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On Onychaster, a Carboniferous Brittle-Star

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II. *On Onychaster, a Carboniferous Brittle-star.*

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[Plates 8 and 9.]

It has recently been shown (11) that the Ophiuroidea may be divided into a group Protophiuroidea, including the Silurian and Devonian forms, and a group Euophiuroidea, including all the modern forms. The Euophiuroidea extend back into the Trias; considerable interest therefore attaches to the rare brittle-stars, which are all that remain to guide us in forming an idea of the group as it existed in the intervening period, *i.e.* the Carboniferous. These are *Onychaster flexilis*, Meek and Worthen, *O. Barrisi*, Meek and Worthen, and *Protaster gregarius*, Meek and Worthen (= *Aganaster gregarius*, Miller and Gurley = *Ophiopege gregarius*, Böhm). It is with the first-mentioned that we are chiefly concerned at present.

Description of Onychaster flexilis, *Meek and Worthen.*

This species was first described by Meek and Worthen in 1868, and the genus was named by them Onychaster, partly because its folded rays present some resemblance to the claws of a bird, and partly on account of its general similarity to the Asteroidea. Through their figures the general form of the species, with its extremely small disc, rounded arms rolled up ventrally, and granular skin, have become familiar to all palæontologists.

Their specimens came from the Lower Carboniferous, of Crawfordsville, Indiana. In their first description they do not arrive at a very correct view of the structure, and they are doubtful whether the species can be included either in the Ophiuroidea or the Asteroidea; but in a further investigation, in 1873, they discovered the interlocking ambulacral ossicles, the true nature of the mouth-parts—which they had formerly regarded as plates of the disc—and the adambulacral plates. They mention the existence of a canal perforating the vertebra horizontally, and they also notice a pore opening on the upper surface of the vertebræ and canals penetrating the pieces of the mouth-skeleton. Their figures show the jaws as radial structures, but they make no comment on this point. They were not able to give any description of the under surface of the arms. Meek and Worthen describe a second species of Onychaster, *O. Barrisi* (= *Protaster Barrisi*, Hall), but they do not state in what respects it differs from *O. flexilis*.

The only other description of *O. flexilis* is that published in 1909 by Schöndorf.

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We cannot refrain from an expression of regret that three specimens of this rare and interesting species should have been sacrificed to methods now out of date. Nevertheless, however much we may deplore this waste of time and material, we cannot fail to appreciate the fact that this author has at least attempted, for the first time, a comparison of the vertebræ of Onychaster with those of modern types.

We shall now describe the structure of the vertebræ and jaws, as it appears in serial sections and reconstructions based upon them, of a specimen which was obtained for us by the great kindness and very persistent endeavours of Dr. BATHER, who procured two specimens, one from Mr. FRANK SPRINGER and one from Mr. FREDERICK BRAUN, and allowed us to examine both and to choose one for further investigation.

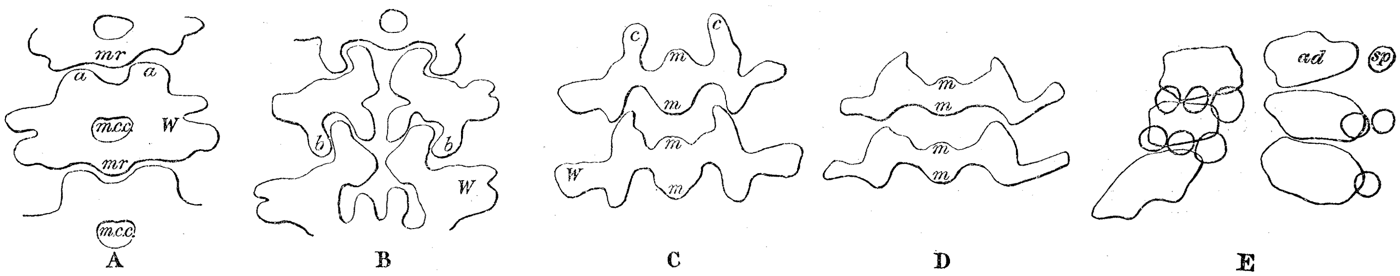
The Vertebræ.

The vertebræ of Onychaster are distinguished from those of all other Ophiuroidea, with the exception, perhaps more seeming than real, of Ophioteresis (see p. 57), by possessing a completely closed radial canal (text-fig. 2B, *r.c.*). This canal is situated well above the middle of the vertebra, and in its neighbourhood the main articular processes are grouped. There can be little doubt that it lodged the radial nerve-cord and water vessel. Its presence was first noticed by MEEK and WORTHEN, but has recently been denied by SCHÖNDORF. A second and spacious canal (*m.c.c.*, figs. 1A and 2B) also traverses each vertebra in a vertical direction in the median line, opening by a wide aperture on the dorsal surface and apparently ending blindly just above the level of the radial canal. Probably it lodged diverticula of the cœlom, the encroachment of the vertebra upon the cœlom being thus somewhat less complete than in modern forms. The length of the vertebra is considerably less in its ventral or lower region than in the neighbourhood of the main articular processes, and this fact, together with the nature of the joint, accounts for the power possessed by the arms of Onychaster of rolling in a vertical plane towards the mouth.

The distinction into a thicker middle portion or body involved in the articulation, and wings which serve as surfaces for the attachment of muscles, is not so sharply marked as in modern forms. A low ridge or wing extends freely at the sides and on to the dorsal surface of the vertebra. In its more ventral region the wing is a simple ridge, more dorsally it is divided longitudinally by a groove (Plate 8, fig. 2). A pair of great grooves running vertically excavates the body below the level of the main articular processes, and lies to the inner side of the articular ridges which we shall describe presently. It is probable that both the wings and the grooves served as surfaces for the attachment of muscles, which we may perhaps call respectively upper and lower intervertebral muscles.

On both the proximal and distal, or adoral and aboral, surfaces of the vertebra a pair of ridges (R, R, Plate 8, figs. 3 and 4) runs from above the level of the radial canal to the ventral edge of the vertebra. The ridges on the posterior surface lie to the outer side of, and sometimes embrace, those of the anterior surface of the adjoining vertebra. Local developments of the ridges give rise to the main elements in the articulation, with the single exception of a dorsal median ridge on the distal or aboral face (the only unpaired element in the joint), which is somewhat complicated, although its derivation from the two pairs of ridges is still patent.

On the proximal face these ridges are developed at their dorsal extremities as a pair of rounded prominences (*a*, *a*, text-fig. 1, and Plate 8, figs. 1–4), separated by a broad median groove, which receives the median ridge of the distal face (*mr*) referred to above. Immediately below these prominences lie a pair of pits (*b′*, *b′*), bounded on the inside by the ridges (R, R) and on the outside by the wing of the vertebra. Into these pits fit prominent pegs of the aboral surface, which are curved inwards towards the radial line, and thus grip closely the sides of the pits. They must have limited the side-to-side motion of the vertebræ upon one another. Finally, beneath



TEXT-FIG. 1.—A–D. Successive Horizontal Sections of the Vertebræ of *Onychaster flexilis*, proceeding from above downwards. E is constructed from two superposed tracings of a section parallel to the preceding ones, passing below the ventral surface of the vertebra and through the adambulacral plates. *a*, *a*, and *c*, *c*, paired anterior processes, *a* being dorsal to *c*; *b*, *b*, paired posterior processes; *m.*, median ridge; *W.*, wing; *ad.*, adambulacral plate; *sp.*, spine; *m.c.c.*, median vertical canal.

the pits is a pair of very strong pegs (*c*, *c*), which fit into deep sockets on the aboral face, the sockets being continuous with, and at the top of, those great grooves which we have mentioned as probably lodging the lower intervertebral muscles. Above the level of the process *a* is a median ridge, which plays no part in the articulation.

On the distal face the elements of the articulation are thus a dorsal median ridge (*mr*), separating paired shallow grooves (*a′*, *a′*, Plate 8, fig. 4), a pair of pegs (*b*, *b*), and a pair of deep sockets (*c′*, *c′*, Plate 8, fig. 4). Below the level of the radial canal around which these processes and pits are grouped, the paired ridges of both faces still play a part in the articulation, those on the posterior or distal face embracing those on the anterior or proximal face, here as elsewhere, and limiting the amount of rolling towards the mouth; any rolling in a vertical plane away from the mouth is prevented by the existence of the paired dorsal prominences (*a*, *a*), the ridge (*mr*) of the distal face, and the inward curvature of the processes (*b*, *b*) of the distal face.

One effect of the abutting of the lower portions of the ridges (R, R) against one another is to increase the size of a great pair of intervertebral spaces, formed by the apposition of the two pairs of great grooves already mentioned as excavating the lower portions of the vertebræ on both faces, and probably lodging the lower intervertebral or flexor muscles. A median ridge (m) separates this pair of grooves, but takes no part in the articulation. It is more pronounced on the distal than on the proximal face, and on each face it increases in size just below the radial canal.

