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[BY ALEXANDER AGASSIZ.]

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NORTH AMERICAN STARFISHES.

BY

ALEXANDER AGASSIZ.

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PREFACE.

The Plates which accompany this volume* have now been drawn on stone for more than twelve years. It was the intention of the late Professor Agassiz to add to them the anatomy of several of our more common species, but the duties connected with the care of the Museum prevented him from accomplishing this task. Although during the last twelve years several important papers have been published on the anatomy of Echinoderms which would necessitate a complete re-examination of the anatomy of Starfishes, it has been thought best, since there was no probability of being able to finish within a reasonable time the necessary anatomical investigations to complete this volume as originally planned, to publish the Plates as they were left by Professor Agassiz; all that has been added to them is the lettering necessary for their proper explanation. However incompletely the subject of Starfishes is thus presented. these Plates cannot fail to be of value not only as illustrations of a number of our American Starfishes, and as showing the systematic value of characters thus far almost completely neglected, but also as determining the homology of several genera not previously figured, the solid parts of which are given in detail. As several European naturalists are at the present moment engaged upon the study of the Starfishes, it appeared judicious to issue these Plates before they became antiquated.

* They were intended to accompany the text of the fifth volume of the "Contributions to the Natural History of the United States," by L. Agassiz.

The Memoir on the Embryology of the Starfish, Part I., has been republished substantially as it originally appeared in 1864, in advance of the remainder of the volume. I have added notes in brackets on the points where additions have been made by subsequent investigations for the sake of calling attention to the present condition of the subject, and I beg the reader to remember that it was written thirteen years ago.

ALEXANDER AGASSIZ.

MUSEUM OF COMPARATIVE ZOÖLOGY,
CAMBRIDGE, April, 1877.

CONTENTS.

PREFACE.

PART I. Embryology of the Starfish.

CHAPTER FIRST. Artificial Fecundation, and History of the Development of the Larva, p. 3.

CHAPTER SECOND. History of the Development of the Starfish proper, p. 30; Recapitulation, p. 36.

CHAPTER THIRD. Embryological Classification of Starfishes, p. 59.

CHAPTER FOURTH. Examination of the Investigations of former Observers, p. 66.

CHAPTER FIFTH. On the Plan of Development of Echinoderms, p. 75.

PART II. On the Solid Parts of some North American Starfishes.

Homologies of Echinoderms, p. 87; Description of the Hard Parts of some North American Starfishes, p. 94; Asterias, p. 94; Echinaster sentus, p. 97; Crossaster, p. 98; Pycnopodia helianthoides, p. 100; Brisinga, p. 102; Luidia Guildingii, p. 105; Asterina folium, p. 106; Asteropsis imbricata, p. 106; Pentaceros reticulatus, p. 108; Solaster endeca, p. 112; Cribrella sanguinolenta, p. 113; Astropecten articulatus, p. 114; Luidia clathrata, p. 117; Fascioles of Starfishes, p. 119.

NOTE, p. 121.

EXPLANATION OF THE PLATES, p. 122.

PART I.

EMBRYOLOGY OF THE STARFISH.

By ALEXANDER AGASSIZ.

[Part I., together with Plates I.–VIII., was published in December, 1864; the text included in brackets has been added with the subsequent part.]

EMBRYOLOGY OF THE STARFISH.

CHAPTER FIRST.

ARTIFICIAL FECUNDATION, AND HISTORY OF THE DEVELOPMENT OF THE LARVA.

Differences of the Sexes. — Since the existence of different sexual organs in separate individuals was first pointed out among the lower animals, the tendency of every additional advance in our knowledge of their structure has been to bring out more fully the differences of sex between them. But recently, we did not even know that among the Medusæ there were male and female individuals; and yet, at the present day, it is a comparatively easy task to distinguish, among the larger Jelly-fishes, the males from the females. The difference of coloring is very striking. The spermaries of the males are often brilliantly tinged, while the ovaries of the females are of duller hues. We thus find among Jelly-fishes the first indication of an almost universal law in the animal kingdom, and which is nowhere carried out to so great a degree as among Birds. A casual observer could not fail to distinguish a male from a female Aurelia, — though the great difference in the coloring of the males and females had not been perceived by naturalists till it was first pointed out by Professor Agassiz, in Aurelia flavidula *Pér. et Les.* In Melicertum, in Turris, in Staurophora, in Circe, a glance will suffice to determine the sex of the individual; while a single look through a magnifying-glass will reveal to us the sex of the smaller species, such as Eucope, Pennaria, Euphysa, and the like. The difference of the sexes of some Echinoderms is easily perceived by their difference of coloring at the time of spawning; among them are our common Starfishes and our Sea-urchins.

The males and females of our common species of Starfishes, Asteracanthion pallidus *Agass.* (A. vulgaris *Stimp.?*), and Asteracanthion berylinus *Agass.*, can readily be distinguished by their difference in coloring: all those having a bluish tint being invariably females; a reddish or reddish-brown color indicating a male. Among the many specimens I have had occasion to open, I have thus far never found a single exception. When cut open, so as to expose the genital organs, the difference between the males and females is still more striking. The long grape-like clusters of reproductive organs extending from the angle of the arms, on both sides of the ambulacral system, to the extremity of the rays, present very marked differences in the two sexes. The ovaries are bright orange, while the spermaries are of a dull cream-color. At the time of spawning, which is very different in the two species mentioned above, the genital organs are distended to the utmost, filling completely the whole of the cavity of the ray; the abactinal system itself being greatly expanded by the extraordinary development of these organs.

Artificial Fecundation. — If we take a male and female Starfish in this state, and cut a portion of the genital organs into small pieces, we shall find that the eggs and spermaries escape in such quantities as to render turbid the water in which they are placed. Throwing these small pieces of the genital organs into shallow dishes containing fresh sea-water, and stirring the mixture thoroughly to insure the contact between the spermaries and the eggs, will be sufficient to fecundate the latter. In order to make the operation perfectly successful, some precautions are necessary: all the pieces of the genital organs, which are left after repeated stirring, must be carefully removed; there must not be too many eggs in one dish, so that the water can have free access to them in every direction. The removal of the remnants of the ovaries and spermaries is very necessary, as the pieces which remain clotted together decompose very rapidly, and endanger the safety of the eggs, even when the water can be changed with the greatest facility. As soon as the fecundation is fulfilled, the water in the dishes must be repeatedly changed until it becomes perfectly clear, for the presence of too many spermaries, rendering the water milky, prevents a favorable result. It is best only to use one male and one female for the mixture in each vessel, as eggs taken from many individuals lessen the chances of success. The eggs sink to the bottom, so that the water can be poured off and changed without much danger of throwing them away. Immediately after the mixture is made, the water should be changed three or four times in succession; after that, every half-hour, until the fourth hour, when an interval of two to four hours may elapse before renewing the water. As it is extremely difficult to change the water after the embryos have hatched and are swimming freely about in the jar, without losing many of them, it is advisable, before they hatch, which is about ten hours after the fecundation, to reduce the water to a minimum volume, and then simply to add a little fresh sea-water and remove the contents of the vessel to larger and larger jars. In this way the water can be maintained sufficiently pure, until the young embryos have taken the habit of swimming near the surface, when it may all be drawn off by means of a siphon. A great deal of time and trouble will be saved by this mode of procedure, and fewer specimens lost. The jars containing the eggs should be kept in a cool place; the most convenient method of securing a low and even temperature is to place the small jars in large tubs filled with cold water.

Changes in the Egg. — At the time of spawning, the eggs in the ovaries are so closely packed that they are pressed into all sorts of shapes, triangular, polygonal, elliptical; but when placed in water, and allowed to remain a short time, they soon become perfectly spherical (Pl. I. *Fig.* 1). The following numbers are the ratios of the diameters of the yolk, the germinative vesicle, and the germinative dot, the outer envelope being 1: the yolk is 0.75, the germinative vesicle 0.22, and the germinative dot 0.08. The formation of the egg in the ovary, and its changes up to the time of spawning, I have had neither time nor opportunity, thus far, to examine.

The spermatic particles, which swim about with great rapidity on escaping from the spermaries, soon find their way to the outer envelope of the egg to which they attach themselves, beating about very violently the whole time. The particles remain imbedded in the thickness of the outer envelope, and are sometimes so crowded as to form a halo round the egg (Pl. I. *Figs.* 1–4). I have not, in a single case, seen any of the particles penetrate through the outer envelope and reach the yolk itself.

Probably a great deal of the difference of opinion prevailing among Physiologists, as to whether the spermatic particles penetrate through the successive envelopes of the egg to the yolk itself, is due to the want of precision still existing in our knowledge concerning the envelopes of the yolk in the different branches of the animal kingdom. We do not know whether what we call the outer envelope of the egg of an Echinoderm is homologous to the outer envelope of the egg of an Acaleph, of a Polyp, or of Worms, Insects, or Crustacea, or how far these envelopes are found in the ovarian eggs of Mammals, Birds, Reptiles, and Fishes. And before we can come to a satisfactory result as to the place in the egg which the spermatic particles reach before changes can be observed to take place in the yolk, the eggs of the different classes of Animals must be carefully compared with reference to this point. The first phenomenon which precedes any change in the egg is a rotary motion given to the whole egg by the constant beating of the spermatic particles; the germinative vesicle disappears (Pl. I. *Fig.* 2) soon after this, and next the germinative dot (Pl. I. *Fig.* 3). The yolk has then all the appearance of an egg which has undergone segmentation, and the yolk of which should consist of innumerable small spheres. The yolk has the same granular structure previous to segmentation which has usually been considered to belong to it only after the segmentation is complete. [The phenomena preceding segmentation, the structure of the yolk, the mode of formation of the Richtung's-Bläschen, the manner in which the germinative vesicle disappears, are subjects which since the preceding investigations were made have all received considerable attention. The explanations given of these points are therefore all subject to revision and to correction. See more particularly the papers by LUDWIG, C. SEMPER, LANKESTER, HARTWIG, FOL, AUERBACH, BALFOUR; sundry Embryological Memoirs by E. VAN BENEDEN, Composition de l'œuf, 1870; KOWALEWSKY A. Mem. Akad. St. Peters, XVI., 1871; BLÜTSCHLI, Die Eizelle; HAECKEL E., Die Gastræa Theorie; STRASSBURGER, Die Zelle.] The resemblance between these two stages is still more marked in the eggs of Ctenophoræ, where the ratio between the diameter of the yolk and that of the outer envelope is large, and in which the segmentation is carried on until the whole yolk consists of such minute spheres that it is impossible at first sight to distinguish an egg of a Ctenophorous Medusa, which has undergone complete segmentation, from one in which the segmentation has not even begun, after the germinative vesicle and dot have disappeared. The disappearance of the germinative dot is accompanied by a separation of the yolk from the inner wall of the outer envelope of the egg (Pl. I. *Fig.* 3); this is the first step towards segmentation, and the presence of such a marked interval would greatly facilitate the detection of spermatic particles upon the surface of the yolk, if any of them had penetrated through the outer membrane. The first trace of segmentation consists in a depression of the yolk, visible on one side of the sphere (Pl. I. *Fig.* 4), and is soon followed by a similar change on the opposite pole.

The segmentation takes place very rapidly, passing in about eight hours from the stage represented by Pl. I. *Fig.* 3 to that of Pl. I. *Fig.* 21, immediately before the escape of the embryo from the egg. The spheres in the earlier stages of segmentation are well separated (Pl. I. *Figs.* 7, 9, 11, 13). They have a centrifugal tendency, and, as they increase in number, arrange themselves in a shell-like envelope, which eventually becomes the wall of the embryo. This tendency is already apparent when there are not more than eight spheres (Pl. I. *Figs.* 13, 14); and as early as the stage represented on Pl. I. *Fig.* 16, where there are only thirty-two spheres, the envelope is quite prominent. The rotation of the spheres of segmentation commences before this (Pl. I. *Fig.* 6), and is entirely independent of the motion given to the whole egg by the spermatic particles; this stops soon after the rotation of the spheres of segmentation has commenced.

As the egg of the Starfish presents nothing peculiar in its process of segmentation beyond what has been just remarked, I refer the reader to the explanation of the plates for the details concerning every successive step of this process, as observed in Asteracanthion berylinus.

The Richtung's-Bläschen of Schultze, which he first noticed in the segmentation of Mollusks, and which were afterwards seen by Lacaze-Duthiers and by Robin, who traced their mode of development, were also observed in the segmentation of the yolk of our Starfish. They are noticed, before the yolk has been divided into halves (Pl. I. *Fig.* 5), as three or four small granules, situated at the extremity of the axis which is to divide the yolk into two portions (Pl. I. *Fig.* 6). They are developed from the yolk itself as a slight swelling, which afterwards becomes entirely distinct from the mass of the yolk (Pl. I. *Fig.* 7), retaining always throughout the whole process of segmentation the same relative position to the axis of segmentation (Pl. I. *Figs.* 9–17). What part they play in the subsequent history of the embryo I have not been able to ascertain. Without doubt they always hold the same relation to the first axis of segmentation, and are, as far as I have observed them in the segmentation of

Asteracanthion and of Toxopneustes, invariably at one pole of the first axis of segmentation.

The Embryo after Hatching. — At about the end of the tenth hour after fecundation, the segmentation has been carried so far that the walls of the future embryo have become quite conspicuous, and it is now ready to hatch (Pl. I. *Fig.* 21). When the outer envelope is torn, the young rotate slowly about, around a shifting axis, by means of very minute cilia placed over the whole surface; the walls are everywhere of the same thickness, and the embryo is perfectly spherical. A difference soon becomes evident; the walls thicken at one pole of the sphere (Pl. I. *Fig.* 22, *a*), and the thickening is accompanied by a flattening of the same side (Pl. I. *Fig.* 23, *a*); the embryo has lost its regular spherical shape and its homogeneous walls (Pl. I. *Fig.* 23, *a*). The next change consists in a slight depression at this flattened pole (Pl. I. *Fig.* 24, *a*); the wall bends inward, forming a very shallow depression, growing deeper and deeper, until it forms a pouch extending half the length of the embryo (Pl. I. *Figs.* 25, 26, *d*, 27, *d*). [This stage has become well known as the gastræa stage of Haeckel; for a fuller discussion of the gastræa theory see my Memoir on the Embryology of the Ctenophoræ, Mem. Amer. Acad., 1874, p. 379.] While a cavity (*d*) is thus formed by the simple folding in of the outer wall, the embryo is constantly lengthening and becomes more cylindrical; the walls of the extremity opposite the pouch becoming attenuated, while, immediately round the opening of the cavity, the walls have not lost their original thickness (Pl. I. *Figs.* 26, 27, *a*). Water flows freely into and out of this cavity; currents are established, running in different directions along opposite walls of the pouch, showing this opening to be for the present a mouth; the pouch, or digestive cavity, sustains the same relation to the whole body as in the most regular and circular radiated animals, such as young Actiniæ, or young Porites. The motion of the embryo, which immediately after escaping from the egg is an extremely slow rotation, increases in rapidity as it lengthens, and by the time the cavity equals half the length of the embryo (Pl. I. *Fig.* 27, *d*), the motion is much accelerated. Instead of a simple slow rotation, with scarcely any motion of translation, the latter is now quite rapid, and is accompanied by a slow rotation round a vertical axis, through the centre of the longer diameter of the animal; the opening leading into the cœcum is foremost during their motion.

