. Hist.), no. E. 13635.	235.
4.	Ditto; photograph of the oral surface, × $\frac{3}{5}$.—Ibid. British Museum (Nat. Hist.), no. E. 13625.	235.
5.	Ditto; photograph of the oral surface, × $\frac{3}{5}$.—Ibid. British Museum (Nat. Hist.), no. E. 13636.	235.
6.	Ditto; photograph of the oral surface, × $\frac{3}{5}$.—Ibid. British Museum (Nat. Hist.), no. E. 13629.	235.
7.	Ditto; photograph of the oral surface, × $\frac{3}{5}$.—Ibid. British Museum (Nat. Hist.), no. E. 13626.	235.
8.	*Schuchertia stellata* (Billings); photograph of the oral surface, × 4.—Middle Ordovician (Trenton); Ottawa, Canada. Geological Survey of Canada, no. 1399. (Reproduced from Schuchert, *op. cit.*, pl. xxxii, fig. 2.)	211.

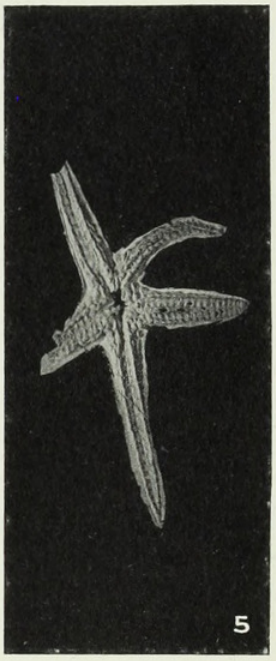
Spencer, Palæozoic Asterozoa. PLATE XVI

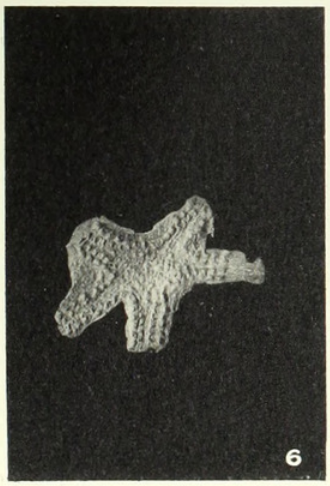

1

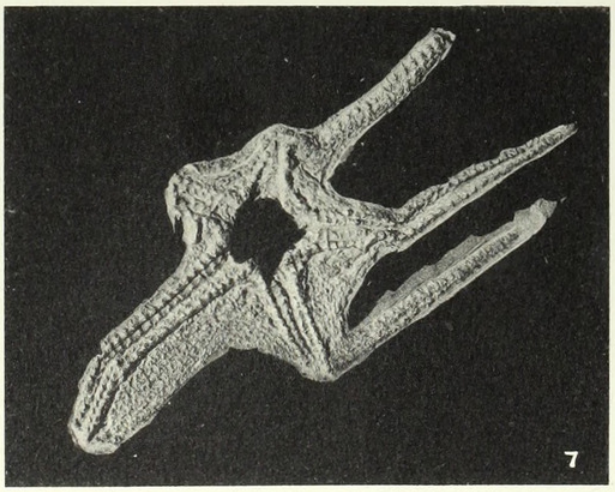

3

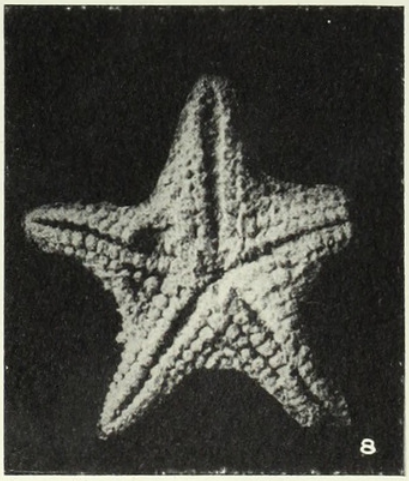

2


4


5


6


7

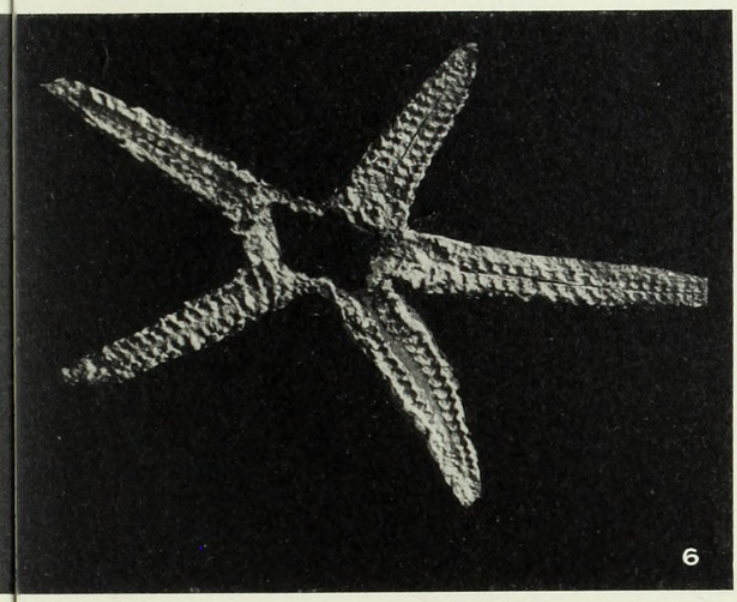

8

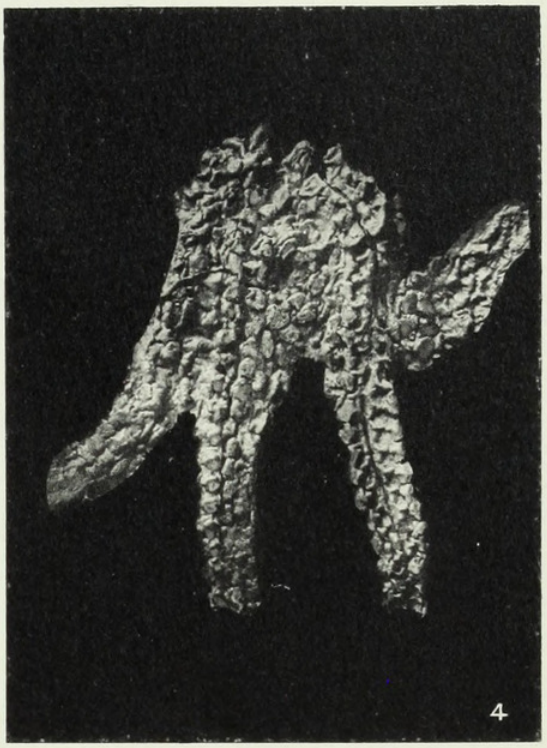
London Stereoscopic Co. Imp.

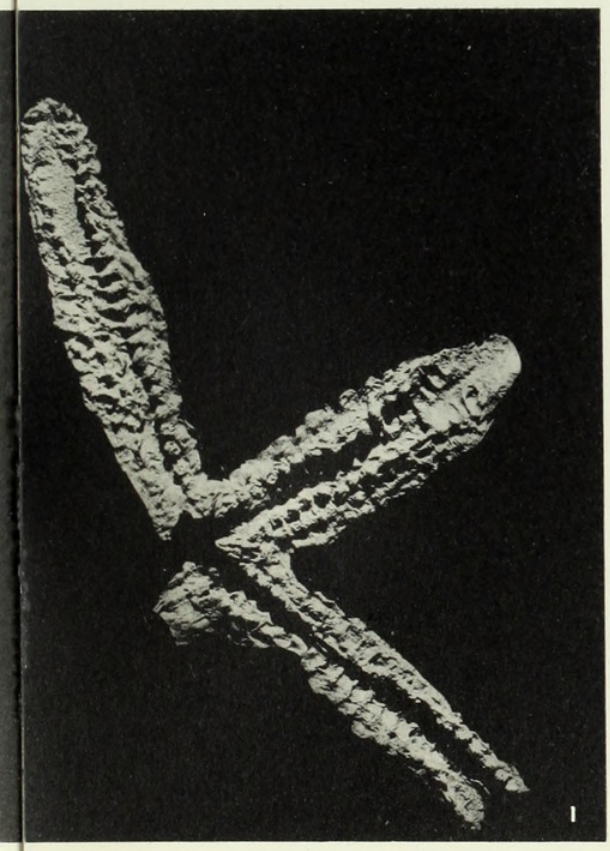
PLATE XVII.