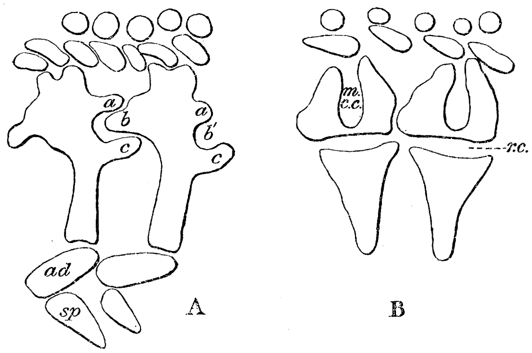
Adambulacral plates articulate with the ventral faces of the vertebræ at the ventral extremities of the paired ridges (R, R). These plates are oblong pieces inclined away from the mouth, and bearing on their outer margin four spines directed towards the mouth. They project inwards towards the middle line from their place of articulation with the vertebra, and thus partially cover the ventral surface of the arm. The second adambulacral plate (ad_2) has not been seen. There are no ventral plates, and likewise no dorsal plates, but the dorsal and lateral surfaces of the arm are provided with a covering of small skeletal pieces lying in the thick skin and outside these again with a layer of skeletal granules, both of which constituents of the skeleton had been noticed by MEEK and WORTHEN.

There is very little difference except in size between the vertebræ at the proximal and distal ends of the arm: the distal vertebræ are slightly longer than the proximal, but they articulate with one another freely in the same manner as the proximal, and by no means adhere to one another, as SCHÖNDORF states, by their whole circumference. The first two or three proximal vertebræ are especially short, and show certain slight modifications which will be mentioned when the jaws are described presently.

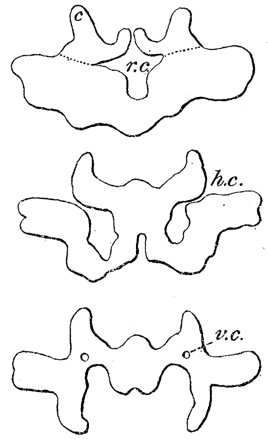
Canals in the Vertebræ.

The central canal gives off in each vertebra paired opposite branches, of somewhat smaller lumen than its own. These proceed outwards and then open freely into the large ventral intervertebral spaces. From each of these paired canals a branch is given off and runs outwards and in a proximal direction to open on the surface of the vertebra (text-fig. 3, *h.c.*). From each of these again a canal takes its origin which runs through the substance of the vertebra to emerge apparently on the ventral surface external to the place of articulation of the adambulacral plate with the vertebra; but it is not possible to trace it quite to its termination.

Presumably the radial canal lodged the radial nerve and water vessel, while of its branches, some served to convey nerves to the muscles and skin, others the canals and nerves to the tube-feet. Though it is hardly possible to say with certainty which of the canals marks the course of the vessel to the tube-feet, analogy with modern forms suggests that the vertical canal, penetrating the substance of the vertebra, had this significance, and probably there need be little doubt that this is the correct interpretation. MEEK and WORTHEN had noticed and figured similar canals in the skeleton of the jaws, and traces of these canals are also to be found in our material in a position corresponding to that of the water vascular canal in the jaws of modern forms.



TEXT-FIG. 2.



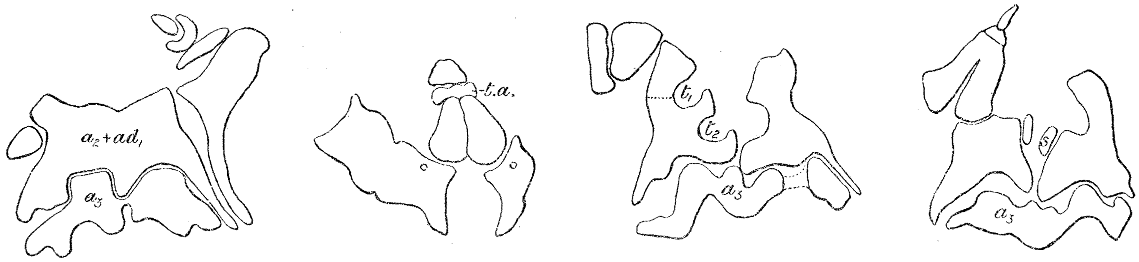
TEXT-FIG. 3.

TEXT-FIG. 2.—Vertical Sections of the Arm Skeleton, A lateral, B median. *a, a, b, b, c, c,* as in text-fig. 1.
TEXT-FIG. 3.—Horizonal Sections of a Vertebra to show Canals Perforating it. *r.c.*, radial canal ; *h.c.*, horizontal branch canal ; *v.c.*, vertical branch canal.

The Jaws.

The jaws have hitherto been only very incompletely seen and described, owing to the inadequacy of the older methods of study. Sections and reconstructions show that they have a structure very similar to that of the jaws of modern brittle-stars, oral angle pieces traversed by the usual suture being recognisable and presumably formed, like that of modern types, of a modified vertebra fused with the first adambulacral plate. At the apex of the jaw a *torus angularis* is present, bearing teeth. Dorsally the two halves of the vertebra which contributes to the formation of the oral angle piece are fused together, forming a solid piece, which projects very near to the centre of the disc and overhangs the oral tentacle spaces which are situated further outwards from the centre. This peculiar arrangement produces the very misleading appearance which led MEEK and WORTHEN, who had only seen the dorsal aspect, to mistake these radially placed pieces for the jaws themselves. The presence of a torus-like piece which lies against the oral border of these ossicles completes the illusion. The outer and posterior angles of these ossicles are produced backwards as long slender laminæ (text-fig. 4, and Plate 8, fig. 6). In text-fig. 4C the two tentacle spaces are clearly seen, and presumably justify us in regarding the vertebra involved in the oral angle as A_2, just as in modern forms. One of the dorsal and radial tori spoken of above bears a cup-like structure (fig. 4A), and in the concavity of the cup is a tooth ; this, perhaps, corresponds to the crescentic outlines shown in MEEK and WORTHEN's figure. A pair of minute ossicles (*s*, fig. 4D) is situated just below the level of the second tentacle pore and suturally attached to the oral angle piece, between and below the two tentacle pores.

Still further ventrally a row of teeth seems to have been borne by the jaw proper (ad_1) at the side of the oral angle (mouth papillæ).



A B C D

TEXT-FIG. 4.—Horizontal Sections through the Jaw Apparatus. *t.a.*, torus angularis; t_1, t_2, first and second tentacle spaces; $a_2 + ad_1$, oral angle piece; a_3, third vertebra; *s.*, small scale adherent to the oral angle piece, between and below the tentacle spaces.

Signs of a canal perforating the oral pieces can be made out in some of the sections; MEEK and WORTHEN had already drawn attention to these.

Modifications occur (Plate 8, fig. 6) in the articulation not only of A_2 with A_3 but also of A_3 with A_4 and of A_4 with A_5. In the vertebræ A_2 to A_4 the backwardly directed processes we have spoken of as *b*, *b*, have a greater vertical extension, and embrace the ridges *a*, *a*, of the anterior face of the next succeeding vertebra. This close and firm interlocking of the proximal vertebræ of the arm provides a suitable support for the jaw, upon which it can move. The region of close grip of A_2 upon A_3 occupies almost the whole of the middle third of the height of the vertebra. Above this level the only connection of A_2 with its successor must have been muscular, and the thin backwardly directed laminæ afforded an increase of surface for muscular attachment. Below the level of close articulation there is a loose interlocking of low ridges into open grooves, and the attachment was in all probability muscular. A_3 and A_4 are short vertebræ, they do not show the difference in length between their dorsal and ventral portions which is so characteristic of the typical vertebræ of the arm; A_5 is also somewhat shorter than its successors, but from A_6 onwards the vertebræ attain the typical proportions.

Within the circle of jaws are skeletal remains of diatoms, presumably some of the contents of the stomach.

No trace of a madreporite has been recognised.

Our knowledge of the structure of Onychaster having become more definite through the study of sections we may naturally ask whether the new facts throw any new light on the systematic position of this genus and whether its vertebræ are comparable in details with those of modern forms. And in seeking a starting point for this inquiry we should naturally choose the most primitive of modern forms, for Onychaster, which occurs in the Carboniferous Limestone, is the oldest known type of Ophiurid in which the ambulacral ossicles are fused together to form vertebræ having a considerable vertical thickness. Now the group of living forms termed by BELL

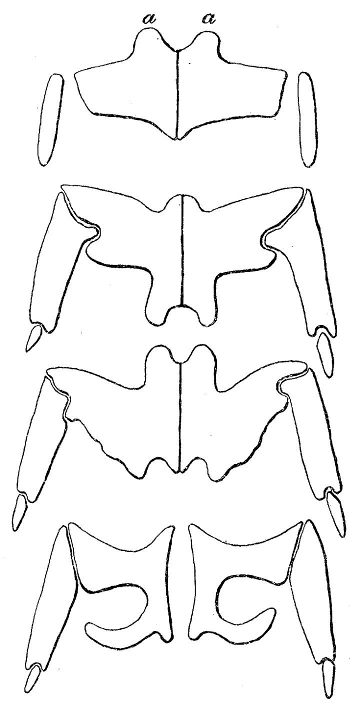
Streptophiuræ is regarded by zoologists as including the most primitive of living Ophiurids, and investigation has shown (2) that the Triassic brittle-stars, that is to say the earliest Euophiuroidea, belong to the group Zygophiuræ, we are therefore justified in selecting the Streptophiuræ as a starting point in our search for relatives of Onychaster.