At the end of about twenty hours after fecundation the embryo has reached the condition just described; it is now somewhat pear-shaped, with rounded extremities (Pl. I. *Fig.* 27), having at one end an opening (*a*), leading into a pouch (*d*), which extends half the length of the cylinder.* We have now the embryo in a condition which can best be compared to the embryos of other Radiates; for there is as yet nothing of the complication hereafter introduced in the subject by the development of bilateral parts, obscuring the plan upon which the embryo is built. It is an embryo closely resembling those of the other Radiates, in which, however, the class-characters, distinguishing it from the embryos of the other classes of the type, are already developed beyond question. In the young Polyps the earliest appearance of the class-characters is denoted by the presence of a few radiating partitions, dividing the cavity of the embryo into distinct chambers. In the Acalephs, in the most rudimentary stages, we already find the chymiferous tubes pushing their way through the spherosome; while in our larvæ the echinodermoid class-character, that of having distinct walls, forming the different organs, is already plainly visible from the mode of formation of this digestive cavity. What unites all these embryos in one great type is, that we have in them all an axis around which are arranged the different elements

* So far, the changes which have been observed do not differ materially from what we know of the earlier stages of Echinoderm larvæ, from the observations of Derbès, Müller, and Krohn. As I have shown, in the Memoirs of the American Academy for 1864, the earlier stages of the Echinus larvæ, as they have been figured by Derbès, agree in the main points with what has been observed of the earlier stages of our American Echinus larvæ (Toxopneustes dröbachiensis). With the exception, however, that Derbès, not having followed all the intermediate stages between his figures 15 and 16 in the Annales des Sciences Naturelles for 1847, did not see the transformations the digestive cavity undergoes, and committed, therefore, the very natural mistake of supposing that the first-formed opening, which we have described as a mouth, retained the same function afterwards. He, however, correctly noticed the separation of the three cavities, the œsophagus, the stomach, and the alimentary canal, into which this primary cavity is gradually differentiated, and has given a correct description of their relation to each other. Müller has taken up this same subject rather where Krohn and Derbès have left it, and although he has traced the development from the egg of several Echinoderm larva, yet he has not given us as detailed descriptions and figures of the earlier stages, as of those which were more advanced, and says simply, that in the main points his observations coincided with those of Krohn and Derbès. Krohn, who has artificially fecundated Echinus lividus, gives us in his figures some of the missing links in the chain of the observations of Derbès, and shows distinctly for E. lividus, that the first-formed opening becomes the anus eventually, and in what way this is brought about by the bending of the bottom of the digestive cavity towards one side of the larva, as is the case in our Starfish, and the formation at that point of a second opening, which becomes the true mouth, while the first-formed opening henceforth assumes the function of an anus.

of which they are composed. Our young Echinoderm in this condition (Pl. I. *Figs.* 23–28) can be strictly homologized with the earlier stages of a Polyp at the time when the digestive cavity is first formed, before the appearance of the partitions; and with an acalephian embryo, where the digestive cavity alone is developed, previous to the pushing of the chymiferous tubes through the gelatinous mass. The stages subsequent to the condition of the embryo here described, represented in Pl. I. *Fig.* 24, not having been traced very carefully by previous observers, we have not had before us the means of forming a true conception of the mode of development of the Echinoderms; for to obtain a clear and precise idea of the functions of those problematic bodies which have puzzled Müller during the whole of his investigations, it is necessary to follow, step by step, the changes taking place in the pouch of the embryo, which is in this early stage its digestive cavity (*d*); for it is as much a digestive cavity as that of a young Actinia or a Scyphistoma, where the same opening serves as mouth and anus. The mode of formation of the digestive cavity is entirely different in the two classes; in the Polyp it is hollowed out of the interior of the embryo, while in the Echinoderm the bending in of the wall forms the stomach. Hence the two cavities are not homologous, and the openings which lead into them, though performing similar functions — those of mouth and anus — are likewise in no way homologous, though they are in all built upon the plan of radiation. This opening always retains its double function in the Polyps and some of the Acalephs, while in the Echinoderms it becomes the anus after the true mouth has been formed, and the currents have ceased to circulate in the extremity of the pouch and to pass out through the same opening which admitted them.

If there is any doubt that Echinoderms, Acalephs, and Polyps belong to the same great type of the animal kingdom, a comparison of the young Echinoderm, Acaleph, or Polyp in their earlier stages of growth, at a time when the spherosome has not yet been divided into its component spheromeres, will show how great is their identity of development, and how little there is in nature to justify the separation of this most natural great division of the animal kingdom, the Radiates, into Echinoderms and Cœlenterata. I shall return to this point when speaking of the homologies of the larvæ of Echinoderms.

Formation of the Mouth. — The perfect symmetry of the larva (Pl. I.

Fig. 27) is soon modified, and in the next stages of development (Pl. II. *Figs.* 2, 4), the digestive cavity (*d*) no longer runs in the centre of the larva, but is bent slightly to one side. If we examine one of the embryos about forty hours old (Pl. II. *Figs.* 5, 6), we find that great changes have taken place in the thickness of its walls. The outer wall has everywhere become much thinner, except near the opening thus far called mouth, where the decrease is not so marked. The walls of the digestive cavity, which were of an equal thickness for the whole length, have become exceedingly attenuated at the bottom of the sac, and have dilated to a considerable extent, forming a sort of reservoir with very thin walls at the extremity of the pouch (Pl. II. *Figs.* 4, 6, *d*, magnified and isolated, *Fig.* 1, *d*). These changes in the thickness of the walls, and in the form of the internal cavity, are also accompanied by corresponding changes of form in the embryo as a whole. The extremity opposite the so-called mouth has increased in bulk, and greatly exceeds in size the perforated extremity (Pl. II. *Figs.* 4, 6) of the body.

When seen in profile (Pl. II. *Figs.* 2, 4, 5), still greater changes are visible; there is a decided difference between the two sides of the embryo, forming what is to become above and below; calling that part below, where the mouth is situated in the adult larvæ, and which is carried downward in its natural attitude while moving. The dorsal portion of the larva projects beyond the so-called mouth, so that the perforated extremity has become bevelled; the narrowing of the central portion of the larva has increased, and the digestive cavity which, in younger embryos, occupies the centre of the cylinder (Pl. I. *Figs.* 27, 28), is bent towards the lower side (Pl. II. *Figs.* 2, 4, 5, *d*). The outer wall has become thickened at a point opposite the bent extremity of the digestive cavity, and the thickening of the wall, together with the bending of the digestive cavity, goes on till the closed end touches the lower side at *m*.

The changes which have taken place during the time elapsed since the twentieth hour have been very gradual. The embryo now enters into a state where the changes are exceedingly rapid and important; so much so that at the end of the third day the embryo has, in a rudimentary state, all the parts characteristic of older, fully developed larvæ.

At the end of the second day the reservoir at the extremity of the digestive cavity has changed its outline from a circular to a lobed one (Pl. II. *Fig.* 8, *o*); the lobes widen towards the sides, almost forming diverticula (*w*, *w′*), from the digestive cavity. During this time the main digestive cavity has entirely lost its cylindrical form; it has become narrowed at the extremities and bulging in the centre (Pl. II. *Fig.* 8, and isolated, *Fig.* 9). When seen in profile, and comparing it with earlier stages (Pl. II. *Figs.* 2, 4, 5, 7, isolated, *Fig.* 10, *a*), it is at once noticed that the opening at one end, the present mouth of the larva, has little by little changed from a position at one extremity of the embryo (Pl. I. *Figs.* 27, 28, *a*) to a slightly eccentric one (Pl. II. *Figs.* 4, 5, 7). While the present mouth is changing its position from a terminal to an eccentric one, and while the digestive cavity has been expanding at the bottom into a large reservoir, its closed end is bending more and more towards one side (Pl. II. *Figs.* 2, 4), until it finally touches the outer wall of the embryo at *m* (Pl. II. *Fig.* 5). At this point of junction an opening is formed, leading into the bottom of the digestive cavity (Pl. II. *Fig.* 7); this second opening (*m*) is now the true mouth, and performs hereafter all the functions of a mouth, while the first-formed opening of the young embryo (*a*, Pl. II. *Figs.* 2, 4, 5, 7) is restricted in its functions, and performs hereafter only those of an anus; although in the early stages (Pl. I. *Figs.* 25, 26, 27, 28; Pl. II. *Figs.* 2, 4, 5, 6) it had performed the functions of a mouth. We have thus an apparent anomaly in the fact that the first opening becomes the anus, while the true mouth is only formed afterwards; but this difficulty is readily explained if we compare the functions of this first-formed opening, the so-called mouth, with what we find among Polyps, where one and the same opening performs the double functions of mouth and anus throughout life.

The diverticula (*w*, *w′*, Pl. II. *Figs.* 7, 10) do not extend, as would seem when seen from above (Pl. II. *Fig.* 8), at right angles from the main cavity, but trend obliquely upwards, as seen in profile (Pl. II. *Fig.* 7), towards the other extremity of the embryo, as in *Figs.* 7, 10, Pl. II. The outer wall, which had formed a connection with the closed extremity of the digestive cavity, on the lower side, has been drawn out in the shape of a slender cone (*o*, Pl. II. *Figs.* 7, 10, 11, 14, 17), and becomes the œsophagus, which leads to an opening (*m*, the mouth), connecting the ventral side with the digestive cavity.

Nomenclature. — It will materially assist in the explanation of the subsequent changes of form, and obviate a great deal of circumlocution, if we at once call the different organs by their true names. The original opening (*a*), which performed at first the functions of the mouth, is hereafter the anus (*a*); the second opening, the true mouth (*m*), is not formed until the embryo has arrived near the end of the second day; it is placed in the middle of the lower surface, and from this time forward the former mouth assumes the function of an anus. That portion of the digestive cavity which leads from the mouth to its bulging portion is the œsophagus (*o*), the bulging portion is the true digestive cavity, or stomach proper (*d*), the short tube leading from the stomach to the anus is the intestine (*c*), while the diverticula (*w*, *w′*) are the two branches of the future water-system. The reasons for calling these parts mouth, anus, œsophagus, stomach, intestine, and water-system will become apparent as we trace the development of the embryo in its more advanced stages, in the following pages.*

The currents, which before had entered through the mouth (*a*), passed to the extremity of the cavity (*a*), and been expelled again through the same opening (*a*), now change their course completely; there is a current which enters the mouth (*m*), flows through the œsophagus (*o*) into the diverticula (*w*, *w′*), then into the true stomach (*d*), and is finally rejected through the anus (*a*). From this time forward it is quite an easy thing to observe the course of the food; it is taken into the mouth by means of the currents produced around its opening, passes rapidly through the œsophagus, rotates for some time in the spherical stomach (*d*), and then passes out slowly through the opening (*a*) of the alimentary canal (*c*). As these currents are more and more distinct as the larvæ grow older, there can be no doubt that the function of the first-formed opening is eventually confined to that of an anus, after having performed the function of mouth during the first stage of growth of the larva.

Formation of the Water-Tubes. — By water-tubes I mean the bodies which have received from Müller the name of problematic bodies, in their earlier stages of growth, and which he has called Schlauchsystem, when they appear, in the older larvæ, as broad tubes running on each side of the œsophagus and stomach. These parts he considered as independent systems, but as they are only different stages of the same thing, as will appear below, they have received here the name which denotes most

* Other terms are also frequently used, to denote the different parts of radiated animals, which are not usually adopted; they will be found fully explained in the third volume of the Contributions to the Natural History of the United States, by Prof. Agassiz, p. 73, and seq.

appropriately the function they assume of circulating water through the body of the larva.

The water-tubes (w, w'), at first (Pl. II. *Figs.* 7, 8, 9, 12, 13, 14) only diverticula from the main digestive cavity (d), become less and less connected with it; and by the end of the second day the constriction at the point of attachment has almost entirely separated them from the digestive cavity (Pl. II. *Figs.* 15, 16, w, w'). A marked difference is noticed in the rapidity of growth of these two bodies; the right-hand one (w'), when the anus is placed in advance, and the mouth downwards, increases more rapidly, extending towards the dorsal side, which it eventually reaches, opening into the surrounding medium by a small aperture (Pl. II. *Fig.* 17, b), the water-pore, or, as Müller has called it, the dorsal pore. A comparison of *Figs.* 8 and 18 of Pl. II. will perhaps render more evident the transformation of the diverticula (w, w') from the digestive cavity into two separate bodies. All we have to do is to swell out the lobed pouches (w, w') of *Fig.* 8, Pl. II., then cut them off, removing them a short distance from the digestive cavity, and we shall have the two independent bodies (w, w') of Pl. II. *Fig.* 18, which have little by little been changing their relation to the digestive cavity, as described above. This transformation I have actually observed in every stage of its progress, as it is represented here isolated (Pl. II. *Figs.* 9–16).

The walls of the œsophagus (o), of the digestive cavity (d), and of the intestine (c), which up to this time are of nearly the same thickness, quite rigid, capable of very limited expansion and contraction (Pl. II. *Figs.* 2, 4, 5, 7, isolated, *Figs.* 10, 11), lose their uniform character with the gradual circumscription of these three regions. The walls now become quite different in their appearance, and the more marked the separation between these three organs, the greater the difference in the character of the walls which circumscribe them (Pl. II. *Figs.* 17, 19, 21, 23). In proportion as the stomach (d) grows more spherical, the angle between it and the intestine (c) is more acute, and the intestine (c) becomes a longer and narrower tube, with walls much less thick than those of the stomach (d). The walls of the œsophagus (o) are even more flexible; the conical tube, leading from the mouth to the stomach, widening and taking a pistol-shaped form, the walls have become so movable, that the opening leading into the stomach can be closed and opened by the greater power of expansion and contraction of this part of the walls (Pl. II. *Figs.* 23, 25). The mouth (m), as it increases in size, grows triangular, with rounded corners; the depression in which it is placed divides the larva into two very distinct regions (Pl. II. *Figs.* 19, 23, 25). Since the formation of the mouth, and the change of position of the first-formed opening to an eccentric one, we find the mouth and anus placed on one side of the larva. These openings present, at this stage (Pl. II. *Fig.* 17), the same relations as the mouth and anus of Clypeaster and Scutella-like Echinoids, while at a much earlier period they are more like Pygorhynchus.

If we now return to the water-system, we find that the two diverticula (*w*, *w'*), mentioned above (Pl. II. *Figs.* 15, 16), have entirely separated from the digestive cavity (Pl. II. *Fig.* 18), and are now distinct cavities, having no connection whatever either with the cavity from which they originated or with one another; one of these cavities is entirely closed (*w*), the other (*w'*) connects with the surrounding medium by means of a very small opening, the dorsal pore (*b*, Pl. II. *Fig.* 23, and isolated, *Fig.* 17). Such is the appearance of an embryo at the close of the second day after fecundation.

Müller never knew the origin of the water-tubes; in his last paper only he becomes aware that they are independent at first, but subsequently unite. It must be remembered, in reading his earlier papers, that he sets at rest, in his last memoir, the doubts he expressed concerning the independence of the two branches of the water-tubes; in fact, to obtain a clear conception of Müller's views, it is advisable to read his last memoirs first, to be able to adopt at once the corrections he himself makes during the laborious course of his investigations. The problematic bodies, however, still remained a puzzle to him, even at the time of his last memoirs, as he was never aware that they were simple diverticula of the digestive cavity, and were finally transformed into the two independent branches of the water-tubes, uniting, in subsequent stages of growth, to form the Y-shaped water-system. Van Beneden saw, in the young Bipinnaria (Brachina *Van Ben.*), that the water-tubes are at first separate, but he did not trace their mode of formation, and no other observer has since returned to this subject.

[Metschnikoff states that in some cases there is but a single water-tube, and that I have mistaken an accumulation of cells for a second water-tube. I can only state that I have frequently repeated my observations on the Pluteus of Starfishes, Ophiurans, and Echini, and have invariably found two water-tubes present, but I have also seen in Starfishes and Ophiurans, as he has well shown in Ophiurans alone, that the whole rosette of the future ambulacral system is developed only upon the surface of one of these, the one communicating with the exterior through the dorsal pore, the future madreporic body.]

Appearance of the Chords of vibratile Cilia. — The cilia, spreading over the whole surface, which moved the embryo so rapidly at first, have almost entirely disappeared, and are no longer capable of propelling such a large mass; consequently, at this last-mentioned stage (Pl. II. *Fig.* 20), the larva is very sluggish, advancing but little, and rotating slowly about a longitudinal axis at the same time. During the third day, the movements become still more sluggish; it is then that we find the first appearance of the organs which are to propel the larva in future. The general outline does not change during the third day; the principal transformations are the greater bending and extending of the œsophagus and alimentary canal, the increase in size of the mouth, of the water-tubes, and the appearance of slight projections, small clusters of vibratile cilia, near the anterior and posterior sides of the mouth, which are the beginning of rows, extending in older larvæ in continuous lines all round the body, and their only means of locomotion (Pl. II. *v*, *v'*, *Figs.* 20–28). These rows are at first two very short arcs (*v*, *v'*, Pl. II. *Fig.* 22), with their convexities placed opposite one another on each side of the depression in which the mouth is placed (*v*, *v'*, Pl. II. *Fig.* 21).

The general outline of the larva has, up to this stage (Pl. II. *Fig.* 20), undergone but slight modifications, the changes taking place principally in the digestive organs. The phases through which the larva passes in the next three days are of a very different character; the alimentary canal, the stomach, and the œsophagus become more circumscribed by the increasing difference noticeable in the walls of these regions. The stomach (*d*) is always marked by the greater thickness of its walls; while, with increasing age, the walls of the œsophagus (*o*) become more attenuated, and capable of greater expansion and contraction (Pl. II. *Figs.* 25, *o*, 27). We observe, also, a rapid increase in the growth of the water-tubes (*w*, *w'*), which by the end of the sixth day (Pl. II. *Figs.* 27, 28) extend as far as the corners of the mouth and along the edge of the walls of the stomach, towards the anal extremity (Pl. II. *Figs.* 24, 26, *w*, *w'*). When viewed in profile (Pl. II. *Figs.* 25, 27), it will be seen that the plane in which these water-tubes run is not parallel to the longitudinal axis, but inclined to it in such a manner, that the œsophagus passes between these two tubes. It is in these stages, represented in Pl. II. *Figs.* 20–28, that the passage from the initial, truly radiate form to a bilateral one is the most obvious, and it may be well to dwell for a moment on the changes which are going on here, and compare them to what we find in other Radiates. Müller has always maintained that, the Echinoderm larvæ being bilateral, we had a passage from a bilateral symmetry to a radiate type, while in reality this seeming bilaterality is subordinate to a truly radiate plan of structure. The first question to settle with regard to this is, whether we have a strictly bilateral form among the larvæ or not, and whether we do not find here a repetition of what is so constantly met with in the animal kingdom, — the undue preponderance of some parts, hiding effectually the plan upon which the whole animal is built; in fact, the engrafting of a subordinate type upon the type which remains predominant. With the gradual development of the plastrons alluded to, as formed from the chord of vibratile cilia, the embryo assumes more and more a shape which renders it quite difficult to perceive the original plan of radiation, concealed, as it gradually becomes, by the symmetrical arrangement of the edges of these plastrons, which leads one involuntarily to mistake their mode of execution for the plan upon which the animal is built. This apparent passage from a strictly radiating form to a seeming bilateral one is nothing more than what we find constantly among the adults of this same class, and yet no one has attempted, for that reason, to make bilateral animals of the Echinoderms. The Spatangoids might as well be called bilateral, and not radiating animals, on account of the perfectly regular symmetrical arrangement of the fascioles, extending over all the spheromeres composing the body of such Spatangoids, and in which even the ambulacral system presents marked features of bilateral symmetry. The case is exactly a parallel one; this chord of vibratile cilia, and the chord of fascioles, arranged so regularly, simply conceals in both cases the plan upon which the animal is built, but does not, in either case, change the plan of radiation into that of bilaterality. As little should we be justified in removing some of the Holothurians, such as Cuviera and the like, from the Radiates, simply because the greater preponderance of some of the ambulacra has brought out, in these animals conspicuously, a dorsal and a ventral side, and an anterior and posterior one. In the embryo of our Starfish, which told so plainly, in its early stages, of the plan upon which it is built, that plan is now lost sight of in the extraordinary bilateral development of some of the parts. But, until Spatangoids and flat-soled Holothurians are proved to be truly bilateral animals, and not genuine Radiates, with subordinate bilateral features, these seeming bilateral Echinoderm larvæ must be considered as truly radiate, with bilateral features engrafted upon them.