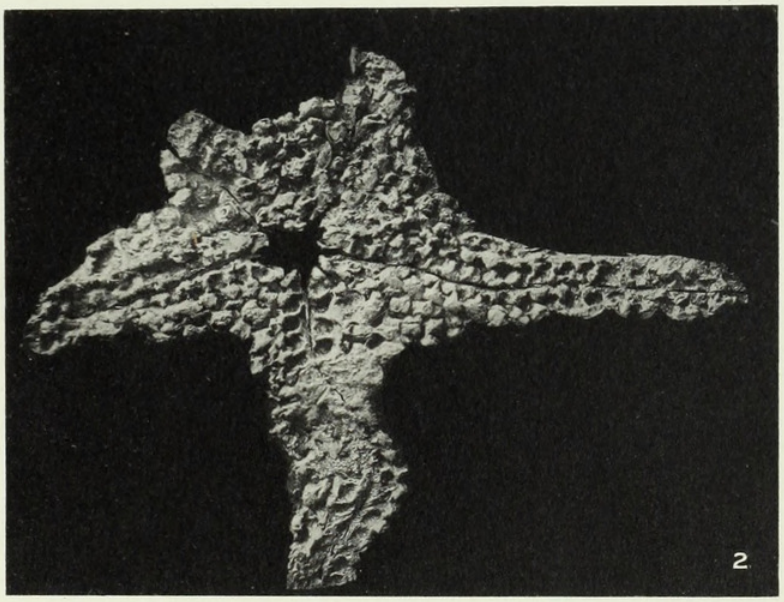
FIG. PAGE.

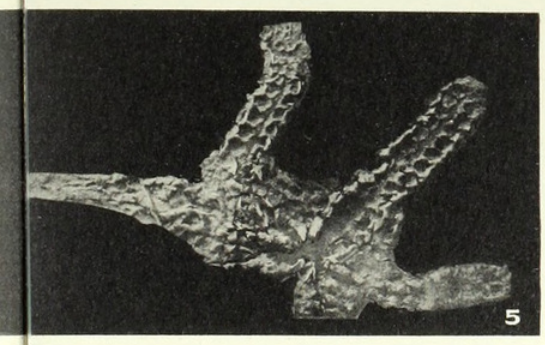
1. *Baliactis ordovicus*, n. gen., n. sp.; photograph of the oral surface, × 2. —Upper Ordovician (Caradocian); Habberley Brook, Shropshire. Shrewsbury Museum.
2. *Baliactis wenlockensis*, n. sp.; photograph of the oral surface, × 3½. —Middle Silurian (Wenlock); Gutterford Burn, Pentland Hills. Royal Scottish Museum, no. 32/439, 1897.
3. *Palasterina primæva* (Forbes); photograph of the oral surface of a group of individuals on the same slab, nat. size.—Upper Silurian (Ludlow); Westmoreland. Kendal Museum. 223.
4. *Tæniactis wenlocki*, n. sp.; photograph of individual with arms flexed upwards over the disc, × 4.—Middle Silurian (Wenlock); Gutterford Burn, Pentland Hills. Royal Scottish Museum, no. 32/522, 1897.
5. Ditto; photograph of the oral surface, × 4.—Ibid. Royal Scottish Museum, no. 32/498, 1897.
6. *Palæura ?*; photograph of the oral surface, × 1-2.—Ibid. Royal Scottish Museum, no. 32/469, 1897.

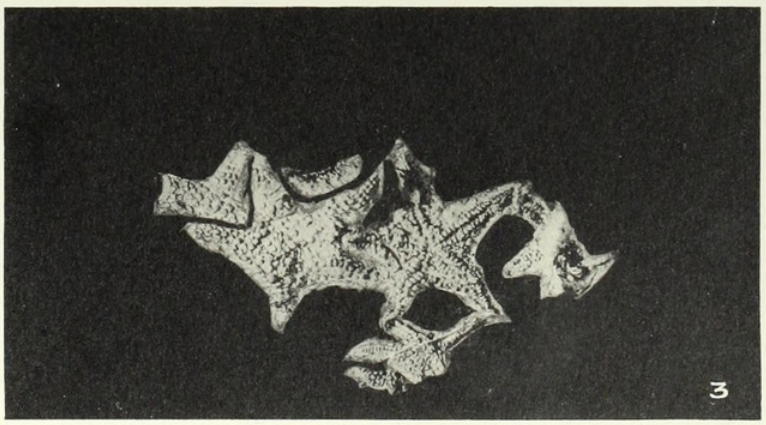












London Stereoscopic Co. Imp.