The Streptophiuræ include the genus Ophioteresis, the vertebræ of which are described as generalised Ophiurid vertebræ and figured as perforated, a short distance above the ventral surface, by a radial canal the nature of which has been disputed but never investigated (9). Material of this interesting genus was obtained, through the kindness of Dr. HARMER and Prof. JEFFREY BELL, from the British Museum and a further supply from the authorities of the Cambridge Museum, who generously spared one of the two specimens obtained by Prof. STANLEY GARDINER from Cargados Carajos, an island N.E. of Mauritius. Both horizontal and transverse sections show that the radial canal contained the radial nerve and water vessel, as Prof. MINCHIN had thought probable (9). The branches from the radial canal to the tube-feet proceed horizontally outwards through the substance of the vertebra, the tube-feet themselves coiling upwards over the dorsal surface of the arm. The skeleton of the arms exhibits many features of interest. Dorsal calcareous plates are completely absent. The vertebral ossicles are by no means so simple as has been supposed. Photographs of their adoral and aboral surfaces (Plate 9, fig. 2) reveal at once a general similarity to those of typical Zygophiurids and a close examination shows that this resemblance is more than superficial.

The articulation in a typical Zygophiurid is thus described by McBRIDE: On the proximal surface of the central portion of the vertebra is a central knob and two ventro-lateral knobs, a median ventral pit and two dorso-lateral pits, and on the distal surface there are pits corresponding to the knobs on the proximal side and *vice versâ*. In Ophioteresis on the distal or aboral (LYMAN'S "outer") face, just above the radial canal, are a pair of sharply marked depressions (Plate 9, fig. 2, 1) which appear to represent the two ventro-lateral pits (LYMAN'S "holes to receive the knobs on the inner face"). Above these depressions and continued downwards by a ridge between them is a conspicuous boss (2) which is probably the median ventral knob (LYMAN'S "articulating peg") more dorsally situated than is typical. Immediately above it is a pit (3) which appears to represent the central pit (LYMAN'S "shoulder to receive the umbo"), and on each side of the shoulder and continued downwards alongside the articulating peg are paired somewhat ill-defined prominences, corresponding to the usually well marked dorso-lateral knobs of typical Zygophiurids. Correspondingly, on the proximal or inner face, just above the radial canal are two ventro-lateral knobs (5), above them a median ventral pit (6), above this the umbo or central knob (7), and at the sides of the median ventral pit and central knob are paired depressions (8), the dorso-lateral pits. It seems then that justification for separating Ophioteresis from the Zygophiuræ is not to be found in the nature of the articulation, and the genus must be removed from the Streptophiuræ as defined by BELL. In all the photographs a suture (*su*) can be traced which marks off the median ventral region of the vertebra, suggesting that a separate piece, hexagonal in outline and apposed to the ventral surface of the ossicle, has become fused with it and has formed a floor to the radial canal. The sutures are not visible in sections of decalcified material except in the case of the second arm segment, in which this plate is clearly marked off from A_2. It can hardly be doubted that this hexagonal piece represents a ventral plate which has sunk inwards and merged its individuality in that of the vertebra. From this we see that the pits and prominences above described deviate less from the typical position than would be the case if the vertebra were the simple structure it appears at first sight to be, and not compound as closer inspection reveals. Also it is clear that the radial canal is of a different nature from that of the corresponding canal in Onychaster, since it is not wholly surrounded by the tissue of the vertebral ossicle. Ophioteresis is thus in the structure of its vertebral ossicles not much more valuable for comparison with Onychaster than any other Zygophiurid. It is true it has the power of coiling its arms in the vertical plane, but it owes this feature rather to the looseness of the articulation between its vertebræ than to any special modification such as characterises Onychaster. A feature in the tissue of the vertebræ of Ophioteresis is perhaps worth pointing out; horizontal sections of the vertebra in its more dorsal regions show a central area in which the proportion of calcareous matter is slight, the meshes of the network being conspicuously large. This structure extends right up to the dorsal surface of the vertebra where it is conspicuous in cleaned and dried ossicles. A seam of dense calcareous matter divides this area, forming a median vertical plate. It seems not impossible that this central area may be a reminiscence of the central vertical space, which presumably contained cœlom, in Onychaster.

Having found then that the vertebral articulation of Ophioteresis does not differ in any marked way from the Zygophiurid type, other more typical members of the Streptophiuræ were examined, namely *Ophiomyxa vivipara* and *O. australis*, obtained from the Cambridge Museum through the kindness of Mr. DONCASTER. Serial sections of the vertebræ of the former species were obtained by embedding in plaster of Paris and grinding down; they were also isolated by potash and examined whole, and were studied as well in decalcified sections. The results show that the vertebræ posesss the essential characters of the Zygophiurid ossicle. It seems therefore that if the group Streptophiuræ is to stand it cannot be defined by the character of its vertebral ossicles, and in seeking relatives of Onychaster among more modern forms we are limited to the Zygophiuræ.

Let us first consider the articulation only, neglecting the form of the vertebra. In any Zygophiurid, as we know, the articulation is characterised by a change from a condition of opisthocoely in the dorsal region to one of procoely below, if we may so express it. In Onychaster, as we have stated, there are three regions, and these three merge more or less into one another, owing to the fact that the processes are local developments of a pair of ridges. In cross-sections there is at one level obvious similarity to a section of a Zygophiurid vertebra taken through the peg and paired ventro-lateral sockets. This is in the neighbourhood of the radial canal. It is clear that if we suppose the radial canal to sink, and its place to fill up with skeletal tissue, we should then have a posterior knob and paired sockets at its sides, and correspondingly an anterior pit and paired knobs (compare fig. 1B, and Plate 9, fig. 3). The latter are very closely embraced by the outer walls of the sockets. Passing upwards from this level, we find throughout the greater length of the arm that these embracing walls retreat, the paired ridges on the anterior surface broadening out and fitting, as we have said, into shallow grooves, open at their outer or interradial border. But in the neighbourhood of the mouth, the vertebræ A_3–A_5 show a modification; the embracing ridges on the posterior surface are greatly strengthened and continued to the upper limit of the articulation, while at the same time the median groove on the anterior face, separating the two ridges, is not so wide or deep. Here we have a suggestion of the process by which the condition of procoely in the upper region of the vertebra in Onychaster may well have been converted into the opisthocoelous condition characteristic of the corresponding region of the Zygophiurid ossicle.



TEXT-FIG. 5.—Horizontal Sections through a Vertebra of *Acrura squamosa* Pic., to show the nature of the joint and in particular the processes *a*, *a*.

DELAGE and HÉROUARD (3) speak as follows of the unpaired dorsal prominence and the unpaired ventral socket of the anterior or proximal face of the Zygophiurid ossicle:—"Cette fossette et cette tête sont formées en réalité de deux demi-fossettes et deux demi-têtes rapprochées, condition nécessitée par le fait que la vertèbre est formée de la soudure de deux pièces symétriques." It does not, of course, follow that the "demi-têtes" were at one time separated by an interval, and were, in fact, a pair of prominences, though this may have been the case. In *Ophioderma egertoni* from the Lias the two "demi-têtes" are clearly recognisable (Plate 9, fig. 3). In this connection, *Acrura squamosa* Pic. from the Trias proved to be of remarkable and unexpected interest. *Acrura* has long been regarded as possessing a structure resembling in all essentials that of modern Ophiurids, and a casual glance over the series of photographs of successive grindings might seem to confirm this view, but there is a striking difference in the dorsal sections. Here paired anterior processes forming a series of homologues of the paired anterior processes of A_3 are clearly seen; below them follow the typical elements of a Zygophiurid joint. It should be mentioned that SCHÖNDORF, in attempting to establish homologies, assumed that the paired anterio-dorsal processes in Onychaster were the homologues of the unpaired dorsal process of Zygophiurids, and also that he figures the third vertebra of one of this group, but, curiously enough, makes no comment upon it.

With regard to the general form of the vertebra there seem to be two alternatives. The first, which is tempting, is to suppose that the ventral intervertebral spaces contained the homologues of the lower intervertebral muscles, and that the upper intervertebral muscles found surfaces of attachment on the wing, the ventral continuation of the articular ridge (R, R) corresponding to the ridge which marks off one muscle field from the other. If further we suppose that for some reason in the course of evolution the radial canal sank, that fusion of the vertebral halves ventral to the lower level of the articulation ceased to occur, and that the ridges (R, R) became more divergent towards their ventral ends and reduced in size, then a remarkable similarity to the vertebra of such a form as *Ophiarachna incrassata* will result, and the peculiar looping of the vessels running to the tube-feet is accounted for.

The other alternative is that adopted by SCHÖNDORF, viz., to allot both the upper and lower intervertebral muscles to the wings, leaving the ventral intervertebral space unaccounted for as something altogether *sui generis*. SCHÖNDORF figures a horizontal shelf just at the level of the articulation dividing the surface of each face of the wing into a dorsal and a ventral portion. The models do not show such a shelf.

The difficulty of the first alternative, if it be a difficulty, is that the lower portion of the upper intervertebral muscle, as a necessary consequence of its position relative to the joint, would function as a flexor, the upper portion as an extensor. And further, Ophiarachna is regarded as a high type.