Development of the Plastrons. — The cylindrical shape, characterizing the earlier stages of the larva, disappears soon after the appearance of the first trace of the appendages which give to these larvæ such a peculiar appearance, and they now assume the features of the adult. The depression (Pl. II. *Figs.* 25, 27, *m*), in which the mouth is placed, becomes more marked; we have a greater separation of the oral (v') and anal (v) swellings of the vibratile chord, little by little changed into two independent breastplates, the edges bound with chords of powerful vibratile cilia, becoming the locomotive organs of the larvæ (Pl. II. *Figs.* 20, 22, 24, 26, 28). These plastrons, at first mere crescent-shaped shields (Pl. II. *Figs.* 20, 22, 24), extend gradually towards either extremity, become elliptical, and then somewhat triangular. The outline of the anal shield becomes sinuous, slight indentations point out the position of the future arms (Pl. II. *Fig.* 26, e' e', *Fig.* 28, e' e', e''' e'''); the rows of cilia creep gradually round the edge of this anal shield, turn towards the mouth again, and extend, on the dorsal side, along the whole length of the larva (Pl. II. *Fig.* 25); this chord of cilia makes a complete circuit, while the cilia, extending along the edge of the oral plastron, do not meet.

The formation of these plastrons is attended with great changes in the general outline of the larva; the anal extremity becomes pointed, triangular, with rounded edges; the body, on each side of the oral opening, bulges out beyond the general outline, and the oral plastron is more and more pointed, as it separates from the rest of the larva. This change of shape can perhaps be better appreciated when seen in profile, and by comparing the drawings of larvæ three days and six days old; compare Pl. II. *Fig.* 19 with Pl. II. *Figs.* 25 and 27 seen from opposite sides. The great elongation of the oral extremity and the marked separation made by the opening of the mouth between the anal and oral plastrons cannot fail to be noticed.

Comparison of Larvæ of Asteracanthion pallidus and A. berylinus. — Up to this time all the larvæ described were raised by artificial fecundation from eggs taken out of the ovaries of Asteracanthion berylinus *Ag.* When I first discovered the larvæ of our Starfishes, I immediately examined the ovaries of our two most common species, the A. berylinus *Ag.* and A. pallidus *Ag.* I found that the eggs of the former were not sufficiently advanced to be fecundated, while those of the second species (A. pallidus) had all escaped. I am, therefore, positively certain that all the larvæ I am about to describe belong to the second species, as they were all found swimming about previous to the time of spawning of the A. berylinus. As the interval between the time of spawning of these two species is not less than three weeks, I had been able, during this period, to make a general sketch of the whole development, from the youngest larva found (Pl. III. *Fig.* 1), to the time when the Starfish is formed, before beginning the artificial fecundation of the species just described, the A. berylinus *Ag.*

I thus obtained a general knowledge of the changes these larvæ undergo, and was enabled, when making the artificial fecundation, to pay special attention to the development of those parts, the origin of which was not easily traced in older larvæ. I was able in this way to carry on, at the same time, the comparative study of the development of two closely allied species, belonging, undoubtedly, to one and the same genus, and to see how far differences could already be noticed in their early stages of growth; a glance at the figures of the young of one species (A. pallidus *Ag.*) on Plate III., compared with the figures of Plate II. of the second species (A. berylinus *Ag.*), will show how far the development of allied species diverges. What is particularly characteristic is the fact that specific differences make their appearance so early. Soon after it became evident that the embryos we were studying belonged to Echinoderms, it was apparent that they were different species. The order of appearance of the characters of the classes, the orders, the families, and genera, is one of the greatest importance in a zoölogical point of view; and we owe to Professor Agassiz to have pointed out, that the characters which make their appearance first are by no means those which have been usually supposed to take precedence; in the present case we do not find it possible to discern the class, the ordinal, the family, the generic and the specific characters, in the order in which they are here mentioned. On the contrary, the specific characters are early stamped upon the embryo, and did we but know how to recognize individual differences among the lower animals as well as we can already in some of the Fishes, we might find that with Echinoderms, as has been shown for Fishes by Professor Agassiz, the stamp of individuality is very early impressed upon the embryo. Long before we can tell that a young Perch belongs to the genus Ctenolabrus, we can already say with certainty whether it will be colored red or gray or brown or green.

The time of spawning of Starfishes is very short, as, three or four days after the A. berylinus began to spawn, it was quite difficult to find females with eggs; and a week after the beginning of the spawning, I never succeeded in finding a single one. Owing to this great difference in the time of spawning and its short duration, there can be no doubt, from the date at which I first caught the Starfish larvæ floating about, to which of our two species they belong. A careful comparison of the youngest specimens also shows very striking differences, and will always enable an observer to distinguish readily the larvæ of the two species, even in their earliest stages. Compare Pl. III. *Figs.* 1, 2, 3, 4, 5, with *Figs.* 22 – 28 of Plate II. These differences become more marked as they grow older, as will be seen when we describe adult larvæ. In fact, the larva of A. berylinus is pear-shaped, with the thick end at the oral extremity, while in the larva of A. pallidus the thick end of the equally pear-shaped, but relatively shorter body is at the anal extremity.*

The principal points of difference in the young larvæ of this second species (the A. pallidus), from those previously described, are differences of proportions. The larvæ of the A. berylinus are elongated cylindrical; the oral extremity is somewhat broader and more prominent than the anal. The larva of A. pallidus can at once be recognized by its shortness; the small size of the oral extremity, when compared to the anal, the latter being by far the most prominent.

Water-System. — Before going on with the description of more advanced

* Though we now consider the further progress of development of our larvæ in a different species from the first, we proceed without interruption, as the phenomena of growth are identical in both; and we link them here together only because our most complete observations for the younger stages relate to A. berylinus, and to A. pallidus for the older stages. Had we presented these changes for a single species only, the one would have been defective in the beginning, the other in the end. As it is, our history is tolerably complete, the course and nature of the changes being identical in both species.

stages, I will take up the development of the water-tubes at the point to which we had traced them (Pl. II. *Fig.* 28) in the larvæ of A. berylinus. After the ends of the water-tubes have extended beyond the oral opening (Pl. III. *Fig.* 4), the tubes increase rapidly in diameter (Pl. III. *Figs.* 6, 8, *w*, *w′*), bending at the same time towards the longitudinal axis (Pl. III. *Figs.* 4, 5, 6, 8, 10, *w*, *w′*), the other extremity of the tubes creeping round the stomach until they touch, but without uniting (Pl. III. *Figs.* 6, 8, 10, *w*, *w′*). The tubes at the oral extremity bend towards each other (Pl. III. *Fig.* 4), come in contact (Pl. III. *Fig.* 6), and, soon after, a communication is made, the water-system assuming the shape of an elliptical ring (Pl. III. *Fig.* 6, *ww′*); and the water which enters into the right tube through the dorsal pore (Pl. III. *Figs.* 2, 5, 7, *b*) passes into the other branch on the opposite side of the stomach, through the fork at the oral extremity, and not round the stomach, where the water-tubes simply touch, but do not communicate. The small tube leading from the dorsal pore to the main branch of the water-system widens and becomes funnel-shaped as it approaches the main tube. The dorsal pore is cut obliquely across the end of this small tube, giving it an elliptical shape. By the time the two branches of the water-system have joined (Pl. III. *Fig.* 6) at the oral extremity of the larva, it has assumed an entirely different outline from any we have met with in the former species. The anal extremity is very much flattened, the corners of the anal plastron project slightly beyond the general outline, the indentations have become very distinct, the oral plastron has grown rectangular with rounded angles and concave sides, the oral triangular opening leads into a deep pouch. The sides of the body are marked by three strong indentations (Pl. III. *Fig.* 8). The oral extremity of the water-system changes rapidly from a rounded to a pointed outline (Pl. III. *Fig.* 8, *ww′*); it advances more and more towards the oral extremity. In proportion as the dorsal region projects beyond the oral plastron, the water-system extends into this projection, sending off, at the same time, two branches leading into small appendages (Pl. III. *Figs.* 10, 11, *f*, *f*), (only developed in more advanced larvæ), which have, in the adult larvæ, a peculiar structure (Pl. IV. *Figs.* 4, 5, 6).

Changes of Form of the Larva. — The prominent changes now going on are only changes of degree. The larva has completely lost its cylindrical shape, and even the pear-shaped form it assumed afterwards; it has become rectangular, with deep indentations, gradually assuming the character of short arms. The transformation from the pear-shaped (Pl. III. *Fig.* 1) to the rectangular flattened larva, with undulating outline (Pl. III. *Fig.* 6), can readily be traced by comparing the successive stages here represented. After the digestive cavity of the younger embryo (Pl. II. *Fig.* 7) is bent at the extremities, bringing the mouth and the anus on the same side of the larva, the anal and oral extremities increase rapidly in bulk, and the larva, when seen from above (Pl. II. *Fig.* 18) or in profile (Pl. II. *Fig.* 19), becomes somewhat dumb-bell shaped. The depression thus formed grows deeper, especially on the lower side, at the time when the chords of vibratile cilia make their appearance (Pl. II. *Fig.* 21), and the mouth (Pl. II. *Fig.* 21, *m*) is placed in the convexity of a deep curve. As the oral and anal vibratile chords extend towards the oral extremity, slight grooves arise (Pl. II. *Fig.* 23), starting from the depression in which the mouth is placed, and extending towards the oral extremity. These grooves are gouged out from the oral extremity; they extend but little way towards the stomach, forming a very well-marked channel separating the anal from the oral vibratile chord (Pl. II. *Figs.* 25, 27). The oral is less broad than the anal plastron; the former retains its shield-like shape, while the sides of the latter become somewhat undulating from the bending of the ciliary chord (Pl. II. *Figs.* 26, 28). These slight undulations, as the larva grows older and more elongated, increase in size, giving it more and more a rectangular outline (Pl. II. *Figs.* 27, 28; Pl. III. *Figs.* 3, 4). With its quadrangular shape, the larva assumes also a more flattened character, and loses its cylindrical form, as will be readily seen on comparing *Figs.* 21 and 27, of Pl. II. These slight undulations of the ciliary chord are formed at points where accumulations of pigment cells have taken place. The ciliary chord, at first simply a wavy line (Pl. III. *Fig.* 4), soon becomes quite deeply indented by the formation of loops at these indentations (Pl. III. *Fig.* 6). The loops, at first, scarcely project beyond the general outline of the larva (Pl. III. *Figs.* 6, 7). Little by little they increase in length (Pl. III. *Figs.* 8, 9), extending slightly beyond the edge of the outline, like short arms; until, passing through somewhat older stages (Pl. III. *Fig.* 10), these loops are gradually transformed into larger and larger arms (Pl. III. *Figs.* 11, 12), and finally attain the shape of the long, slender arms of the adult Brachiolaria (Pl. IV. *Figs.* 1, 2, 4; Pl. VII. *Fig.* 8). During the process of the formation of the arms, the cut in which the mouth is placed becomes deeper (Pl. II. *Figs.* 25, 27; Pl.

III. *Figs.* 2, 5, 7, 9, 12; Pl. IV. *Fig.* 4), as well as the groove extending along the sides of the larva, which runs from the median anal arms (e') to the oral extremity, and separates the anal from the oral plastron. In all these larvæ the ventral part of the anal and the oral plastron are much narrower than the dorsal portion of the anal plastron. This difference is at first slight (Pl. II. *Figs.* 26, 28; Pl. III. *Figs.* 3, 4); it becomes more marked with advancing age, passing through the different stages represented in Pl. III. *Figs.* 6, 8, 10, 11); Pl. IV. *Figs.* 1, 2; Pl. VII. *Fig.* 8; and in proportion as all the ridges and edges are more prominent, the surfaces circumscribed by them become flattened and more spreading.

Nomenclature of the Arms. — For the sake of brevity, I shall call the rudimentary appendages by the names proposed for them in the adult larvæ, and shall adopt the names given by Müller, with slight modifications, viz. ventral side, that on which the mouth is situated; dorsal, the side on which the water-pore is placed; anal plastron, what Müller has called "anales Bauchfeld," or "hinteres Bauchfeld"; oral plastron, what he calls "antorales Feld," or "vorderes Bauchfeld"; the oral region (m) is situated between these two plastrons. The arms are designated according to their position by the following names: the median anal pair (e' e'); the dorsal anal pair (e'' e''); the ventral anal pair (e''' e'''); the dorsal oral pair (e'''' e''''); the ventral oral pair (e^5 e^5); the odd anterior arm (e^6), from which projects, at the base, a single arm of a different character from the others; the odd brachiolar arm (f''); and another pair of smaller brachiolar arms (f f), connected with the oral ventral pair (e^5 e^5) of arms (Pl. III. *Fig.* 11). The brachiolar arms are provided at their extremity with wart-like appendages (Pl. IV. *Figs.* 4, 5, 6; Pl. VII. *Fig.* 8); the other arms have nothing of the sort, but are surrounded by chords of vibratile cilia, making a complete circuit from the anal extremity round the dorsal side, while on the oral side it is not closed.

Development of the Arms. — In adult larvæ the arms have, at their extremity, clusters of orange pigment cells. These colored cells make their appearance early in the younger stages, and it is easy to trace the first appearance of the arms by the presence of these pigment cells. Before the appearance of the arms, the course of the chord of vibratile cilia is very sharply defined; it is like a narrow binding extending round the outline of the larva, seen either from above or from below (Pl. III. *Figs.* 3, 4, 6, and Pl. II. *Figs.* 26, 28). When seen in profile (Pl. III. v, v', *Figs.* 2, 5, 7, and Pl. II. *v*, *v′*, *Figs.* 25, 27), it follows the two edges of the deep groove which separates the dorsal from the ventral side. The median anal arms (e' e') are the first to make their appearance (Pl. III. *Figs.* 2, 3, 4, 6, 7); these arms take the greatest development in the adult larvæ; the other arms appear also at the same time, but as simple bulgings of the ciliary chord. The anal ventral pair (e''' e''') and the odd dorsal arm (e^6) are both developed about the same time (Pl. III. *Figs.* 8, 9, e^6); the odd anterior arm increasing in size, and changing its shape more rapidly at first than the median anal pair. The next set of arms formed is the dorsal pair (e'' e''); then follows the oral dorsal pair (e''' e'''), and next the ventral oral pair (e^5 e^5). These develop very rapidly, and soon attain as large a size as the dorsal oral pair, which had preceded them (Pl. III. *Fig.* 10). In this same figure we see the first trace of a small thick arm (f''), cut off square at the extremity, placed at the base of the odd anterior arm (e^6), and also a similar arm (f f) at the base of each of the ventral oral pair (e^5 e^5); the water-system branches into this small pair of arms which are not surrounded with vibratile cilia (Pl. III. *Figs.* 9, 10, 11). Of the brachiolar arms, the one which is odd precedes the two that form a pair.

The chord of vibratile cilia keeps pace with the growth of the arms, and extends to their very extremity; the most important change which takes place, from the time when the median arms first appear, is the extraordinary increase of one of the diameters of the water-tubes. The portions (*w*, *w′*) extending along the stomach become much flattened; when viewed from above (Pl. III. *Figs.* 8, 10, 11), their great increase in size is not seen, and it is only when examined in profile that the changes the water-system has undergone in the vertical diameter, compared to the transverse, can best be appreciated (Pl. III. *Figs.* 9, 12, *w*).

It is in this condition that Müller has seen the greatest number of his larvæ; struck by their symmetry, he has, throughout his memoirs, insisted upon the bilateral symmetry of the Echinoderm larva, as contrasting directly with the radiate structure of the adult animals. It appears to me that this interpretation of the form of the larvæ of Echinoderms is incorrect; they are radiate animals, and are no more bilateral than a large number of Radiates exhibiting, as will be shown hereafter, bilateral characters, such as Arachnactis, the Ctenophoræ, the Spatangoids, and the Holothurians.