These points must remain for the time matters of speculation. Whichever view we take, the important fact remains that there is nothing in the structure of Onychaster to prevent our regarding it or some Onychaster-like form as standing in the direct line of descent of modern Ophiurids. Through the study of Onychaster we are able to interpret the joint of modern forms as a derivative of a primitive pair of vertical ridges, and, further, a pair of ridges is just what would result from the increase in vertical extent of a plate-like vertebra in which the articulation is made by means of a pair of pegs—a condition which we find foreshadowed if not fully developed in Lapworthura.

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DESCRIPTION OF PLATES.

PLATE 8.

All the figures represent models of parts of the skeleton of *Onychaster flexilis*. $\times 7\frac{1}{2}$.

a, *a*, and *c*, *c*, paired anterior processes, *a* being dorsal relative to *c*; *b*, *b*, paired posterior processes; *m.*, median ridge; *W.*, wing; *ad.*, adambulacral plate; *sp.*, spine; *m.c.c.*, median vertical canal; a_2–a_6, the second-sixth vertebræ.

Fig. 1.—Dorsal or aboral aspect of three interlocking vertebræ and one disarticulated from its neighbour after the completion of the model.

Fig. 2.—Side view of two interlocking vertebræ and one disarticulated, the model in this case being built up from vertical sections.

Fig. 3.—Anterior or proximal surface of a vertebra with the accompanying adambulacral pieces attached below.

Fig. 4.—Posterior or distal face of a vertebra; the adambulacrals are not complete.

Fig. 5.—Ventral aspect of the skeleton of a mouth angle and of the vertebræ A_3 to A_6 and their adambulacral plates.

Fig. 6.—Dorsal aspect of the same model as the model shown in fig. 5.

PLATE 9.

Fig. 1.—Horizontal section of *Acrura squamosa*, Pic. The dorsal anterior paired processes are clearly seen at the point of the arrow.

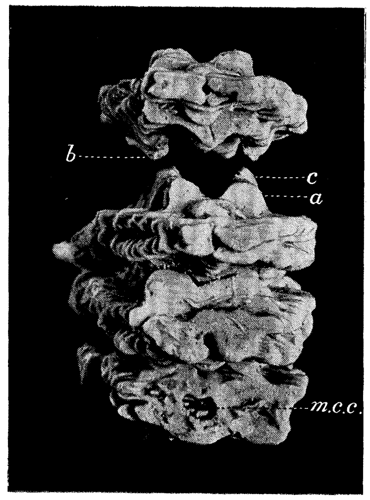
Fig. 2.—Vertebræ and adambulacral plates of *Ophioteresis elegans*, showing the former both faces. On the distal face 1, paired ventro-lateral pits; 2, median ventral knob; 3, central pit; 4, dorso-lateral knobs. On the proximal face 5, paired ventro-lateral knobs; 6, median ventral pit; 7, umbo or central knob; 8, dorso-lateral pits. *Su.*, the line of suture between the ventral plate and the vertebra.

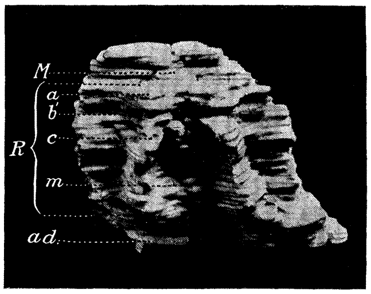
Fig. 3.—Horizontal sections of *Ophioderma egertoni*, dorsal.

Fig. 4.— „ „ „ ventral.

BIOLOGICAL SCIENCES THE ROYAL SOCIETY PHILOSOPHICAL TRANSACTIONS OF

FIG. 1.





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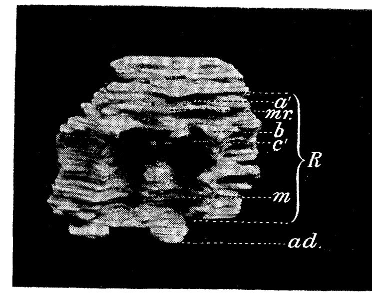

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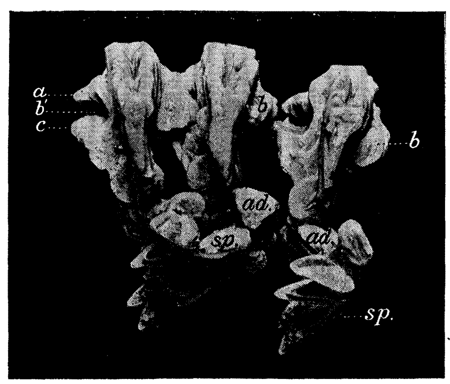


FIG. 2.

FIG. 5.

FIG. 6.

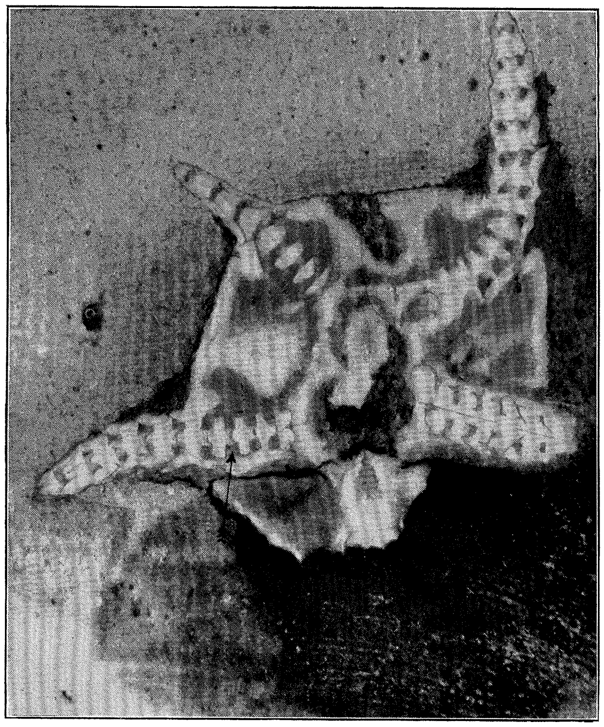
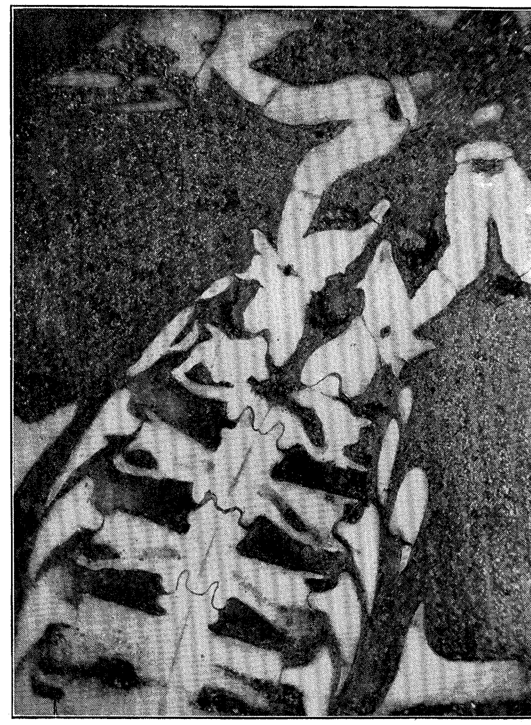


Fig. 1.



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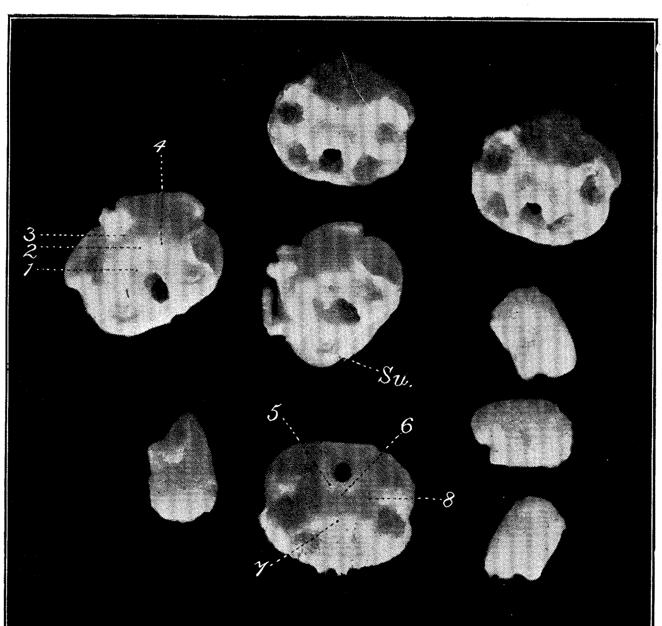