The larvæ figured on this plate (Pl. III.) correspond to the larvæ observed by Van Beneden, and called by him Brachina; the latter resemble more our larvæ than any figured by Müller. I am strongly inclined to believe that Van Beneden's Brachina will eventually prove to be the larvæ of the Asteracanthion rubens *M. T.*, or of a closely allied species. The more advanced specimens of his Brachina began to show signs of the brachiolar appendages, though Van Beneden did not notice them. See *Fig.* 8 of the Plate accompanying his notice in the Bulletin de l'Académie des Sciences de Belgique for 1850. These larvæ are easily distinguished from ours by the shortness and thickness of the arms, as well as the less elongated shape of the larva. The time of breeding is also different; the European species spawning during the end of March and beginning of April. The A. berylinus spawns in the last part of July; by the 26th no eggs could be found in any of the females, and the other species (the A. pallidus) spawns during the third week in August. These facts are additional proofs of the specific difference between our species of Asteracanthion and the Asteracanthion rubens of Europe.

[I have retained in this memoir the specific names adopted in 1863. At that time no description had been published of Stimpson's A. vulgaris; his name has subsequently been adopted by writers on American Starfishes, although the figure given on Pl. VIII., had it been baptized and described as a new genus and species, and subsequently proved to be the young of A. vulgaris, would have obtained precedence; but failing to give it the mythical diagnosis, this memoir was not entitled to recognition by the strict rules of systematic zoölogy!

It is only comparatively recently that A. berylinus and A. arenicola of Stimpson have both proved to be probably identical with A. Forbesii of Desor, so that the name of pallidus would at any rate have to give way to that of Desor.]

When seen in profile (Pl. III. *Figs.* 9, 12, *w*, *ww'*; Pl. IV. *Fig.* 4, *w*, *ww'*), the water-system runs in an arch, from the alimentary canal to the opening of the mouth; here the diameter increases, forming a reservoir (*ww'*), from which are sent off small pouches (*f' f'*), leading into the brachiolar arms (*f f*); the whole of the oral opening is placed below the water-system. When seen from above or below (Pl. III. *Figs.* 6, 8, 10, 11; Pl. IV. *Figs.* 1, 2; Pl. VII. *Fig.* 8) the water-system is an elliptical ring tapering to a point in the odd brachiolar arm, enclosing the stomach and œsophagus, which form, as it were, a solid axis to this elliptical envelope. On one side of the stomach appears a large hole (Pl. V. *Fig.* 7, *h*, anal part only; Pl. VII. *Fig.* 8), the opening of a cul de sac of one branch of the water-system passing between the stomach and the intestine. The portions of the water-system extending along the stomach appear to be made up of distinct chambers (Pl. V. *Figs.* 6, 7, 8, *w*, *w'*): these chambers are merely the result of an optical delusion, arising from the greater or less flattening of certain parts of the tube; this gives it the appearance of having been divided off into segments.

The Adult Larva. — The anal part of the larva, in its adult condition (Pl. IV. *Figs.* 1, 2), has become pointed; the general shape is still somewhat rectangular; the ventral and dorsal side are separated by a deep groove (Pl. IV. *Fig.* 4), extending from the stomach, from the base of the median anal pair of arms, to the base of the ventral oral arms, thus separating the larva into very distinct dorsal and ventral regions (Pl. IV. *Fig.* 4), from the earliest stages of its growth. The body of the larva itself is capable of great motion; nothing is more common than to see the larvæ almost broken in two, by the strange habit they have of bending the oral extremity upon the opening of the mouth as a pivot, to such an extent as to make quite an angle with the anal part (Pl. III. *Fig.* 5). The larvæ generally assume this position when disturbed, and usually remain stationary in the same attitude, simply striking violently up and down with their extremities (compare *Fig.* 5 and *Fig.* 2, where the larva is at rest). The whole substance of the body is tinged with yellow, and is made up of large transparent cells with irregular nuclei, giving the mass about the consistency of a Salpa; very minute granular epithelial cells cover the whole surface. The powerful contraction of portions of the body is simply that of the cells themselves, and what has frequently been mistaken by Müller, when describing these larvæ, for muscular striæ, are strings of such contracted cells. The extremities of the arms are tipped with orange, the stomach and the alimentary canal are of a slight yellowish-brown color, the chords of vibratile cilia are somewhat darker. The œsophagus is perfectly transparent, capable of violent movements; it expands and contracts by sudden jerks, forcing open violently the passage leading into the stomach, when the contents of the œsophagus rush in, and are set slowly rotating in the stomach. The interior surface of the œsophagus is covered with vibratile cilia, so closely crowded that the walls appear striated from the regularity of these rows (Pl. IV. *Fig.* 1; Pl. VII. *Fig.* 8); they are particularly powerful round the opening of the mouth.

The rejection of the digested food takes place quietly, and there are none of those violent jerks attending its admission into the digestive cavity. The anal opening simply expands, and the fecal matter is forced out slowly, in a constant stream, until the whole of the contents of the alimentary canal, which had become very much distended before the operation, has been cleaned out.

Motion and Habits of the Larvæ. — The adult larvæ move about rapidly by means of the cilia; their natural position is more constant than when young. The oral extremity is kept in advance while in motion, and the larva still rotates about a longitudinal axis, though not frequently; it generally moves with either the dorsal or ventral side uppermost, and quite frequently in such a way as to show the lateral groove.* When at rest, the larvæ invariably assume one and the same position; the anal extremity is the lowest, and the oral extremity inclined to the vertical; in this attitude they often remain a long time, drifting about with the currents; their only movements being the expansion and contraction of the œsophagus and the play of the arms. The movements of the arms are exceedingly graceful; comparatively longer and more slender than the tentacles of the Tubularians, they have none of the stiffness of their movements, the constant curving and thrusting in every direction

* The position in which the larvæ figured in this memoir have been placed requires a short explanation. To be able to compare readily the different stages, it is necessary to have them all in the same position, and this should, if possible, be the natural attitude. But in the younger stages of the larva the body of the embryo is not loaded down at one extremity by the young Starfish, thus compelling the larva to assume always one and the same general attitude when in motion. It is more common, in the younger stages, to see the embryo moving with the anal extremity uppermost; it would be as unnatural to turn these younger stages upside down, as it would be to represent an adult larva in anything but its natural attitude (Pl. VII. *Fig.* 8) with the anal extremity downward. I have therefore compromised, by representing all the stages in the same position in which they are generally represented by Müller, to facilitate the comparison with his figures, and have given one figure of an adult Brachiolaria, in its natural attitude (Pl. VII. *Fig.* 8), with which the others can be readily compared in their theoretical position. The figures here given are drawn from the larvæ as they appear swimming through the water; and I have endeavored, as much as possible, in representing them, to give an accurate idea of the mobility of the arms; avoiding, in this way, the unnatural stiffness which characterizes drawings made under compression, like the majority of those of Müller.

reminding us rather of the motions of the tentacles of Phyllodoce and similar Annelids. They are never at rest, being always kept in motion to produce currents round the mouth of the larvæ; and, in addition to the action of the powerful vibratile cilia placed round the mouth, are continually bringing fresh water into the œsophagus.

The large triangular mouth (Pl. IV. *Figs.* 1, 2, 4, *m*; Pl. VII. *Fig.* 8) opens into a rectangular pouch (Pl. IV. *Fig.* 4, *m'*, *m''*), extending back from its posterior edge; from this pouch the œsophagus tapers rapidly, and attains, near the apex of the mouth, the size (*o*) which it retains till it joins the stomach. The surface of the œsophagus (*o*) presents a more or less corrugated appearance near its junction with the digestive cavity, owing to the somewhat greater thickness of the walls (Pl. IV. *Fig.* 1).

Brachiolar Arms. — The brachiolar arms (*f f*, *f''*) are appendages belonging only to adult larvæ. Our larva has three of them (Pl. IV. *Figs.* 1, 4, 5, 6), one pair (*f f*), and a somewhat larger odd arm (*f''*), placed at the base of the odd anterior arm (e^6); the branches of the water-system terminating in these arms proceed from a large pouch (*ww'*) in the oral extremity (Pl. IV. *Fig.* 4). The brachiolar arms are, like the others, tipped with orange, but have, in addition, wart-like terminal appendages, each having six to eight nipples, according to the age of the larva (Pl. IV. *Figs.* 4, 5, 6, 8; Pl. VII. *Fig.* 8). These knobs give to the short arms the appearance of the hind feet of Sphinx larvæ. In the hollow between the base of the brachiolar arms there is a small elliptical disk (*f'''*, Pl. IV. *Figs.* 4, 5, 6; Pl. VII. *Fig.* 8), reminding us of the madreporic body of a Starfish, and a row of similar disks, two or three on each side of the odd brachiolar arm, the pair of small brachiolar arms having no such appendages. It has been found convenient to retain for these peculiar arms the name of brachiolar, used by Müller to distinguish one of his genera (Brachiolaria) of Echinoderm larvæ. I have not succeeded in ascertaining the functions of the disks; the terminal buttons undoubtedly are used in the last stages of growth of the larva as supports, by means of which they can attach themselves, while the young Starfish is resorbing the larva; for during that process the larvæ never float about, but invariably sink to the bottom of the jar in which they are kept, and remain attached, apparently by means of the brachiolar arms, during the resorption of the larval appendages.

These larvæ are found floating in large numbers at night near the surface, among cast-off skins of barnacles, which furnish them with food during the time when they swim freely about, in company with multitudes of small Crustacea, Annelids, and Hydroids. They seem to be nocturnal, as I have only found here and there single specimens when fishing for them under exactly the same circumstances of tide and wind during the daytime.

CHAPTER SECOND.

HISTORY OF THE DEVELOPMENT OF THE STARFISH PROPER.

We have thus far described the changes the embryo undergoes from the time it leaves the egg, and have traced its gradual transformation into the complicated being called Brachiolaria. All the phases through which the embryo passes thus far have not the least resemblance to a Starfish, nor have we yet alluded to any of the changes which must take place to produce the Echinoderm proper. However wonderful the process by which an animal seems to pass from a radiate form to an apparently bilateral one be, the changes we shall now see taking place, by which this seeming bilateral animal is again reduced to a strictly radiate structure, are perhaps still more remarkable.

For the development of the Starfish itself, we must turn back and examine the larva in some of its younger stages, in order to trace the first changes in its anal extremity. There alone transformations take place affecting the development of the Echinoderm proper, until the whole of the complicated framework upon which the Starfish is fastened has disappeared, being resorbed by the very Echinoderm it has helped to raise. The Brachiolaria is completely drawn into the body of the young Starfish, before it leads an independent existence. This is contrary to the observations of Müller and of Koren and Danielssen respecting Bipinnaria asterigera; where it is said that the Starfish and the Bipinnaria separate, both becoming free. [Metschnikoff's and my own observations on this point seem to throw doubt on the separation of the Pluteus and of the Echinoderm, so that renewed observations are necessary regarding the Bipinnaria of Koren and Danielssen to establish the fact which thus far is contrary to all the observations of Müller, Metschnikoff, and myself on the Starfish Pluteus, and on the other orders of Echinoderms.] The process by which the young Starfish eventually resorbs the Brachiolaria (Pl. IV. *Figs.* 7, 8, 9) is similar to that observed by Sars in the development of Echinaster, where the whole larva and all its appendages are gradually drawn into the body, and appropriated during the growth of the young Starfish.

It has already been shown that the anal portions of the water-system, as they increase in size, spread little by little over the surface of the stomach; the edges creeping towards each other and surrounding the stomach on both sides, like a cap, yet without uniting. The funnel leading from the dorsal pore shortens as the water-system extends towards the dorsal region, and the anal extremities of the water-tubes come so near together (Pl. V. *Figs.* 1, 2, 3, 5, *w*, *w'*) that we might almost be tempted to believe they join, like the oral portions, and thus form a complete circuit (Pl. III. *Fig.* 10); this, however, is not the case, as an examination in profile of the above figures readily shows.

First Appearance of the Starfish. — In the drawings here given to illustrate the development of the Starfish, only a small portion of the Brachiolaria is figured, that which has direct reference to the Starfish itself; as this part is limited to the anal extremity of the larva immediately surrounding the stomach, the anal extremity alone of the Brachiolaria is drawn, with the arms cut off, somewhat beyond the opening of the anus. To make the references to the figures of Plate V. more satisfactory, a reference has also been made to a drawing of a whole Brachiolaria, in a stage of growth nearly identical, in order to show more readily the relation of the Starfish to the whole framework of the Brachiolaria. These stages are so similar that, with this explanation, it will always be possible to refer the anal extremities, upon which we are tracing the development of the Starfish in its different phases of growth, to some figure of Brachiolaria, very nearly representing its actual condition. The stages of development figured in Plate V. have been selected simply for the sake of the young Starfish, without reference to the Brachiolaria, and would, if drawn on the same scale as the other figures of the Brachiolaria here given, show no differences, which would make the mode of growth of the young Echinoderm more intelligible. For instance, the earlier stages of the development, such as *Figs.* 1 – 7, correspond to the stage of Pl. III. *Fig.* 10; while the more advanced *Fig.* 8 corresponds to that of Pl. III. *Fig.* 11, and the others to the adult stages of the Brachiolaria on Plate IV., when the Starfish undergoes extensive changes, while none take place in the general appearance of the Brachiolaria.

Up to the stage of the larva represented on Pl. III. *Figs.* 6, 7, the outline of the *left water-tube* (*left* when seen from above in its *natural attitude*), in a profile view, is that of a flattened cylinder (Pl. V. *Fig.* 1, *w′*), with the end slightly bent towards the anal opening. Near the point where the upper line of the water-tube bends downwards, a marked indentation is formed, having in the centre a slight projection. There appear, soon after starting from the anal edge of this depression, five very faintly defined folds, the first trace of the future ambulacral system, extending obliquely across the water-tube (*w′*) (Pl. V. *Fig.* 2, *t*; Pl. III. *Fig.* 8). If we examine the other side of the anal extremity, we find deposited opposite the angles of these folds (Pl. V. *Fig.* 2, *r′*), five rods of limestone; the anal part of the larva having at the same time lost its former transparency, and assumed a dull yellow color. These two parts are the first traces of the future Starfish. The limestone rods, and the whole of the granular surface covering the *right water-tube*, with the dorsal pore, forms eventually the abactinal area of the adult Starfish; while the folds, running obliquely across the *left water-tube*, are the first rudiments of the future rows of suckers extending along the lower side of the future rays; the rods are placed exactly opposite what will hereafter be the extremity of the rays.

It is apparent, from the above description, that the abactinal area (the rods), and the suckers (the folds across the water-tube), are not situated in one plane, or even in parallel planes. The arc containing the rods and the arc passing through the folds make an acute, nearly a right angle, as is better understood by referring to older stages. It will also be seen, by a glance at the drawings (Pl. V. *Figs.* 1, 2, 3, 5; Pl. III. *Figs.* 7 – 10, *t*), that the folds denoting the place where the suckers will make their appearance, and the rods (*r′*, *r″*) marking the position of the future rays, *are neither of them closed curves, but are always open*, forming a sort of twisted crescent-shaped arc. When describing the young Starfish immediately after it has resorbed the larva, and is ready to crawl about by means of its suckers, I shall show how these curves become closed; and also point out the changes these parts undergo to form diverging rays, as well as the manner in which the warped surfaces developing the actinal and abactinal regions are brought into parallel planes.

Relative Position of the Actinal and Abactinal Areas. — The folds of the water-tube (*w′*), which forms the actinal area, are not contained in one plane, but are placed upon a spiral; the same is the case with the five limestone rods situated on the surface of the other water-tube (w), which forms the abactinal region. When we look at the Brachiolaria from the side, that is, when facing the groove which separates the ventral from the dorsal side, as in Pl. IV. *Fig.* 4, or in the corresponding profiles, from the side of the right and left water-tubes of Pl. V. *Figs.* 1, 2, 3, 5, 10, 11, 12, we see either the actinal or abactinal side of the Starfish. We look in one case at the water-tube (w) upon which is developed the abactinal system; while in the other profile, drawn from the opposite side, we see the water-tube (w') which develops the actinal system; the two water-tubes are placed on different sides of the stomach, and have no connection whatever at this extremity, but are separated by the whole diameter of the stomach, over parts of which these tubes have spread like a cap. It will at once be noticed that, in any of these figures, each side of the future Starfish makes an independent open curve; these curves form what appears to us, when seen from the profile view, part of a circular arc. On looking, however, at the same sides from the ventral or dorsal view of the larvæ, as in Pl. IV. *Figs.* 1, 2, or the corresponding views of Pl. V. *Figs.* 4, 6, 7, 8, 9, 13, 14, we do not see the arc formed by these sides projected as a simple straight line, as it would be were it all contained in one plane. The extremities of the arc, both of the actinal and abactinal area, — that is, the two ends of it which are nearest, one to the water-pore, and the other to the anus, — are seen, as in Pl. V. *Figs.* 1, 2, 3, 5, 10, 11, 12, one on one side of an axis passing through the centre of symmetry of the Brachiolaria, and the other on the other side. The only curve which fulfils the conditions of such a projection is that of a warped spiral, so that, in reality, when passing (in Pl. V. *Fig.* 10) from r'''_1, along the edge of the disk, to r'''_2, r'''_3, r'''_4, r'''_5, we do not move in a plane, but are constantly winding, somewhat as when ascending a spiral staircase; this is seen in Pl. V. *Fig.* 9, when passing from r''_5, the arm placed nearest the anus, along the edge of the abactinal area, to r''_1, the arm next to the water-pore (b). It is the same for the actinal arc, which forms a spiral identical to that of the abactinal area, only bent in the opposite direction.

The actinal and abactinal regions are, in reality, two warped spiral surfaces, making an angle with one another, separated by the whole width of the stomach. This is best seen in a view from the dorsal or oral side (Pl. VII. *Fig.* 8), when the folds are distinctly visible one above the other, but so arranged as to be all seen at the same time (Pl. V. *Figs.* 4, 6, 7, 8; Pl. III. *Figs.* 8, 10, 11). Three of the folds are near the edge, while the other two are placed close to the digestive cavity on the ventral side. This spiral, seen from the dorsal or from the ventral side, has all the appearance of the foot of a bivalve (*t*, Pl. V. *Figs.* 4, 6, 8). The spiral position of the five rods indicating the position of the future rays of the Starfish ($r_1''' - r_5''$) is also apparent from the same point of view. Two of the rods are placed on the dorsal side of the larvæ, running somewhat obliquely (r_1''', r_2'''), the three others (r_3''', r_4''', r_5''') turning away still more from the median line; the last (r_5'') placed very near the edge, on the ventral side, close to the base of the median arms (Pl. V. *Figs.* 3, 5, 6, 8, 9, $r_1''' - r_5''$); the nearest distance between these two spiral surfaces being fully as great as the width of the water-tube: in fact, it seems as if the rudimentary tentacles and the dorsal system had as yet no connection whatever with one another (Pl. V. *Figs.* 6, 8).

It is very important that this oblique position of the actinal and abactinal areas, as well as their great distance apart, should be distinctly kept in mind; as it will explain many of the errors committed by previous writers on this subject, and greatly assist us in correctly understanding many points in the anatomy of Echinoderms hitherto unexplained.

From what has been shown thus far, it is self-evident that the water-tubes, the problematic bodies, as Müller has called them in their early condition, are the surfaces from which the future Starfishes are developed, and not the surface of the stomach. The spiral of tentacles is developed by folds placed on one side of the stomach (Pl. III. *Figs.* 6, 8, 10, 11), on one of the water-tubes (w'), that with the water-pore (b); while round the other water-tube (w), placed on the other side of the stomach, is formed the spiral surface of the abactinal system. The stomach has remained as it was before, and has in no way contributed to the formation of the young Starfish. A glance at any figure of the larvæ, either in profile or from above or from below, will show that no change has taken place in the shape of the stomach, or any part of the alimentary canal, as Müller believed (Pl. V. *Figs.* 1, 8; Pl. III. *Figs.* 1–11), but that a kind of cap has been formed round it by the water-tubes. Owing, however, to the accumulation of very fine granules of limestone, the anal extremity has by this time lost its transparency; this would be easily mistaken for an encroachment on the stomach itself. In proportion as the abactinal region becomes solidified (Pl. III. *Fig.* 11; Pl. IV. *Figs.* 1, 2; Pl. VII. *Fig.* 8), the stomach loses its globular shape, and becomes from this time forward flattened and pear-shaped. Previously to the formation of the Starfish on the surface of the two water-tubes, placed on opposite sides of the stomach, we could trace no change of form in the stomach itself. From the time, however, when the Starfish encroaches little by little upon the anal extremity of the larvæ, it pushes the stomach and the intestine slightly to one side, owing to the great increase in bulk of its actinal and abactinal areas. The anal portion of the water-tubes now swells and contracts in such a way as apparently to divide that portion of the water-tubes into chambers; but, on watching the circulation of the fluid in the water-tubes for any length of time, the currents can be followed flowing from one of these elliptic chambers to the other, plainly showing the different planes in which the ventral and dorsal part of the tubes are placed to be the only cause of this delusion.

Müller has distinctly stated, over and over again, during the course of his investigations, that the young Echinoderm was formed by encroaching upon the stomach itself; I am satisfied, from repeated observations of this point, in Starfish, Sea-urchin, and Ophiuran larvæ, that this is not the case. The mistake arises from the fact that the water-tubes, by their extension and increase, cover and conceal part of the stomach, forming a sort of hood over it; while the two sides of the young Echinoderm, separated by the whole width of the stomach and the thickness of the two water-tubes, form upon the outer surface of the latter, and do not in any way encroach upon the stomach, which is simply enclosed by the actinal and abactinal areas of the Echinoderm. Had I not traced this with the greatest care, I should scarcely venture to doubt the statements of Müller, but I am satisfied that he was mistaken in this explanation of the mode of the formation of the Echinoderm.*

Formation of the Ambulacral System. — We have already seen that the very first changes which take place in the water-system (*w, w′*) consist of the five folds (*t*, Pl. V. *Fig.* 2) extending obliquely across the exterior surface of one of the water-tubes (*w′*). From the fact that these folds

* It may not be out of place to say, that Professor Agassiz, during this investigation, satisfied himself of the accuracy of every point which seemed in the least contradictory to the statements of Müller.

develop across the surface of an elliptical tube, the five folds naturally form a twisted spiral, with a pentagonal outline, each side of this spiral forming the first nucleus of the five ambulacral tubes. I speak constantly of pentagonal spirals, pentagonal ambulacral system, and pentagonal abactinal system. In using these terms, I do not mean a pentagon with five equal sides, the adjacent sides making equal angles with one another and surrounding a closed surface, but simply that we have five sides limiting an open space, the two extremities of this five-sided figure being separated by the whole vertical diameter of the water-tubes. One extremity of the ambulacral five-sided open figure is placed at the water-pore (*b*, Pl. V. *Fig.* 2), the other at the opposite side of the water-tube on the surface of which the ambulacral system is developed. The two extremities of the abactinal open five-sided figure are placed, one above the water-pore (*b*, Pl. V. *Figs.* 8, 9, 13, r_1'''), the other on the opposite side of the water-tube, which develops the abactinal surface on one side of the anus (*a*, Pl. V. *Fig.* 14, r_5'''). A glance at the figures of the Brachiolaria from the dorsal or ventral side (Pl. IV. *Figs.* 1, 2; Pl. VII. *Fig.* 8; Pl. V. *Figs.* 8, 9, 13, 14) shows that the two surfaces, upon which the actinal and abactinal areas are developed, do not correspond to one another, or fit into each other as in the full-grown Starfish. That is, if the ambulacral system were projected upon the abactinal system, in order to bring these two surfaces into the same relation which they hold in the adult Asteracanthion, we should find the ambulacral system projecting beyond the outline of the abactinal system, and placed nearer the mouth of the Brachiolaria, while a portion of the abactinal system — that which is placed at the anal extremity of the larva — would, in the same way, project beyond the outline of the ambulacral system.

The sides of this twisted pentagonal spiral are somewhat concave, and the apex of the angles of adjacent sides are rounded. It is in consequence of the changes taking place at the apex of the sides of this irregular ambulacral pentagon that we have the simple apex transformed, by its gradual extension beyond the general outline of the open pentagon, into the five-folded loops (Pl. V. *Figs.* 10, 12), each of which corresponds to an ambulacral tube and its accompanying suckers in an adult Starfish.

The ambulacral pentagon with concave sides and rounded angles, seen in profile (Pl. V. *Figs.* 2, 5; Pl. III. *Figs.* 7, 9, *t*), changes its shape rapidly; the convex cavity becomes greater, the apex of each angle of the pentagon more prominent and less pointed, a double line is formed by the ruffling of their folds (Pl. III. *Fig.* 11), and each apex of the pentagon has the appearance of a small loop projecting beyond the curved sides; the loops grow larger and larger, until they have reached a size somewhat less than one third of the diameter of the water-tube, when they stand out freely from the pentagon, and seem to form no part of the water-tube (Pl. V. *Figs.* 10, 11, 12, *t*; Pl. IV. *Fig.* 4). When seen either from above or from below, the folds appear as small flaps on the broad side of the foot-like appendage projecting from the surface of the stomach, formed by the folding of the water-tube (Pl. V. *Figs.* 4, 6, 8, 9, 13, 14, *t*; Pl. III. *Figs.* 10, 11; Pl. IV. *Figs.* 1, 2; Pl. VII. *Fig.* 8). These small folds are, in reality, nothing but open bags communicating with the main water-tube (w'); small pouches leading from it. The outer and inner fold of each loop do not remain concentric, and we can soon trace, in the inner fold, changes similar to the first folding of the water-tube. The rounded end of the inner fold becomes triangular; this is the first indication of the formation of the separate suckers (Pl. V. *Figs.* 10, 11, 12, *t t t t t*). The ambulacral pentagon remains in this state until the Starfish has resorbed the many appendages of the larva.

Formation of the Abactinal System. — Let us now follow the corresponding changes of the abactinal system, accompanying the modifications, just described, of the ambulacral pentagon. On examining the anal extremity, at the time when the larva has reached the state represented on Pl. III. *Fig.* 10, we are at once struck with the fact that the outline of the abactinal system has undergone analogous changes to those of the actinal pentagon. Instead of remaining a uniform spiral, the two ends of which are separated by the whole height of the water-tube, while the two areas are divided by the combined width of the stomach and the two water-tubes, it has a slightly lobed pentagonal outline, the convexities corresponding to the apex of the pentagon of suckers (Pl. V. *Fig.* 5, $r_1'''-r'''$; Pl. III. *Fig.* 10). The rods, simple at first (r', Pl. V. *Fig.* 2), have increased in size; small Y-shaped appendages have developed at their extremities. We also see that in the intermediate spaces, corresponding to the concavities of the lobes of the actinal system, a second set of small rods (r'', Pl. V. *Fig.* 5), of a similar character to the large ones, have developed. The whole of the abactinal system has become coated with a very fine granular deposit of limestone; and the edge of the surface, connecting the two extremities of the abactinal pentagon, can readily be seen in profile (Pl. V. *Fig.* 5). The five large rods placed in the middle of the sides of the spiral abactinal pentagon, and the five small ones placed in the angles of this same pentagon, are the first trace of the plates composing the abactinal surface of the young Starfish.

The water-pore (*b*, Pl. III. *Fig.* 10; *b*, Pl. V. *Figs.* 7, 8) remains open, the only change being an accumulation of limestone matter round the opening, forming a sort of solid tube to protect it. This water-pore, as we shall see hereafter, eventually becomes the madreporic body; and the canal formed by the deposition of limestone is the stone canal of the full-grown Starfishes.

Abactinal System. — The double line on the edge of the abactinal pentagon (Pl. V. *Fig.* 2) is formed by the thickness of the surface of the abactinal system. This double line, at first only slightly undulating, becomes gradually more indented (Pl. V. *Figs.* 3, 5); at the same time, additional rods arise round the primary ones with such rapidity that we soon find a complicated network of limestone rods, forming ten clusters (Pl. V. *Figs.* 8, 9, 13, r', r''), five large (r') and five smaller ones (r'') round the original rods. This network is produced by the addition of a Y-shaped rod, at each extremity of a simple primary rod; presently, eight Y-rods arise upon the shanks of the first set of Y-rods, followed by a third set upon the shanks of the second set, and so on; in this manner are formed the closed polygons composing the clusters of the patches of limestone deposit (Pl. V. *Fig.* 9, r', r''). The small granular cells, filling the larger meshes of the network, increase in number, rendering the whole abactinal system somewhat opaque; when the larva is seen in profile from the abactinal side, the outline of the stomach (Pl. V. *Fig.* 5) can be traced exactly as it was before the Starfish had begun to form; and outside of it, the edge of the future back is distinctly visible (Pl. V. *Fig.* 5).

As the two water-tubes are placed on opposite sides of the larva, it follows that when seen in profile (Pl. V. *Figs.* 11, 12), from the left or from the right, it presents, in the one case, a full view of the tentacular pentagon (*t*), and only the lower oral edge of the abactinal system, the network of limestone meshes being quite indistinct, as seen through the thickness of the abactinal surface (Pl. III. *Fig.* 7; Pl. IV. *Fig.* 4; Pl. V.

Figs. 10, 12); while, in the other case, a full view of the abactinal pentagon (Pl. III. *Fig.* 10; Pl. IV. *Fig.* 4; Pl. V. *Figs.* 5, 11) is obtained, and the arrangement of the different rods forming the plates of the limestone network is distinctly seen. A view of the larva from the dorsal side (Pl. III. *Fig.* 11; Pl. VII. *Fig.* 8; Pl. V. *Figs.* 8, 9, 13) shows the abactinal system extending in such a way as to surround the stomach entirely on one side, while the tentacular pentagon covers it on the opposite side. This attitude gives us the position of the lobes ($r'''_1 - r'''_5$), the future rays of the Starfish, next to the water-pore (r'''_1, r'''_2), while a view from the oral side (Pl. V. *Figs.* 4, 14) indicates the trend of the lobes on the opposite extremity of the spiral of the abactinal system (r'''_4, r'''_5).

[Metschnikoff was able to trace most satisfactorily the development of an Ophiuran in which the formation of the abactinal system was shown to be identical in every respect with that here given of the Starfish. In the Ophiuran of which I had previously* traced the growth the formation of the plates of the disk could not be seen. These I only traced at that time in one of the viviparous species.]

Formation of the Rays of the future Starfish. — The plates of the abactinal system early reach a condition when the changes they undergo are merely quantitative, and the only modifications affecting the appearance of the Starfish take place on the edge of the disk. A depression is formed in the middle of the convexity of the lobes of the abactinal area; this is soon followed by two other depressions in the middle of the small arcs thus formed, dividing each lobe of the pentagon into four smaller lobes; at the same time the indentations between the original sides of the pentagon have grown much deeper, separating these five lobes in a very marked manner. We can now no longer mistake the true character of the lobes; they are the five rays of the Starfish, but as the actinal and abactinal regions are not yet fitted together, as in the adult (Pl. V. *Figs.* 10, 11, $r'''_1 - r'''_5$; Pl. IV. *Fig.* 4), they represent only the dorsal sides of the rays. A glance at *Fig.* 9 of the same Plate (Pl. V.), seen from the dorsal side, will show how far the suckers (*t*) are removed from the abactinal portion of the arm which is to protect them. The position of the water-pore (*b*) is immediately on the edge of the disk, at the extremity of the dorsal end of the pentagon (Pl. V. *Figs.* 10, 13, *b*).

* Mem. Am. Acad. 1864.

Formation of the Spines. — Such is the state of the abactinal system when the pentagon of tentacles is composed of simple loops; let us now examine this system in more advanced larvæ, at the time when the inner fold of the loops has become triangular at the extremity. When seen from the ventral side (Pl. VII. *Fig.* 8), we find that the small lobes have become wart-like projections, surrounding the whole edge of the abactinal system (Pl. V. *Fig.* 9). These projections are composed of accumulations of Y-shaped rods, connected with the system of network in the larger plates. The surface of the abactinal system has also become covered with these wart-like projections, rendering the outline irregular. In an abactinal profile, smaller tubercles are seen on each arm, identical, in everything except size, with those of the edge; the tubercles are young spines, arranged in regular lines (Pl. VI. *Figs.* 2, 4, 6); one row of four alternating on the edge of the abactinal system with one row of three, this again with one of two, followed by single tubercles, forming a pentagon, placed in the apex of adjoining rows, in the angle between two arms; the older tubercles are those nearest the edge.

When the young Starfish has reached this state, it has the rudiments of nearly all the external parts of the adult. I shall, therefore, apply to these rudimentary organs the names usually given to them. The spines are warts, not rising much above the general level of the abactinal region, and they are arranged in regular rows. The position of the network of limestone meshes has become well circumscribed, the plates formed by them occupying the position of the original rods. The five smaller plates in the angles of the arms are arranged round a central plate, the larger plates alternate with them and occupy nearly the whole of the surface of the arm; this arrangement is identical with that of the plates of the abactinal surface, as shown in Pl. VI. *Fig.* 10, l, l_1, l_2. The indentations of the rays are now so well marked (Pl. V. *Figs.* 12, 13) that there is quite a large open space between the outer spines on the edge of any two adjoining arms. On examining the plates formed by the network of limestone meshes, we see that the cells are polygonal; they are usually hexagonal, and are more or less quadrangular near the exterior of the plate. The original rod can be recognized by the larger cell it has developed (Pl. V. *Figs.* 9, 13, r'); and it is from this central cell that the others diverge, growing smaller and smaller as they approach the edge.

In the present stage of the young Starfish the anal extremity of the

Brachiolaria (Pl. VII. *Fig.* 8) has almost entirely disappeared, and the embryo Starfish has taken its place (Pl. V. *Figs.* 9 – 14). This embryo is so heavy that, when floating about, it loads down the anal part, which is always the lowest, and the larva is compelled to move always more or less obliquely, having to drag this great weight after it. The water-pore remains in the position in which it was at first, in the angle of the arm (r_1''), which opens the pentagon, and is encased in a stronger deposit of limestone.

Resorption of the Brachiolaria. — While the Starfish is growing upon the outer surfaces of the two opposite water-tubes, and is gradually becoming a part of the Brachiolaria, no changes take place in the external appearance of the larvæ (Pl. IV. *Figs.* 1, 2; Pl. VII. *Fig.* 8). But when the Starfish has become so far advanced as to occupy a very prominent position at the anal extremity of the larva (Pl. IV. *Fig.* 4; Pl. VII. *Fig.* 8), the complicated appendages designated as arms, which have served for the development and for the locomotion of the Starfish, are resorbed by the little Echinoderm.