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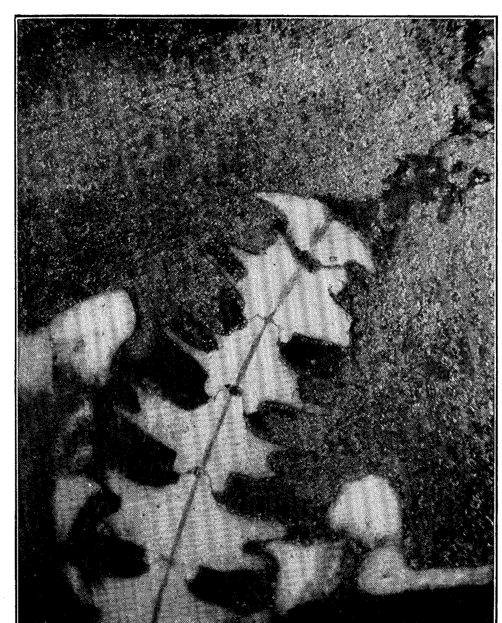
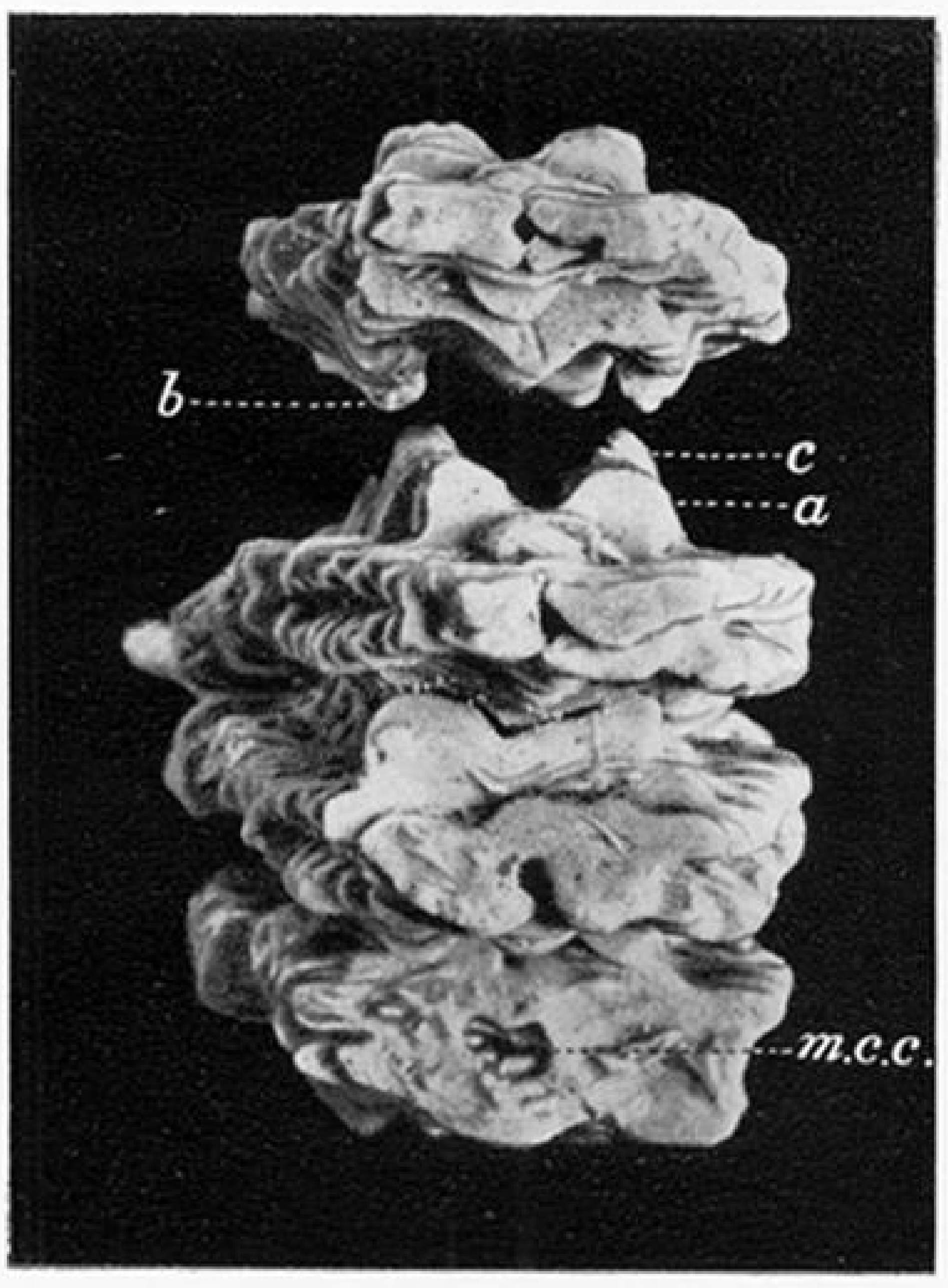


Fig. 4.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

FIG. 1.



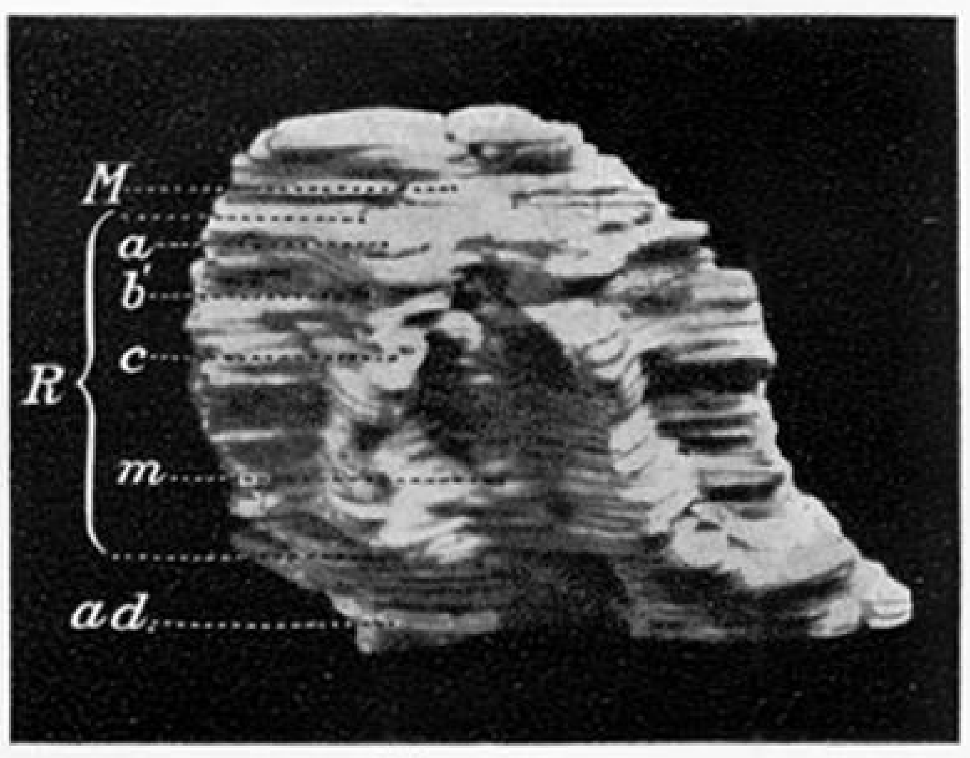


FIG. 3.