We now come to a most interesting period in the history of our Starfish. The larvæ, very active up to this time, grow sluggish; the body, which, with the exception of the anal portion, is, in the early stages, perfectly transparent and clear, becomes cloudy and opaque. Changes are first visible in the side arms (Pl. IV. *Figs.* 7, 8, 9); they contract, and apparently divide into many large cells. Next in turn the anal ventral arms, and, lastly, the dorsal arms, contract in the same manner. This contraction of the arms is accompanied by a corresponding shrinking of the anal part of the larva, beyond the mouth (Pl. IV. *Fig.* 9), so rapid that in a few hours the anal arms have shrunk to quite a small compass (Pl. IV. *Fig.* 9); the oral dorsal arms and the oral ventral arms contract in their turn, until there remains nothing but the brachiolar arms, brought close to the Starfish by the shrinking of the mass of the body (Pl. IV. *Fig.* 8). They soon follow the rest, and we can actually see the gradual disappearance of this complicated fabric. It has served its purpose of developing and feeding the young Starfish, which has now reached a state when, in a few hours, it will move about independently, having resorbed, for what purpose is not known, the whole of the framework. *Not a single part is dropped off, the whole of the larva passes into the Starfish,* and, before twelve hours have elapsed from the commencement of the first sign of contraction of the anal tentacles, nothing is to be seen of the larval appendages, except a few indistinct swellings on the actinal side of the little Starfish (Pl. VI. *Fig.* 1).

The Starfish after the Resorption of the Bipinnaria. — The process of resorption, which I have frequently had the opportunity to examine and trace in all its stages, leaves no doubt, at least in this case, that the young Starfish does not separate from the Brachiolaria. We cannot, therefore, consider the Starfish and the framework (the Brachiolaria) as two individuals, leading a separate existence at different stages of growth, but must regard them both as one and the same thing. This is in direct contradiction to the statements of Müller, and of Koren and Danielssen, with regard to the Echinoderm, the development of which they have had occasion to watch. I must add that my own observations concerning the development of Echinoids and of Ophiurans have led me to an entirely different opinion from the one they have expressed; see my remarks on the Embryology of Echinoderms, in the Memoirs of the American Academy for 1864.

Closing of the Actinal and Abactinal Areas. — Although the young Starfish has now resorbed all the appendages of the Brachiolaria (Pl. VI. *Figs.* 1, 2, 3, 4, 6, 7), it is very different from the adult; the rays do not yet make a complete circuit, nor are they similar to each other; the pentagon of tentacles is still open, and the first step, preceding any other great change, is the closing of the actinal and abactinal areas, by which the two regions are brought into their proper relations. While the arms of the larva are shrinking away, the tentacular and abactinal pentagons are drawn closer together by the contraction of the water-tube. The extremities of the two open pentagons approach each other simultaneously by the flattening, in opposite directions, of the two pentagonal spirals, until the surfaces are brought into parallel planes, and the space, still separating the two ends of the pentagon (Pl. VI. *Fig.* 4) gradually diminishes, when they finally join; the Starfish is then in its normal condition, and the circuit is completed, though the embryo is by no means symmetrical.

[Metschnikoff has since also shown the same thing in his development of an Ophiuran. See l. c. Pl. IV.]

Development of the Ambulacral Tentacles of the Starfish. — While the closing of the spiral goes on, the pentagon of the tentacular side is undergoing great changes. We will follow these until the tentacles have acquired their normal shape, and then return to the changes of the abactinal surface. The points of the inner folds of the tentacular pentagon, as seen in Pl. V. *Figs.* 11, 12, *t t t*, become rounded, forming a rosette, dividing each loop into five lobes. The terminal lobe in its turn goes through the same process; two smaller lobes are developed on each side of it (Pl. VI. *Figs.* 3, 5), thus dividing the original simple loop into seven lobes, a terminal one (t'), and three pairs (t t t) arranged symmetrically on the sides. The first-formed lobes retain their greater size until the tentacles are well developed, which at first is always in proportion to their proximity to the base of the loop. The odd lobe, from which the last pair of tentacles was formed, does not participate in the rapid growth of the others, and is soon outstripped by all the lobes formed along the side of the original loop (Pl. VI. *Figs.* 3, 5). The point at which additional tentacles are formed is plainly seen in this early stage of growth; a pair is always added at the outer extremity of the arm, immediately at the base and on the side of the odd tentacle (the eye-bearing tentacle), which remains at the termination of the ray during the whole life of the Starfish. It is quite the reverse with the additional spines of the abactinal surface of the disk; they are always formed upon the disk, and are pushed out upon the arms by younger spines growing up nearer the centre of the disk. This will be plainly seen when describing more advanced conditions of the young Starfish. As the loops increase, they expand, lose their character of simple folds, and soon become quite extensive sacs (t t t, Pl. VI. *Fig.* 8), opening into the main tube (t''), from which they were formed, until, finally, they attain the shape represented upon Pl. VI. *Fig.* 9. They soon grow long enough to be quite movable; they contract at the base, the walls thicken towards their extremity, and they become club-shaped. The result of this contraction is a change of the tentacular cavity into a rudimentary radiating tube (t''), with the tentacles attached to it; it also draws together the first pair of tentacles, which are usually seen in such a way as to appear like knobs (Pl. VI. *Fig.* 5). This basal pair does not lengthen so rapidly as the second pair, which in a couple of days becomes the longest (Pl. VI. *Fig.* 9). Before the base of the radiating tube (t'') has contracted, the adjacent basal tentacles of adjoining loops are placed nearer together than those of the same basal pair, the basal tentacles thus forming five pairs of tentacles

(Pl. VI. *Fig.* 8, *t t*), separated by the radiating tube (t''). In proportion as the tentacles elongate, the separation between them and the radiating tube is more distinct, and very soon the tentacles appear like club-shaped branches projecting from it (Pl. VI. *Fig.* 9); the first pair of tentacles are somewhat shorter and stouter than the second, which is the longest, while the three terminal tentacles have nearly the same size, the odd tentacle (t') not showing as yet the slightest tendency to become club-shaped, though developed so much earlier than the larger basal pairs at its base.

Formation of the Sucker of the Tentacles of the Starfish. — When the tentacles have reached the state of Pl. VI. *Fig.* 9 they develop rapidly; the walls at the extremity of each tentacle thicken so much, that the cavity becomes a pointed tube set into a somewhat conical head, which grows more club-shaped, and projects beyond the walls of the tentacles as they increase in length, so that, when the basal pair of tentacles equals again in length the second pair (Pl. VI. *Fig.* 12), the clubs at the extremities are supported upon comparatively narrow bases. This club-shaped termination is the future disk of the tentacle, the sucker, by means of which the Starfish adheres so firmly to rocks. From an early period, even when there is only one large pair of tentacles at the base of the ray, and when the others exist only in the most rudimentary condition (Pl. VI. *Fig.* 5), these tentacles are used by the embryo in adhering to the surfaces upon which it is placed; and, though they are not provided with a regular sucking disk, they fasten themselves so firmly, by means of these loops, that it requires considerable force to make them loose their hold.

Formation of the Eye. — We have seen that, unlike the others, the odd terminal tentacle does not become club-shaped, but increases slowly in length alone, the walls retaining a uniform thickness. It is not till all the pairs of tentacles are well developed that we begin to perceive slight changes (Pl. VIII. *Fig.* 5). The opening leading into the radiating canal contracts, the basal portion of the tentacle swells, and it assumes a somewhat pear-shaped form, the swelling at the base increases, principally on the oral side, and we soon trace in it an accumulation of pigment cells (Pl. VII. *Fig.* 6, *e*), which, by the time the other tentacles have developed knobs, and equal in length the diameter of the arms, has become a brilliant carmine spot (Pl. VI. *Fig.* 12, *e*; Pl. VII. *Fig.* 6, *e*, and Pl. VIII. *Fig.* 5, *e*). This odd tentacle, placed at the extremity of the radiating tube, is the ocular tentacle. Ehrenberg discovered the presence of eyes in Starfishes, but their true relations to this odd terminal tentacle was first pointed out by Professor Agassiz, in his Homologies of Radiata.

[The nature of this terminal tentacle in the young Starfish and all young Echinoderms seems to have been entirely overlooked by all writers who have described the eye of the Starfishes, which they have usually represented as an organ totally unlike any other Echinodermal appendage.

The Embryology of Echinoderms certainly shows most distinctly that the eye of the Starfish is only a modified tentacle, an organ of sense, such as we find at the base of the marginal tentacles of Acalephs.]

Formation of the Mouth of the Starfish. — From the manner in which the tentacles are formed by folds of the water-tube, it is plain that, in the younger stages of the Echinoderm, the two ends of the circular tube must remain disconnected; the rapid accumulation of limestone particles on the lower surface prevents us, however, from ascertaining this point. Soon after the larva has disappeared, the whole actinal surface between the pentagon of tentacles is covered by a membrane; this membrane, in the centre of which is placed the mouth, is the remnant of that part of the larva situated in the groove between the anal and oral plastrons (*m*, Pl. VI. *Fig.* 12; Pl. VII. *Fig.* 1). The mouth of the Starfish, however, is not in reality the mouth of the larva. During the shrinking of the larva the long œsophagus has become shortened and contracted, bringing the opening of the mouth of the larva to the level of the opening of the œsophagus, which becomes eventually the true mouth of the Starfish.

Before the limestone particles have accumulated sufficiently to cover the base of the radiating tubes, the mouth is movable, shifting its position from one side to another indifferently (Pl. VI. *Figs.* 3, 7, 8, 12, *m*; Pl. VII. *Fig.* 1), though by the time the deposit of limestone has formed a small pentagon inside of the base of the radiating tubes, it has lost its mobility. The water-pore (Pl. VI. *Fig.* 12, *b*), or the madreporic body, connects with the circular tube through a long, narrow tube, and is placed on the actinal side in the angle between two rays; it is, as yet, only a simple opening, protected by a thick funnel-shaped limestone projection (Pl. VI. *Fig.* 12, *b*). The young Starfish has no other anus than that of the larva, which is placed on the very edge of the disk; but, with the rapidly increasing deposit of limestone cells, it is soon hidden from view, and I have not been fortunate enough to find it again in more advanced young. I am therefore unable to say where the anus opens outside, though it undoubtedly discharges, at this time, through one of the many limestone cells. Owing to the difficulty of tracing its opening in the dædalus of round cells, I am not able to state this positively, never having seen, from any point, discharges of fecal matters. Like the madreporic body, it is not yet upon the abactinal area, but on the actinal side, near the edge of the disk. The madreporic body itself would have been lost in a similar manner, had it not been possible to track it by means of its connection with the circular tube (Pl. VI. *Fig.* 12); and, even then, it was only by the closest attention, and at moments when the position of the young Starfish was especially favorable for the inspection, that the opening of the madreporic body could be distinguished from that of the surrounding limestone cells.

[With regard to the functions of the mouth of the Pluteus and its subsequent fate in the young Starfish and Ophiuran, my observations as well as those of Metschnikoff would show that it becomes the mouth in both. This does not seem to be the case in Auricularia, and the fate of the openings (both the anal and oral) of the Pluteus of Echinoderms is not yet definitely known for all the orders. Additional observations are needed on this point. Embryological studies on Mollusca would seem to favor the formation of a new mouth distinct from that of the early stages of the embryo, but the direct observations on Echinoderms all tend to prove that there is no new opening formed, and that the mouth of the Pluteus passes directly into that of the young Echinoderm.

Selenka shows for Holothuria also that the original opening of the Pluteus becomes the permanent anus.]

Formation of the Actinal Limestone Surface. — The actinal side of the disk is at first a narrow flat band (Pl. VI. *Fig.* 3), following the general outline of the rays. This band increases in breadth, loses its convex outline, and soon reaches the terminal tentacle, when the actinal band has assumed a pentagonal shape. Inside of this small pentagon is situated the ambulacral system, entirely independent, as yet, from the limestone deposit on the actinal surface, the whole rosette of tentacles expanding and contracting, with perfect liberty, in every direction. This freedom soon ceases; the points of the limestone pentagon develop rapidly towards the centre of the disk, and soon reach the base of the radiating canal (Pl. VI. *Fig.* 7). There they unite by bridging the intervening spaces, and form five triangular openings, enclosing the tentacles, which are still at liberty, with the exception of this band across the base of the radiating tubes (Pl. VI. *Fig.* 9). The additions made to this deposit of limestone take place more rapidly near the bridge, where additional limestone cells are sent out, enclosing at first the basal pair of tentacles, but leaving the remaining five still unconfined. The next pair is then imprisoned by a similar process, without, however, interfering with the terminal tentacles. Finally, the last pair of tentacles is surrounded in a like manner, and all the tentacles are now confined somewhat as we find them in the adult (Pl. VI. *Fig.* 12; Pl. VII. *Fig.* 1). A row of limestone cells, extending along the median line, separates the base of the suckers, while transverse bands join the larger cells of adjoining spaces. It is plain that the transverse bands correspond to the ambulacral plates of the adult, and that, in the earlier stages, the embryo Starfish has no trace whatever of any interambulacral system. This mode of formation of the ambulacral system may explain the absence of interambulacral plates in the Crinoids and Ophiurans. The deposit of limestone is not sufficiently transparent to allow a good view of the radiating canal, or of the formation of the vesicles of the tentacles.

Formation of the Spines of the young Starfish. — We have seen that, at the time of the closing of the young Starfish, the abactinal region is already covered with regular rows of spines (Pl. VI. *Fig.* 4). These spines are, however, simple warts, slight protuberances, in which limestone cells are formed, connecting with the general network. The cells of these spines are arranged in regular tiers one above the other; the younger cells, formed at the base, being always more numerous, and pushing up the older ones. All the cells send off Y-shaped appendages, which unite, forming stories (Pl. VII. *Figs.* 3, 4, 5) of circular cells; the cells of the spine near the edge do not close, but project beyond the margin, giving the spines the appearance of small Gothic spires.

The spines of the first row — viz. those immediately on the edge of the rays — increase rapidly, curving sideways, expanding at the tip, and assuming as fantastic shapes as those of Rhabdocidaris Orbygniana (Pl. VI. *Figs.* 10, 11, 12, p p). The other rows of spines, diminishing in size as they approach the centre, are exactly similar to the former (p_1,

p_2), but not so broad at the extremity, and somewhat more slender. New spines are always added between those originally at the extremity of the rays and the centre of the disk; the latter always remain the most advanced and most prominent of the spines, even when the young Starfish has assumed many more of the features of the adult than it has at present, and has reached a stage when it would not be mistaken for anything but a Starfish, closely allied to our common species.

Network of Limestone Cells. — As we have seen in the earliest stages of the Starfish, there are, on the abactinal area, rods from which, by the addition of Y-shaped processes, clusters of polygonal cells are gradually formed (Pl. VII. *Fig.* 7); one cluster in the middle of each ray (Pl. VI. *Fig.* 10, l_2), one around the smaller rod placed in the angle of the rays (l_1), and a still smaller one round the rod placed in the very centre of the abactinal area (l). The large clusters extend and unite along the edge of the rays, forming a continuous network; it is from the cells of the edge that the limestone deposit is formed, which extends over the abactinal surface. The clusters of cells placed in the angle of the rays do not unite laterally, though they become indirectly connected in the more advanced stages of our Starfish, joining with the plates of the rays by a few cells (Pl. VI. *Fig.* 10). The central plate remains unconnected with the others in the most advanced of the young which I have raised from the Brachiolaria. The whole of the network is quite movable, and the plates, before they become united, are capable of independent motion by the contraction of different portions of the abactinal area.

[Lovén has given excellent figures of the young of Asterias glacialis, corresponding to some of the stages here figured. They differ, however, in having the plates more distinctly separated even in the young stages (Pl. VI. *Fig.* 10). The reticulation is compact, so that it is only in certain stages of expansion that the original composition of the abactinal surface can still be traced.

It is from the careful comparison of these young stages (Pls. VI. VII. VIII.) with the corresponding stages of the young Ophiurans, given by Metschnikoff, Pl. IV. of his memoirs, and in my memoir on the Embryology of Echinoderms, *Figs.* 29, 32 (Mem. Am. Acad.), and of young Echini with the young of Comatula figured by Allman, Carpenter, and Thomson, that we can make out a satisfactory homology of the test of Echinoderms as has been so successfully done by Lovén in his superb

Memoir on Sea-Urchins,* where he has most thoroughly proved the homology of the basal and radial plates of Crinoids with their corresponding plates, still readily to be traced in the young Starfish, and with their homologies in the apical system of Echini.

An admirable paper by Selenka in the Zeits. f. Wiss. Zool. (June, 1876) gives us a complete history of the development of Holothuria, showing an entire agreement in its general features with the Embryology of other Echinoderms in the mode of formation of the water-system as diverticulum for the alimentary canal, forming eventually (as in the Starfish) the circular canal with the ambulacral system.]

Change of Outline of the young Starfish. — With advancing age, the outline of the young Starfish is greatly modified; at first, when the actinal and abactinal areas are not yet closed, while the larval appendages are still visible on the lower side of the young Starfish (Pl. VI. *Figs.* 1, 2), immediately after the larval appendages have disappeared, and the surfaces of the actinal and abactinal areas are brought nearer together (Pl. VI. *Figs.* 3, 4), it is hardly more than an irregular pentagon, with slightly convex sides, and small rounded notches cut in at the angles (Pl. VI. *Figs.* 3, 4). These notches become deeper, the arms of the Starfish assume more the appearance of a Greek cross (Pl. VI. *Figs.* 6, 7); the sides of the rays are strongly concave, and the concavity is increased with the development of the spines to such a degree that the extremity of the ray is almost twice as broad as its base (Pl. VI. *Figs.* 10, 11, 12). The outline of the inner wall of the disk can be easily seen through the limestone network. The pentagonal form, so different from that of the adult, is still less like it when seen in profile (Pl. VII. *Fig.* 2). The abactinal area rises like a high, rounded cone, supported upon the spines (p) of the edge of the disk; the tentacles project far beyond the edge on every side (Pl. VII. *Fig.* 2). In fact, the regular rows of spines, their great size, the convexity of the disk, are features so unlike our usual conception of a Starfish that, without closer examination, one would readily mistake this Echinoderm, at first sight, for a young Sea-urchin, like the flat, conical Echinocidaris.

The tentacles are longer than the rays, extending far beyond the edge in front and on the sides. The pairs of tentacles move in every direc-

* Kongl. Svenska Vets. Akad. Handl. XI. No. 7. Études sur les Echinoidées par S. Lovén. Stockholm, 1874.

tion; but the odd tentacle is always curved upward, and carried between the two middle spines of the extremity of the rays. When we see the Starfish in profile (Pl. VII. *Fig.* 2), the red eye-speck appears prominent near the edge of the disk, surmounted by the upturned tentacle (*t' t'*), of a slight rosy hue. This manner of carrying the terminal tentacle reminds us strongly of the way in which Æginopsis, as well as the young of so many of our Hydroid Medusæ, carry their marginal tentacles: Nemopsis, Staurophora, Turritopsis, Willia.

This is the most advanced stage of the young Starfishes (Pl. VI. *Fig.* 11) which I have succeeded in raising in confinement. When we compare this with an adult, having long, slender-pointed rays, four rows of suckers, its surface covered with pedicellariæ and water-tubes, surrounding individual spines, like so many wreaths, we cannot fail to be struck with the astonishing changes of form which must still take place to bring this pentagonal star to any shape resembling a slender five-rayed Starfish. In fact, when we remember how rarely embryologists continue the study of the egg beyond the moment of hatching of the embryo, it is not to be wondered at that this same young Starfish should be introduced to us again and again, in its different stages of growth, under half a dozen new names, both generic and specific. It is only by a thorough knowledge of all the changes of form through which these young embryos pass, from the first moment of their existence till they are full-grown, that we can hope to remedy this evil.

The next state of our young Starfish is, when magnified (Pl. VIII. *Fig.* 1), even more different from the adult than the pentagonal state of Pl. VI. *Fig.* 11. The young Starfishes figured on this Plate (Pl. VIII.) were all found attached to roots of Laminaria, thrown up on the beaches, in the neighborhood, after a storm; and from their different stages of growth, as compared with the oldest Starfish raised from a Brachiolaria (Pl. VI. *Fig.* 11), specimens of which were also found upon these roots, it is probable that the sizes here figured are one (*Fig.* 1), two (*Fig.* 8), and three (*Fig.* 10) years old. A considerable number of specimens were picked up in this way, and they could all be arranged into very distinct groups, representing the Starfishes of the present and of two previous seasons. There seemed to be no gradation from one group to another, such as we have among the young Sea-urchins, which, in consequence of their manner of breeding during the whole year, form series, the relations of which it is impossible to determine. In this connection I would say, that by arranging the Starfishes found upon our rocks into series according to their size, we are able to obtain a rough estimate of the number of years required by them to attain their full development; this I presume to be somewhere about fourteen years.* They begin to spawn before that time, as specimens have been successfully fecundated which evidently were not more than six or seven years old. It is during the fourth year that the rate of growth seems to be most rapid. A young Starfish, measuring one and a half inches across the arms, was kept, during five months, alive in Mr. Glen's tank at the Museum, and during that space of time it grew to three inches.

In the youngest specimens (Pl. VIII. *Fig.* 1) it is easy to see how the young Starfish has changed its outline from a pentagonal cross (Pl. VI. *Fig.* 11) to the one here represented. The original plates are sufficiently distinct to enable us to trace the process. The arm-plates at the extremity have been pushed away from the body by the addition of new spines formed at the base of the ray, and on each side of the interradial plates (l_1) (the ovarian plates?). The terminal plate (l_2) is perfectly well defined at the extremity of each ray, and, by cutting out the remainder of the arm, and bringing the extremity of the ray close upon the disk, we should have our former pentagonal Starfish almost identically the same; the only change being the greater stiffness of the suckers, the more rounded character of the spines, as well as their greater number upon the original radial plates. The spines have almost entirely lost their fan-shaped embryonic type, and are gradually assuming the aspect of the full-grown rounded spines of the adult Starfish. Here and there, however, a spine still occurs which has retained its fan-shaped outline.

Owing to the elongation of the ray, the single median line of spines stands out very prominently, and this, together with the rows of large spines extending from the interradial plates on each side of the rays, gives to the young Starfish the appearance of a small Oreaster. The median line of spines is supported by a long, narrow limestone plate, extending distinctly from the basal plate almost to the terminal radial, plates totally independent, also, of the prolongation of the ovarian plates

* For an account of the method adopted by Professor Agassiz for ascertaining the age of many of our marine animals, see Proceed. Essex Inst., 1863, p. 252.

(p_c), which make a broad binding on each side of the ray, uniting with the terminal plate so as to form a continuous limestone cord round the edge of the Starfish. The interradial plate projects from the angle of the rays towards the basal plate, spreading somewhat, to fill up the space between the median arm-plates. We find, in this stage (Pl. VIII. *Fig.* 1), the first dorsal water-tubes (d'); there are five pairs, one tube on each side of the ovarian plate (p_c). But, as yet, no pedicellariæ have appeared.

From the lower side, no trace of the plates of the interambulacral system can be seen, beyond the spines which have formed at the extremity of the ambulacra. The ambulacral pores are arranged in a single row on each side of the median line, and the slender last-formed tentacles are placed at the extremity of the ray, nearest to the odd ocular tentacle; while the tentacles nearest the mouth are quite short and stout, having a large sucking disk, and resembling, in all respects, those of the adults. The separation of the different ambulacral plates is very faint, and does not become well marked till a later stage. The odd ocular tentacle has retained its function; the eye-speck has increased greatly in size, as well as the bulb to which it is attached, while the walls of the tentacle are nearly as thin as in the younger stages (Pl. VIII. *Fig.* 5), exhibiting no trace of the formation of any sucking disk. Nearest to this are found the last-formed tentacles, easily recognized by their length, and the somewhat less developed sucker. These and subsequent stages of the young Starfish show undoubtedly that new tentacles are formed at the extremity of the rays, while new portions of the upper part of the arm are formed at the base; that is, the actinal system is developed at its periphery, while the abactinal system is developed at the centre.

In young Starfishes of two years (Pl. VIII. *Fig.* 8) the median plate is longer, more closely crowded with spines; the terminal plate being less prominent, though still distinct, while the processes from the median and lateral plates are quite large. No additional dorsal water-tubes have been formed since the last stage (Pl. VIII. *Fig.* 1). When examined from the oral side, the median line is becoming more strongly marked, and the lateral and ambulacral spines more prominent. These features give to the young Starfish a more pointed appearance, and the resemblance to the adult now becomes more apparent.

In somewhat older specimens (three years old) (Pl. VIII. *Fig.* 10), we finally trace the first appearance of pedicellariæ (Pl. VIII. *Figs.* 2, 3, 4,

p', p''), the dorsal tubes (Pl. VIII. *Fig.* 10, d'' d'') are found arranged in greater number along certain portions of the rays; while the median and lateral plates have increased so much in size that the terminal plate has lost entirely the preponderance which it had in younger stages, and the extremity of the arm actually assumes a rounded outline. The dorsal tubes (d''') are found numerous on both sides of the median arm-plate, and along the edge of the oral lateral plates (d'), diminishing somewhat in size as they approach the extremity of the ray; they are not open at the tip. The central basal abactinal plate is still distinct from the others.

The development of the pedicellariæ around the base of the spines gives us no clew as to the function which they perform in Starfishes (Pl. VIII. *Figs.* 2, 3, 4). At first a simple projection, they early assume the character of the head of pedicellariæ without stems, the rounded swelling becoming conical, after which the fork of the head begins to be distinguished. In Plate VIII. *Figs.* 2, 3, 4, we have the different stages of the spines (p), and the pedicellariæ (p', p''), found at their base. It was impossible in these young Starfishes to discover the place of the madreporic body.

[Professor E. Perrier has published a very elaborate and beautifully illustrated memoir on the Pedicellariæ of Echinoderms in the Annales des Sciences Naturelles. For the discussion of the nature of Pedicellariæ see an account in the Revision of the Echini, Part IV., by A. Agassiz, and an article in the American Naturalist, Vol. VII.]

From the oral side these Starfishes (Pl. VIII. *Fig.* 9) exhibit scarcely any difference from those of the stage last described, with the exception of the somewhat more crowded ambulacra. There is a row of median ambulacral spines (u'), quite small, defining the plates distinctly, as well as the presence of a very distinct row of spines (u), the ambulacral spines, along the edge of the ambulacral plates. In the most advanced of these Starfishes we must specially call attention to the absence of a well-defined interambulacral system. The young Starfish is still eminently ophiuroid in its most important embryonic features.

Professor Sars, in his Norge's Echinodermer, has described a new genus, which he has named Pedicellaster. I think there can be but little doubt, on comparing the figure he has given of his Starfish and the different stages of our Asteracanthion, that his Pedicellaster will turn out to be the young of one of the species of Asteracanthion of the northern coast of Europe. The single row of ambulacral pores, the ocular tentacle, the arrangement of the pedicellariæ, the size, all confirm the idea of its being only the young.

Successive Phases of Development of the Larvæ of Starfishes. — Before applying the information thus far obtained to the solution of more general problems, it may be well to consider what are the normal stages of growth, at different periods, in the history of our Starfish larvæ. During the earlier stages of its existence, the young developed from the egg (Pl. I. *Figs.* 22 – 28) laid by one of our Asteracanthion has no resemblance whatever to the future Starfish. This first condition we might call the pyriform, or Scyphistoma stage; when it is simply a symmetrical radiate animal, reminding us of earlier stages of Polyps and Acalephs. It then assumes the shape of a dumb-bell, becomes slightly one-sided (Pl. II. *Figs.* 2 – 19), and has, in its most advanced state, no other appendages but the simple crescent-shaped, slightly undulating, vibratile chord (Pl. II. *Figs.* 20 – 24). The simple, straight digestive cavity is now differentiated into three distinct regions. This second stage we might call the Tornaria stage, from its resemblance to the Echinoderm larvæ, called Tornaria by Müller, in which all the parts of the adult larva are simply hinted at in the most rudimentary form, and during which it is eminently cylindrical. [This Tornaria has been proved by Metschnikoff and myself to be a young Balanoglossus.] Another well-marked epoch is that during which the larva passes from the cylindrical, or, as we have called it, the Tornaria stage, into a quadrangular, somewhat compressed form; and the complicated system of locomotive appendages, so greatly developed in the Brachiolaria, is gradually laid out, thus preparing the larva for the last stages of its existence, characterized by the development of the young Echinoderm. This third stage, corresponding to that observed by Van Beneden, may appropriately be called the Brachina stage. During this period the former independent water-tubes (w, w') of the Tornaria stage (the problematic bodies of Müller) become united, and are gradually transformed into the Y-shaped, elliptical water-system (the Schlauch-System of Müller); this present stage (the Brachina stage) is therefore marked by the great modifications of the water-system (Pl. II. *Figs.* 25 – 28; Pl. III. *Figs.* 2 – 10). In the last stage, which we shall call, with Müller, the Brachiolaria stage (Pl. III. *Fig.* 11; Pl. VI. *Figs.* 1, 2, 4; Pl. VII.

Fig. 8), the rudimentary locomotive organs, laid out during the Brachina stage, attain their greatest development, as long, slender arms. The great changes which take place on the anal extremity of the water-tubes on both sides of the stomach, characterize the present stage (the Brachiolaria stage). These changes upon the surface of the two branches of the water-tube lead to the formation of the future Starfish. But the incipient Starfish is, as it were, a part of the Brachiolaria, or rather the Brachiolaria is undergoing local transformations which lead to the formation of a Starfish. They present thus, for a time, the appearance of a double existence, as if a new being were forming in one which had completed its growth. This third period, during which the twofold nature is preserved, is the one which constitutes the Brachiolaria stage. In the Brachiolaria stage there are several marked periods: the parts which appear at first on the surfaces of the water-tubes have no connection, and stand in such indefinite relation to each other, that they do not seem to tend towards a common result. But in proportion as the young Echinoderm progresses in its development, the relations of the two areas, formed on the surfaces of the two water-tubes, are more apparent; and we finally reach the last of the strictly larval stages, when the Brachiolaria, with its complicated system of locomotive appendages, becomes secondary to the young Echinoderm and is completely resorbed by it, when the embryo enters into its truly echinodermoidal condition (Pl. VI. *Fig.* 1), the different stages of which we have already described.

Examination of the Character of the Development. — The mode of development of Starfishes, thus divided into phases as observed in our Asteracanthion, cannot be called a case of alternate generation, nor is it a metamorphosis in the ordinary sense of the word. It is a mode of development peculiar to Echinoderms, entirely different from that of any other class of Radiates. It is not an alternate generation, for the Brachiolaria can in no way be called a nurse, as each Brachiolaria produces but one Starfish, and the whole of the larva is resorbed by the Starfish, not an appendage being left out. Nor is it strictly a metamorphosis, as the changes which take place are so gradual that at no time can the line of demarcation be drawn between two stages with any degree of precision, as in Crustacea or Insects, where the casting of an envelope marks distinctly different epochs. There is, however, something in these successive phases of development which reminds us of the metamorphoses of Insects. There is a sort of general similarity between this process of resorption and the growth and changes in the chrysalis of Lepidoptera, ending in a butterfly. In the latter case, the chrysalis, though retaining its character throughout the whole growth and development of the Insect, has an earlier stage when it seems to be purely chrysalis, and a later one immediately before the hatching of the perfect Insect, when the butterfly seems to be gaining the ascendency, and the whole outline of its form may be seen through the chrysalis, which now seems to be only its envelope. And yet the character of the development of the Starfish during its Brachiolaria stage recalls also vividly the phenomena of alternate generations. It is, nevertheless, strictly echinodermoid, and whether we observe it in the Ophiurans, the Sea-urchins, or the Holothurians and Crinoids, there seems no doubt, from the observations of Müller, Busch, Thomson, Krohn, and Agassiz, that it is carried on according to one and the same plan in all the orders of the class, where we have corresponding differences in their various modes of development. With reference to the separate existence of the larva and of the Echinoderm, urged by other observers, I can only say that nothing of the kind has occurred in those Echinoderms the changes of which I have traced, whether it be an Ophiuran, an Echinus, a true Starfish, or a Holothurian.

RECAPITULATION.

I shall, in a few words, recapitulate the development of these Starfishes, in order to be able more fully to compare my observations with those of previous writers, and to explain the differences, when they exist.

Changes of the Yolk. — The yolk, after fecundation, separates slightly from the outer envelope. The segmentation takes place rapidly; as soon as the yolk has divided into eight portions, they arrange themselves in such a manner as to enclose the remaining space, which is more and more separated as the spheres increase in number, until, finally, there is a complete envelope formed of spheres of segmentation.

Scyphistoma, or pyriform Stage. — At the time the young escapes from the egg, it is spherical, and the walls of the envelope are of the same thickness. One side becomes thicker, the embryo flattening at this extremity, which is bent in so as to form a slight cavity, in which fluids circulate. This cavity extends half-way the length of the larva, then swells at the extremity, the walls become thinner, the pouch formed at the end of this cavity develops laterally, forming two smaller pouches, which afterwards become hollow bodies, entirely separated from the main cavity, whence they originated (the problematic bodies of Müller).

Tornaria Stage. — The main cavity bends slightly towards one side, and eventually unites with a depression formed there. This depression becomes the mouth; the other opening, which was the first to be developed, and served the purpose of a mouth, is changed to an anus. This agrees with the observations of Krohn, who shows that in an Echinus larva the mouth is formed after the anus. The bent tube, or cavity, divides into three distinct regions, forming the œsophagus, the stomach, and the alimentary canal.

Brachina Stage. — The small disconnected hollow bodies (the water-tubes, the problematic bodies of Müller) are not alike; the left one (*left*, when seen from above) connects with the surrounding medium by means of an opening, the water-pore. This opening in the Starfish is the madreporic body. The water-tubes elongate so as to reach beyond the mouth, when they approach each other and unite, forming a Y-shaped tube.

Brachiolaria Stage. — Arms are developed from the sides of the larva, edged with rows of vibratile cilia. Some of these arms are of a different character, having peculiar appendages, the so-called brachiolar arms. It is on the outer surface of the water-tubes that the Starfish is developed (not from the stomach, as stated by Müller); one of the tubes, the left, when seen from above, developing the actinal or ambulacral side, the other developing the abactinal area. These two areas are open, pentagonal, warped, spiral surfaces, making almost a right angle with each other. The open pentagons do not close till after the Starfish has resorbed the whole of the larva.