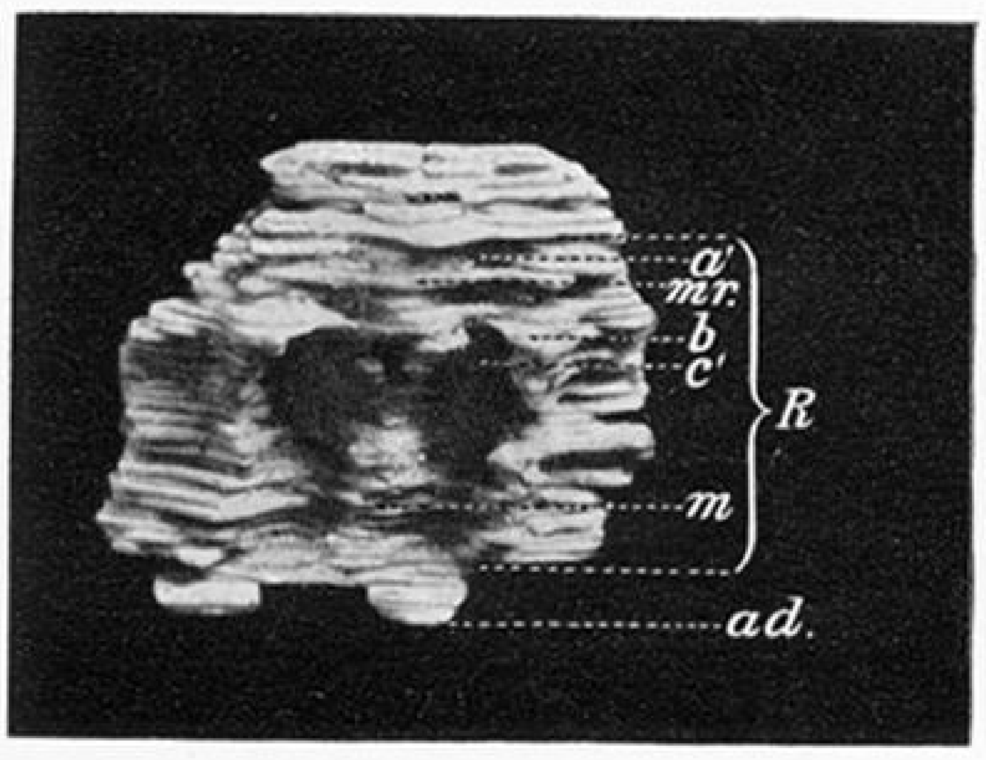
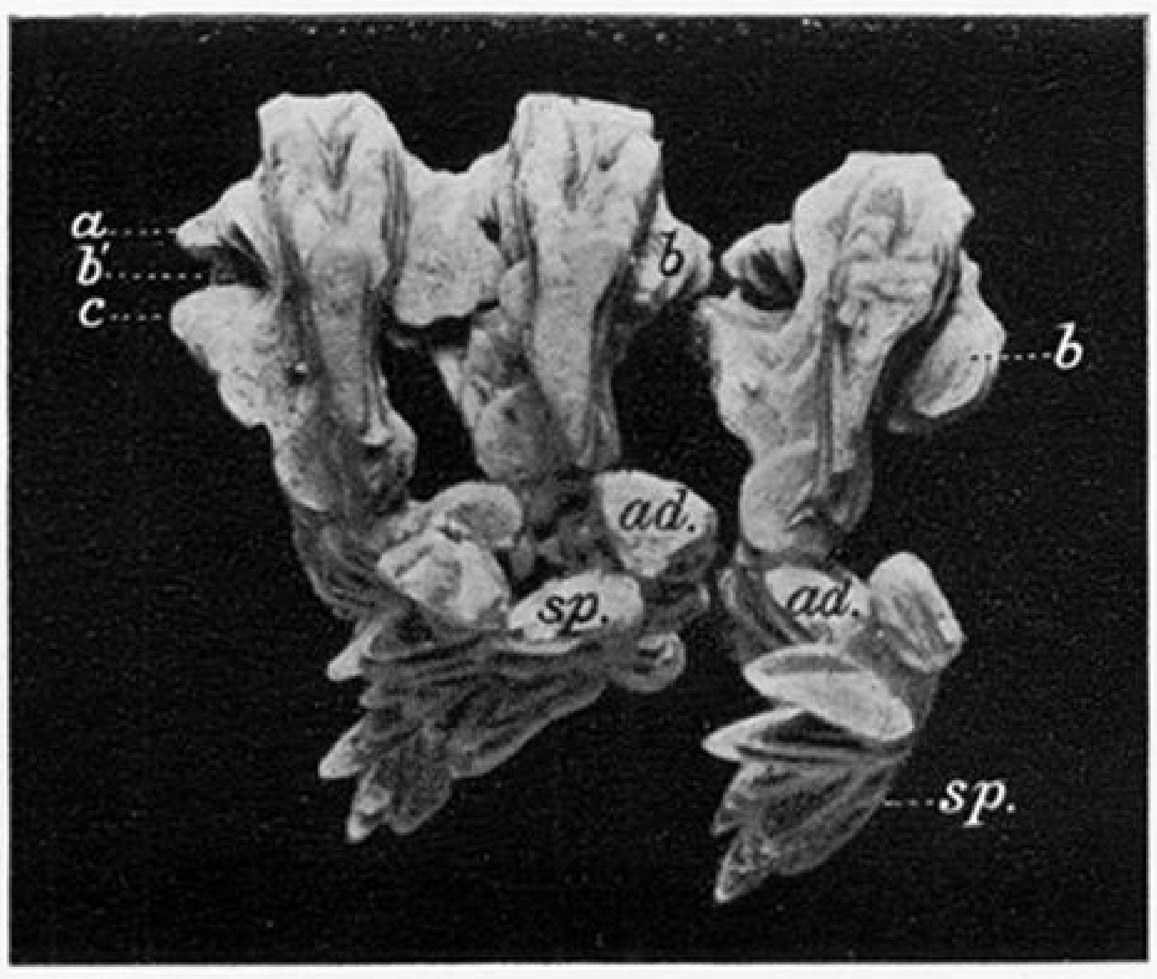


FIG. 4.



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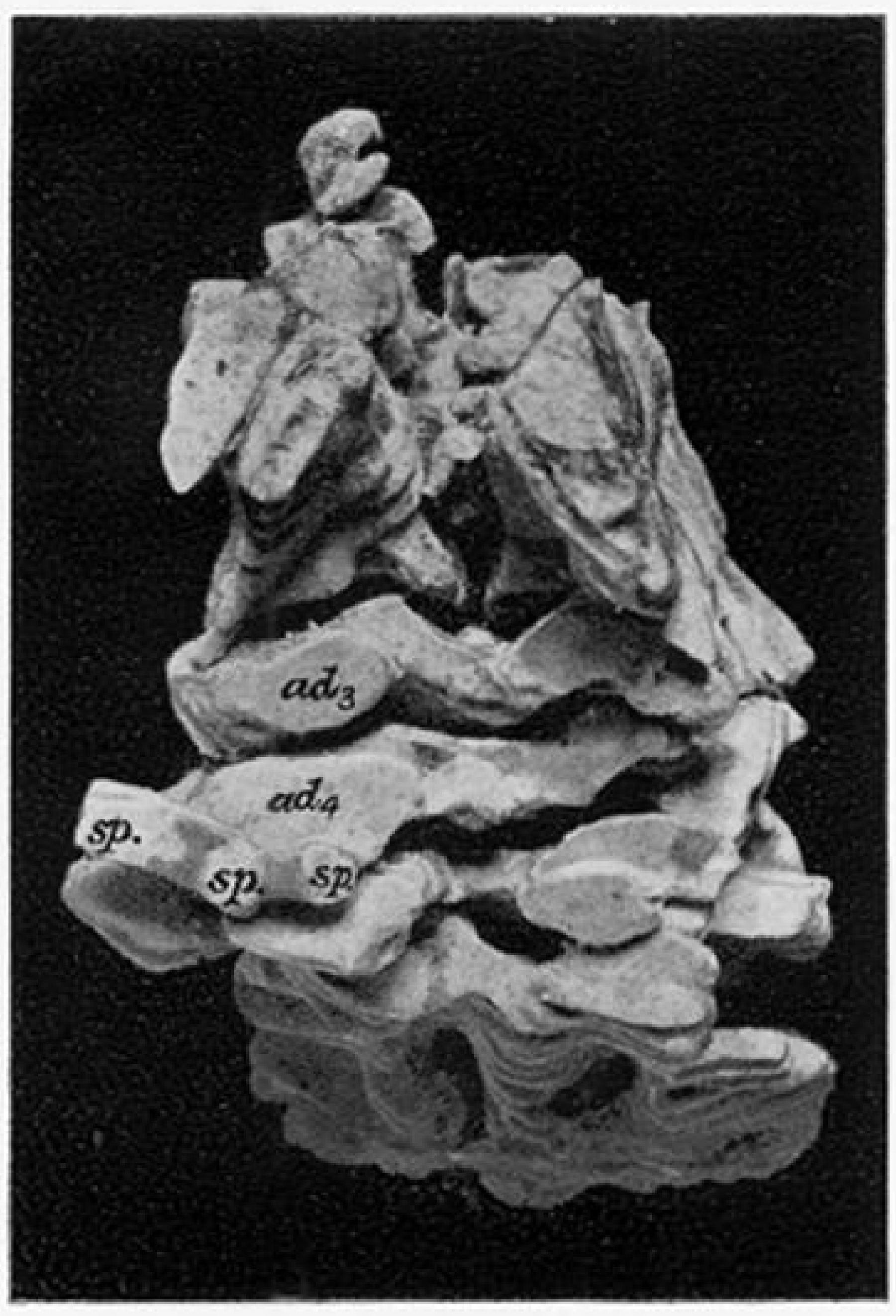

FIG. 5.

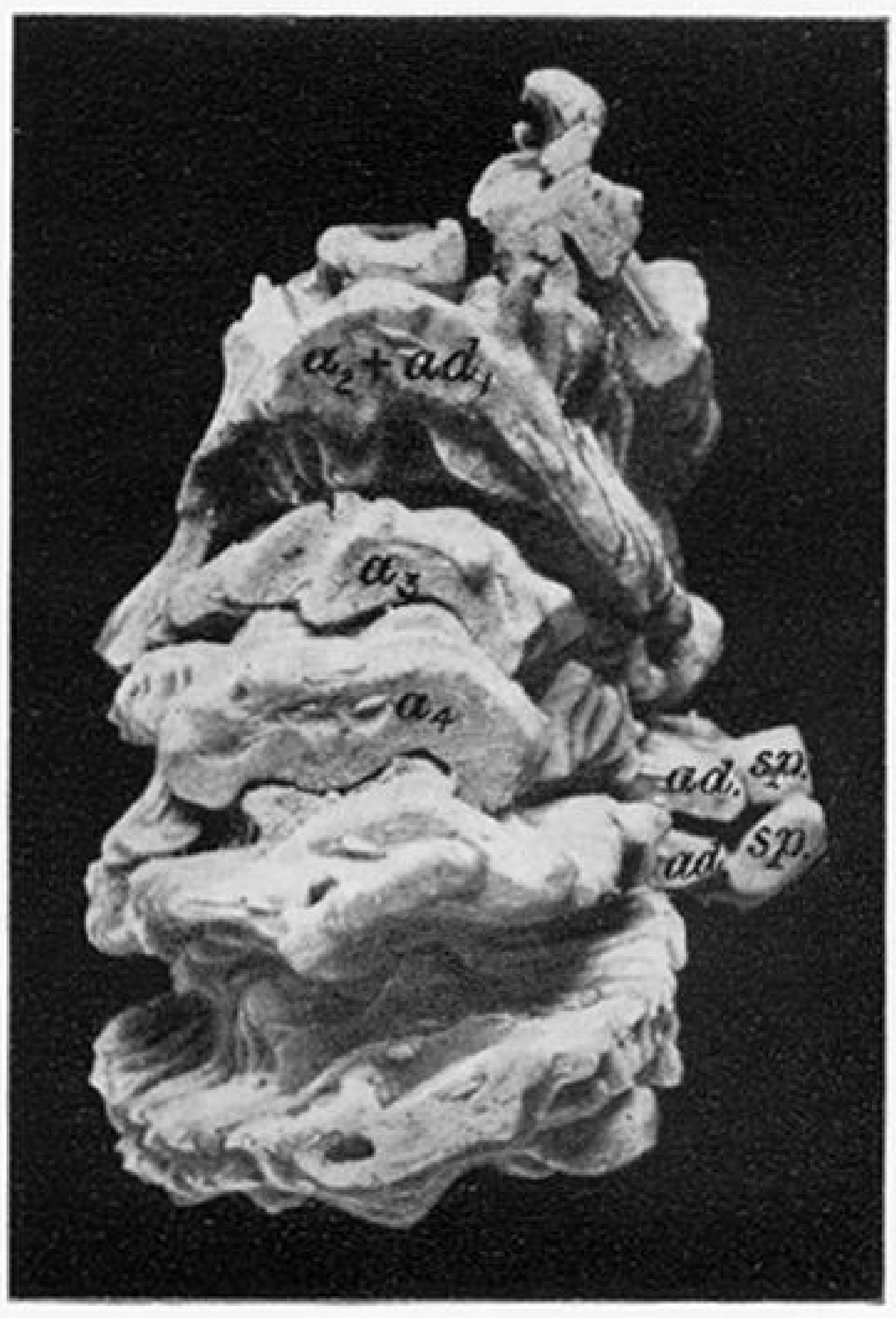

FIG. 6.

PLATE 8.

All the figures represent models of parts of the skeleton of *Onychaster flexilis*. × $7\frac{1}{2}$.

a, a, and *c, c,* paired anterior processes, *a* being dorsal relative to *c*; *b, b,* paired posterior processes; *m.*, median ridge; *W.*, wing; *ad.*, adambulacral plate; *sp.*, spine; *m.c.c.*, median vertical canal; a_2–a_6, the second-sixth vertebræ.

Fig. 1.—Dorsal or aboral aspect of three interlocking vertebræ and one disarticulated from its neighbour after the completion of the model.

Fig. 2.—Side view of two interlocking vertebræ and one disarticulated, the model in this case being built up from vertical sections.

Fig. 3.—Anterior or proximal surface of a vertebra with the accompanying adambulacral pieces attached below.

Fig. 4.—Posterior or distal face of a vertebra; the adambulacrals are not complete.

Fig. 5.—Ventral aspect of the skeleton of a mouth angle and of the vertebræ A_3 to A_6 and their adambulacral plates.

Fig. 6.—Dorsal aspect of the same model as the model shown in fig. 5.

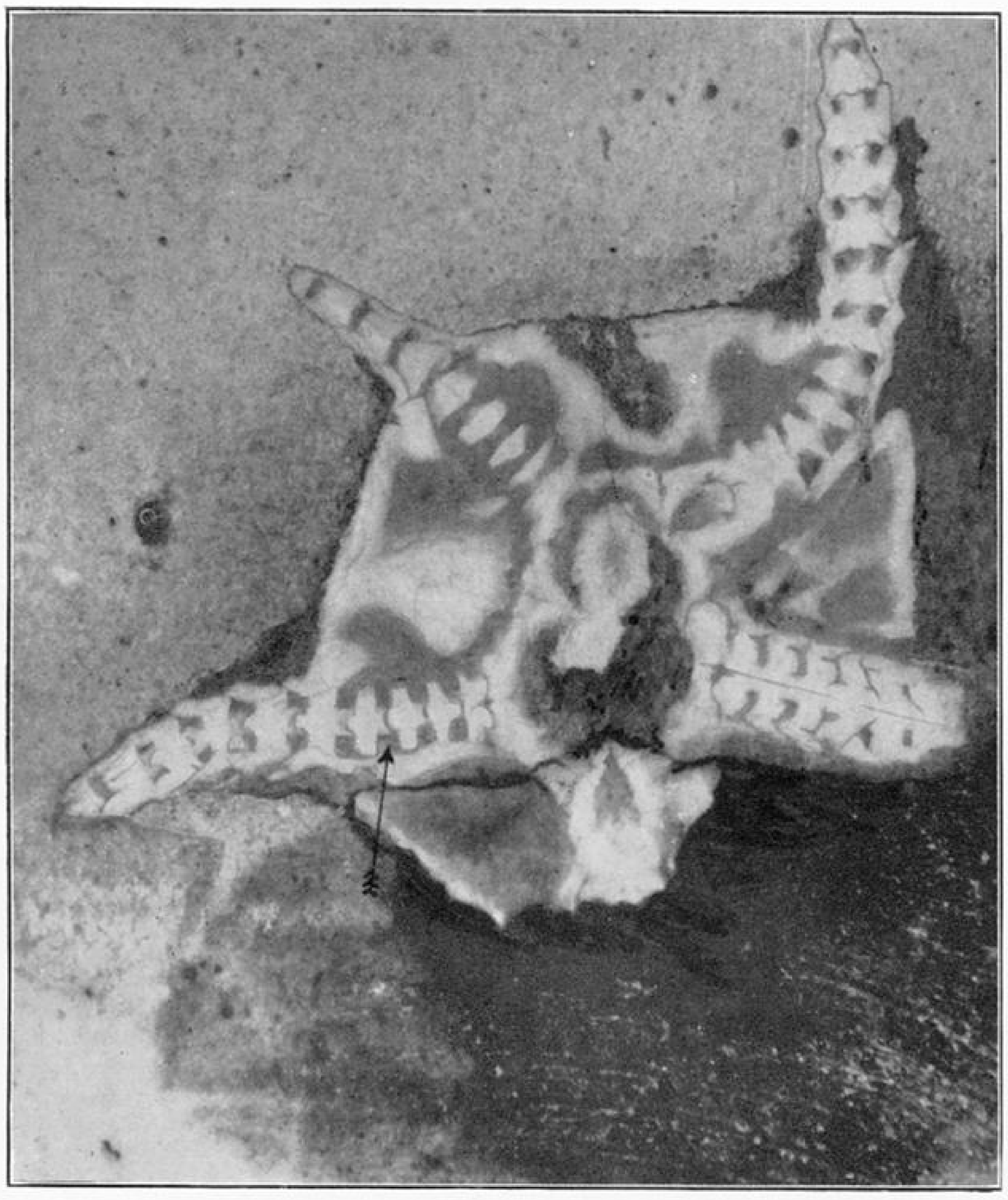

FIG. 1.

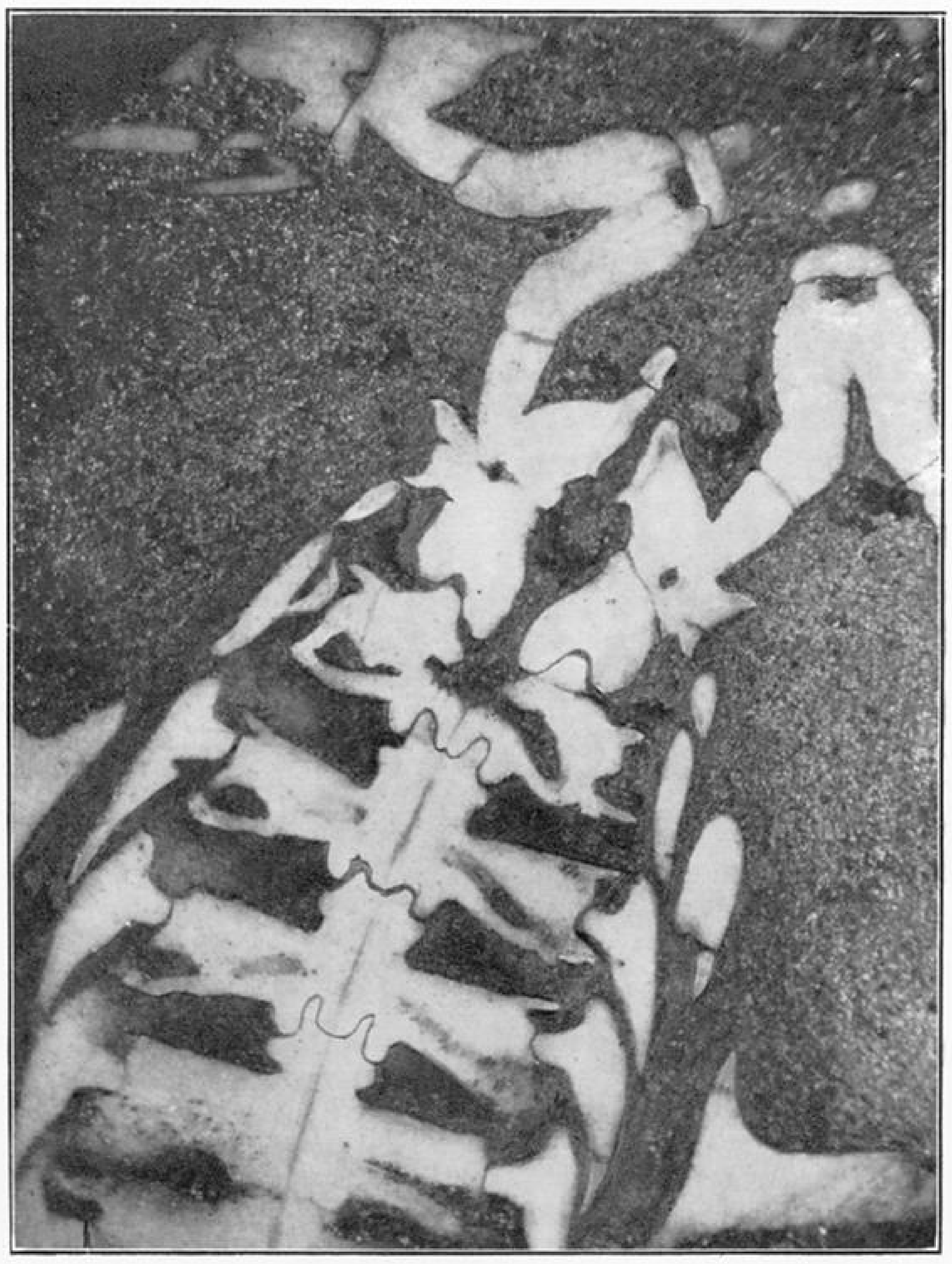

FIG. 3.

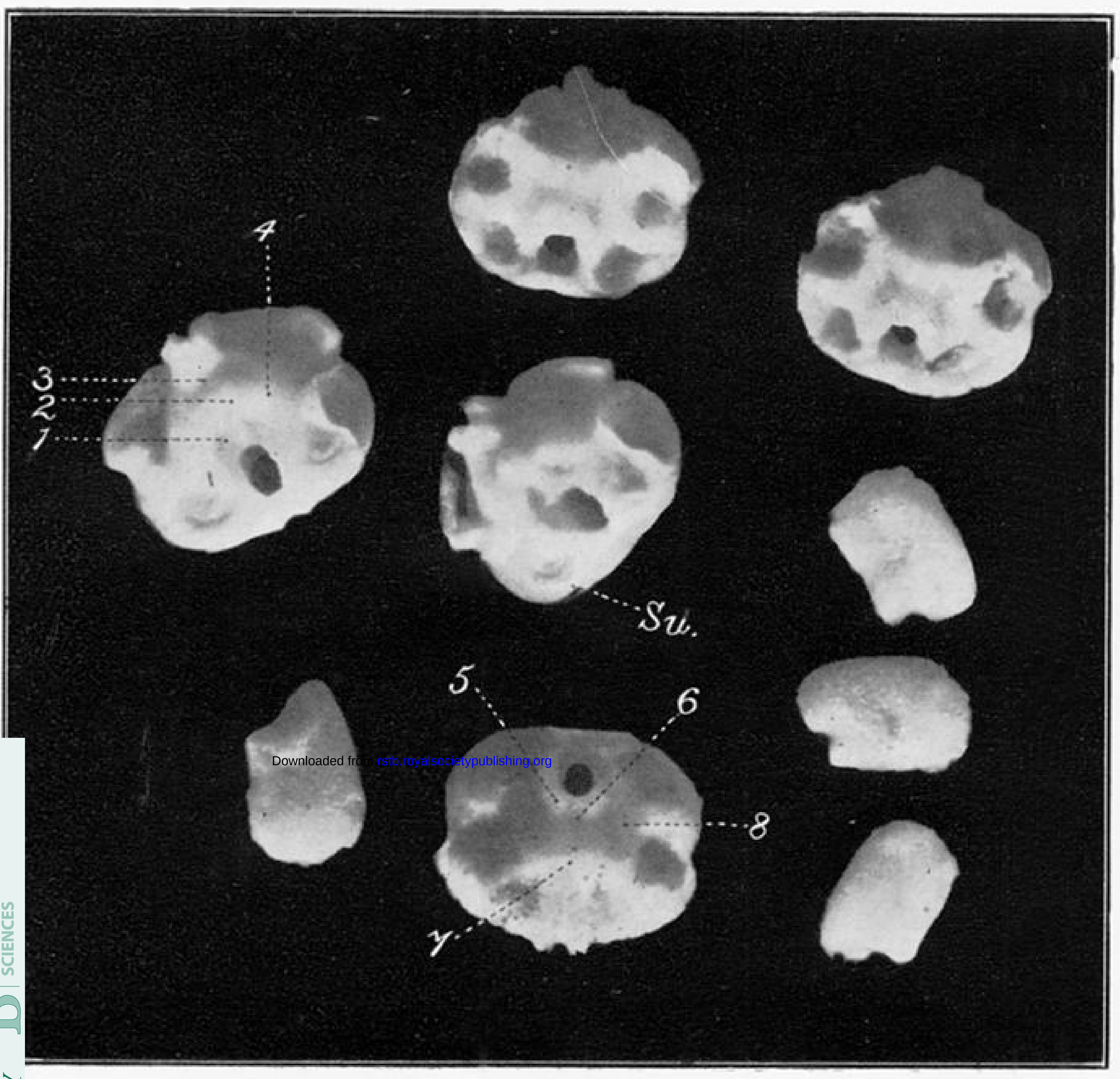

FIG. 2.

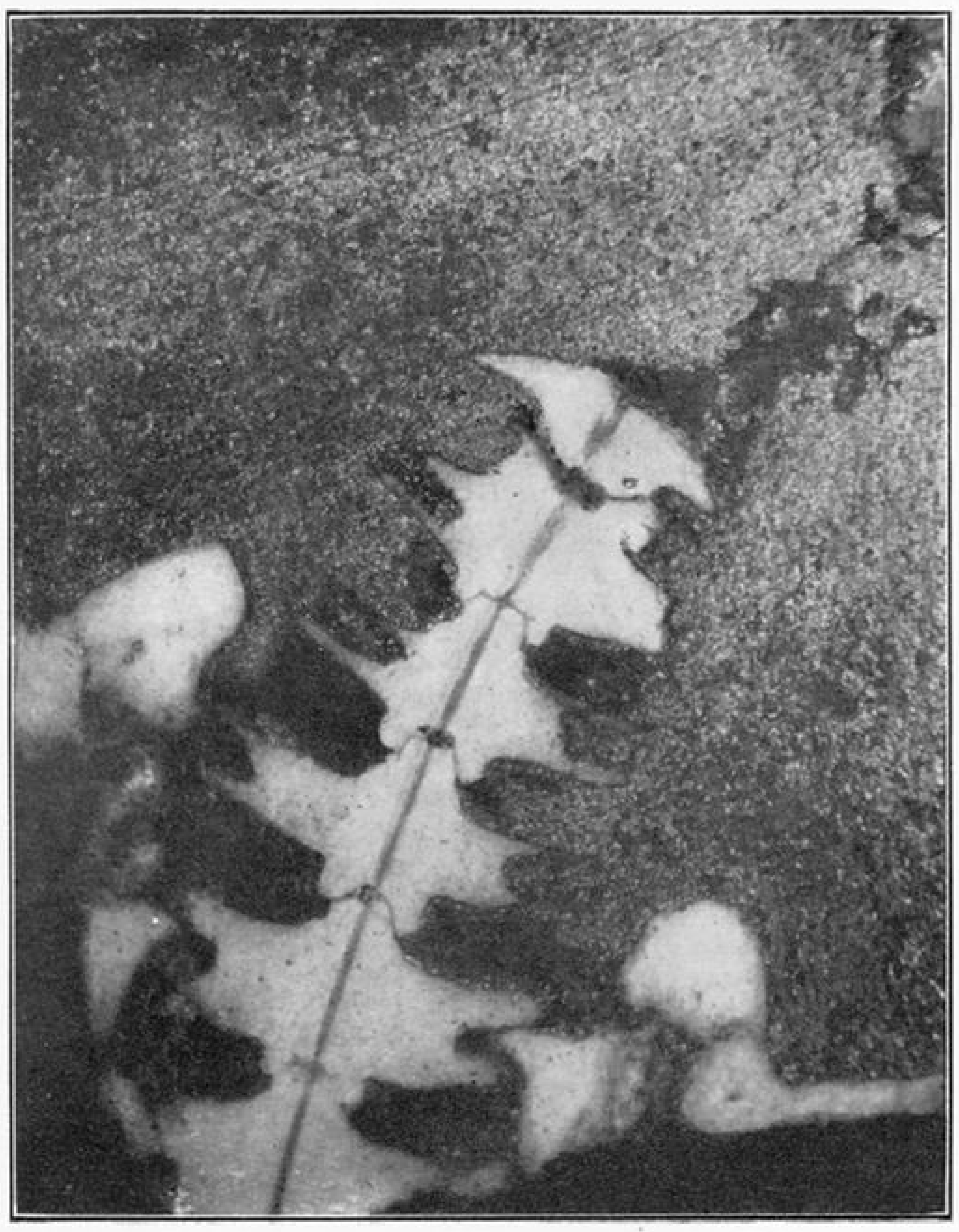

FIG. 4.

PLATE 9.

Fig. 1.—Horizontal section of *Acrura squamosa*, Pic. The dorsal anterior paired processes are clearly seen at the point of the arrow.

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Fig. 3.—Horizontal sections of *Ophioderma egertoni*, dorsal.

Fig. 4.— ,, ,, ,, ventral.