Echinodermoidal Stage. — The complicated system of arms and the whole of the Brachiolaria are resorbed by the Starfish, which does not separate from the larval stock, as seems to be the case of Bipinnaria, from the statements of Müller and of Koren and Danielssen. The arms of the Starfish are broad and short in the young, and not symmetrical; the suckers are pointed, have no terminal disk, and are arranged in two rows, the sucking disk being developed later. The embryo, if compared to Acalephs, might then appropriately be said to be in its Ephyra stage. The odd terminal tentacle has an eye at its base, and no disk is ever formed at the extremity of this tentacle. The abactinal surface is very arched, the spines are arranged in regular rows, and the arrangement of the plates reminds us of the plates of Crinoids; the plates first formed retaining their embryonic or crinoidal character. The anus opens near the edge of the disk, on the lower side; the madreporic body is situated on the edge, but moves to the abactinal area, in more advanced stages. About a fortnight is required for the egg to pass through its different stages, or the embryo to be hatched, and the larva to have reached the condition when the young Starfish is ready to resorb the Brachiolaria; and another week must elapse before it reaches the stage represented in Pl. VI. *Fig.* 11. Those which I raised from eggs artificially fecundated retained this shape four months.

CHAPTER THIRD.

EMBRYOLOGICAL CLASSIFICATION OF STARFISHES.

The study of the young forms, or morphological embryology, if I may so call it, is destined to play an important part in Systematic Zoölogy; though investigations of this kind can only be carried on under peculiar advantages not easily obtained. The fact that many marine animals live, in their early stages, under stones, or firmly attached to roots of Laminarians, in deep water, and are only occasionally thrown upon the beaches after storms, when their small size prevents us from obtaining them in any great number, increases the difficulty of this kind of observations. We must, therefore, limit ourselves to those animals which pass the greater part of their lives near the surface of the water, or within the limits of tide-marks. A commencement has already been made in this direction, in the study of Fishes, the young of which live among the eel-grass, and in that of the young of the several species of Ctenophoræ, so abundant during the summer months along our coasts. For an account of these investigations, I would refer the reader to the Illustrated Catalogue of the Museum of Comparative Zoölogy.*

Comparison of Young and Adult Starfishes. — The difference in appearance between the young and the adult of our Starfishes is so great, that they would not be placed in the same family by one unacquainted with their transformations. The young has characters which, if taken singly, recall a variety of families; in fact, the combination of characters belonging to different families is almost always a sign that these features will disappear, or become modified with age.

Here I must again insist on the importance of the constant comparison of the younger stages of growth with the adult. We are but little accustomed to consider these younger stages in our description of animals,

* [See also my papers on Young Stages of Annelids, Ann. Lyc. Nat. Hist.; Young Echini, No. VII. Ill. Cat. Mus. Comp. Zoöl.; Embryology of Ctenophoræ, Mem. Am. Acad. 1874.]

and we necessarily lose many elements of the greatest importance, whenever we attempt to associate the adults of any class in natural groups, without taking into account the characters of their young. Naturalists, who have not yet entered upon this method of study, cannot conceive what extraordinary facilities this kind of investigation affords for tracing the more complete affinities among animals. One of the principal reasons why embryologists have overlooked these investigations may be found in the fact that they rarely examine more than one species of each type at a time. Who would place the young Echinus, with its Cidaris-like spines and straight simple ambulacra, among the true Echinidæ, or take a young Spatangoid for anything but an Echinus? What has the pear-shaped outline and long tentacles of a young Bolina — which is, indeed, a diminutive picture of a Pleurobrachia — in common with the adult, with its long, twisting rows of ambulacra, and wing-like projections of the spheromeres beyond the actinostome? Yet these embryonic characters remind us of familiar forms, and cannot fail to give us an insight into the relative standing of the forms through which they pass.

Let us commence with our embryo Starfish at the time when it is just forming, and when the first outlines of the abactinal region can be traced. Suppose its development were to stop there (Pl. V. *Fig.* 5), and that the slight lobes should close soon after the formation of the coating of limestone granules over the abactinal area, we should then have a condition strongly reminding us of a Culcita, with its arched back, its almost circular outline, and the total absence of any very prominent spines. In the next stage (Pl. V. *Fig.* 12), the cuts between the rays have become somewhat more marked, the plates of limestone cells are well developed, and there are tubercles in place of future spines. The resemblance of this stage to such forms as Anthenea, Pentagonaster, and the pentagonal Starfishes, in which we find a great development in the abactinal plates, is at once apparent. In a somewhat more advanced stage, the rays are slightly more marked, the spines quite well developed; this type is represented among living Starfishes by such forms as Pteraster, Paulia, Pentaceros, Artocreas, Oreaster: unless it were known beforehand that Pl. VIII. *Fig.* 1 represents a highly magnified young Starfish, the figure would readily pass for a new species of Oreaster. The corresponding changes of the actinal surface are not the less important. In the early stages the tentacles are pointed, they have no disk (Pl. VI. *Figs.* 3, 9);

it is only afterwards that they are developed (Pl. VII. *Fig.* 1; and Pl. VI. *Figs.* 10, 11, 12). In fact, the tentacles of our young Starfish, in its earlier stages, resemble those of Astropecten, Luidia, and Ctenodiscus. We are, therefore, at once provided with a set of characters taken from the young, enabling us to decide the comparative value of the various features, and the order in which they are to be taken. From the tentacles alone we are fully justified, upon embryological data, in placing Starfishes with pointed tentacles lower than those which have disks, like Asteracanthion. Another embryological feature is the fact that the embryo has only two rows of tentacles, while in the adult Asteracanthion we find the tentacles arranged in four rows. [The arrangement of the ambulacral tentacles into furrows seems due simply to the crowding together of adjoining plates in consequence of increasing age, and has not the systematic value formerly assigned to it.] Combining these characters, as we find them in the adults, we have at once good and conclusive reasons for placing all those Starfishes which have, like Ctenodiscus, a pentagonal outline, and at the same time pointed tentacles, lowest in the scale; next in order would come the Starfishes with pointed rays and pointed tentacles, without suckers, like Luidia and Astropecten; above them pentagonal Starfishes, with plates like Anthenea and Hippasteria, and two rows of tentacles, provided with suckers; then those with more prominent rays, and tentacles also ending in suckers, like Pentaceros and Artocreas; higher still, the Starfishes, with long slender arms, and only two rows of tentacles with suckers, such as Cribrella, Ophidiaster, and the like; while highest in the order we should place the genuine Asteracanthion, with four rows of tentacles, with suckers, and highly developed spines on the abactinal area.

The same principles applied to the different families would place Starfishes having plates without spines lower than those in which the network of limestone is covered with spines on the abactinal surface. This classification is not very different, as far as regards the order from that of the three families proposed by Müller and Troschel. It differs materially, however, from the standing given to pentagonal Starfishes in a short paper by Professor Agassiz, in the Proceedings of the Natural History Society of Boston. From this it is plain, that the mere study of the adult is not a sound foundation for a natural classification. The echinoid characters of the young Starfishes were not known at that time, which would naturally give the pentagonal Starfishes an entirely different position. Nor is it always sufficient to have traced the development of any one species; unless it happen to stand highest in its group, its different phases would not tell us anything of the relative standing of the other members of the group with which the adult is associated. Embryologists should, therefore, whenever it is possible, select those species for investigation which, upon anatomical evidence, stand highest in their group.

There are other embryonic features, recalling not simply families of the same suborder, but characters of other lower orders. The situation of the anus on the actinal side, the presence of the madreporic body on the same area, are features of the Crinoids and Ophiurans. These peculiarities are soon lost, and the madreporic body gradually finds its way to the abactinal area. The opening of the anus next to the mouth is eminently crinoidal, and it is accompanied by other structural details reminding us still more of that order. Were there a stem on the central plate of its abactinal area, the young Starfish, when seen from the abactinal side, would have all the appearance of a Crinoid. The central plate corresponds to the basal plate (Pl. VI. *Fig.* 10), the set of five plates in the angles of the arms to the interradial plates, and the arm-plates themselves to the radial plates of a Crinoid; and, to make the resemblance still stronger, the anus opens near the mouth, on the same side with it, as in Comatula. This analogy had already been pointed out by Professor Agassiz, in his Lectures on Embryology; and it shows conclusively that Starfishes are built upon the same plan with other Echinoderms, contrary to the views long entertained by Johannes Müller. This comparison to the plates of a Comatula can be carried out to its fullest extent, and is exceedingly instructive if made with the young Comatula, of which an admirable figure has been given by Professor Allman, in his valuable memoir on the prebrachial stage of Comatula, in the Memoirs of the Royal Society of Edinburgh for 1863. The arrangement strikes one, at once, as identical, though the plates are by no means homologous. The central plate occurs in both, but the most prominent plates, occupying indeed the greater part of the abactinal region of the young Starfish, are the same plates which eventually develop with others at the base of the arms, those at the angle of the arms being but little developed. It is quite the reverse with Comatula, in which the arm-plates are but small at this stage; though, according to

Professor Allman, who quotes Carpenter, these small radial plates eventually encroach upon the others, at the time of the appearance of the arms, the rest of the calyx being formed by the five large interradial plates. I cannot agree with Professor Allman in considering the central plate otherwise than as a solidified homologue of the basalia of the other Crinoids figured by him; the only difference being that in some cases the plates composing this piece are soldered together, as in Comatula, while in others they are kept distinct, as in Coccocrinus, and the like. From the peculiar way in which young tentacles are formed in Starfishes may not the strange toothed plates noticed by Professor Allman, at the base of the tentacula (or cirri, as he calls them), be young tentacles? Their position seems to me to make this very probable.

Position of the Madreporic Body. — There has lately been a great deal of discussion among writers on Echinoderms, as to whether the madreporic body was, or was not, a proper point to start from in determining the axes of the body; Agassiz, on one side, maintaining that the madreporic body was constantly in the same relation to the different parts of the Echinoderms, while Müller, Cotteau, and Desor have warmly opposed this view. The mode of formation of the madreporic body seems to me to decide this question in favor of the former view. The madreporic body is invariably formed on the left water-tube of the Brachiolaria, and is placed, during the development of the Starfish, at the angle of the upper arm. The future position of the madreporic body opposite the third arm of the open pentagon is therefore, after it has closed, the natural consequence of its position. The opening of the anus, on the contrary, has no such clear and precise relation to the middle arm. At any rate, however this may be, one thing is perfectly apparent, viz. that the madreporic body is always placed in the suture of the terminal arms of the pentagon, which brings it opposite the third arm. Thus the madreporic body gives us the means of dividing the Starfish into symmetrical halves, and of determining the position of the odd arm. The case of the Echinometradæ and Salenidæ is constantly quoted to show that the madreporic body is not connected with any definite axis. But might it not be that a stage which is embryonic in the young Starfish — viz. that preceding the closing of the actinal and abactinal areas — is probably retained in those Echinoid families in which the process of closing is not completed? And may not the unsymmetrical position of the madreporic body in such cases be owing to the continuance of this embryonic character? — the natural result of which would be, to throw the madreporic body slightly on one side of the middle line, so that, though still retaining its position opposite the third arm, an axis passing through them both would not divide the spherosome into symmetrical portions. If there were in nature such forms as asymmetrical Starfishes, analogous to the Echinometradæ, they would be represented by the embryonic Starfishes of Pl. VI. *Figs.* 1 – 6, in which a line drawn through the madreporic body and the middle of the odd arm would not divide the Starfish into symmetrical halves. Suppose the flattening of the young to be completed without the loss of this want of symmetry, and we have a form representing Echinometra-Starfishes, if any such exist in nature. The fact that in some of these Echinometradæ the axis, passing through the madreporic body and this long arm, crosses the median line from opposite sides, could be easily explained on the supposition that the former is placed on the ventral instead of the dorsal side of the larva, — an assumption which is not unfounded, as this occurs in Ophiurans and in young Starfishes. In this way the change of position in the direction of the axis which is found in Acrocladia and Podophora on one side, and in Echinometra on the other, could be easily explained. [For fuller discussion of the bearing of the positions of the madreporic body determining the anterior axis of the Echinoderms, see my Revision of the Echini, Part IV., and the description of Salenia. Consult also the Memoir of Lovén (Études sur les Echinoidées).] In Echinoids the actinal and abactinal areas are formed upon the exterior surfaces of the water-tubes, as in Starfish larvæ. This I have shown in the paper referred to above, published in the Memoirs of the American Academy for 1864. The earlier appearance of the tentacular pentagon in Echinoids and in Ophiurans is that of a spiral on the surface of the water-tubes, similar in plan to that observed in our Starfish larva; it is evident that the additional plates formed in a young Sea-urchin arise spirally, and from what is known of the mode of formation of the young Echinus and young Ophiuran, it follows, necessarily, that the ambulacral system in both must have been open pentagons, becoming connected only by the closing of the surfaces upon which the young Sea-urchin or Ophiuran were developed.

An examination of the figures of our young Starfish, just after the resorption of the larva (Pl. VI. *Figs.* 2, 3, 4), in which a line, drawn from the madreporic body through the middle of the odd arm, would by no means divide the Starfish symmetrically, confirms the above explanation of the eccentricity in Echinometra. Supposing the spiral to have been formed from the other side, the obliquity would be in the opposite direc tion. Of course this is simply a supposition on my part, which future examination alone can verify; but it seems to me such a natural explanation of the whole difficulty, that I give it here for what it is worth. The multiplication of madreporic bodies in many Starfishes need not invalidate the view I have taken of its value, as we need only ascertain which is the original one, the others being supplementary. I have found larvæ with two water-pores (madreporic bodies), but have never succeeded in raising them.

CHAPTER FOURTH.

EXAMINATION OF THE INVESTIGATIONS OF FORMER OBSERVERS.

Review of Müller's Observations. — It is with the greatest diffidence that I enter upon this part of my subject. It seems the height of presumption, for one who has scarcely any claim to recognition, to begin by criticising so many statements of one of the great masters of our science. Yet I hope to show, from Müller's own figures, that the observations I have made upon the development of our Starfish, though they do not agree with his earlier memoirs, yet coincide entirely with a few figures which he has given on the last plate of his great memoirs on the embryology of Starfishes; and that it is only because Müller neglected the earlier stages of development, that he failed to arrive at the conclusions to which I have been led by the above investigations. I trust that I have succeeded in describing the successive stages in this development with clearness enough to enable me now to draw a comparison, which the reader may easily follow, with the last drawings made by Müller, and to show that, had he had the good fortune to see so complete a series as that which I have traced, he would undoubtedly have entirely remodelled his former views, with the same frankness which has characterized all his memoirs. No preconceived theories, no observations, however careful, have ever been allowed by him to interfere in the least with his subsequent observations. Hence the great difficulty of following Müller in his intricate discoveries; each memoir modifying, correcting, and sometimes entirely contradicting, the previous ones, so that we must, as it were, begin his book at the end, in order rightly to understand his meaning. Any one who has tried to follow the development of a single animal, so that nothing should be wanting in the evidence of the successive stages, will easily understand how later observations continually modify and explain what had previously been considered as well understood.

Although Sars was the first who followed the development of an Echinoderm, which, at first sight, did not seem to differ very materially from what was known of the development of other Radiates, yet Müller was the first to trace the wonderful changes of the young Echinoderms; his memoirs have been the basis of all subsequent investigations, which are insignificant when compared to the immense amount of labor involved in his researches. Not alone the history of a single animal, but the history of a whole class, is gradually unfolded in his successive memoirs. The very fact that so little has been done in the embryology of Echinoderms since the days of Müller — for, in fact, with the exception of Krohn and Thomson, no one has followed these transformations — is a sufficient proof of the great difficulty attending investigations of this kind. It must also be remembered that these animals are so small that it requires the most practised eye to detect their presence; their habits also are such that we may spend days in watching for them, without obtaining a single specimen, and again be overwhelmed with such an amount of material as to be at a loss where to begin. This can but heighten our admiration of the untiring zeal and perseverance of Müller in following out the development of so large a number of species, in a field where everything was unknown, and where his powers as an observer must have been taxed to the utmost.

Bipinnaria and Brachiolaria. — A glance at the figures of Bipinnaria and of Brachiolaria of Pl. IX. of Müller's seventh Memoir will show how different they are, with few exceptions, from the figures of the same larvæ in his former memoirs; compare Pl. VII. of his third Memoir and Pl. II. of his second Memoir. From the figures and explanations given by the author, it is evident that he had observed, in the last larvæ of Starfishes found by him, the very characters which have enabled me to correct his observations. He has seen the two Y-shaped water-tubes extending the whole length of the Bipinnaria. He has seen, also, that the pentagon of the future back of the Starfish was open in its younger stages, though he did not succeed in tracing the position of the tentacular pentagon, nor does he perceive the connection of these two pentagons with the water-tubes. And, finally, if he had kept his Bipinnaria alive but a short time longer, he would have seen brachiolar appendages develop, and have satisfied himself that Brachiolaria is only an adult state of what he calls Bipinnaria. It must be remembered, however, that the original Bipinnaria of Sars, the Bipinnaria asterigera, has entirely different characters from the Bipinnaria of Müller. Judging from the development of our Starfish, it seems to me that Müller's Bipinnaria von Helsingör, second Memoir (Pl. I. *Figs.* 1–7), is probably nothing but a younger stage of his Brachiolaria von Helsingör (Pl. II. *Figs.* 4, 5; and Pl. III.). Van Beneden's Brachina, in its turn, is a still younger stage of the same thing, or of an allied species. A comparison of the above figures of Müller, and of the figures of Pl. III. of this Memoir, will leave no doubt on this subject. For the same reasons the Brachiolaria of Marseilles is probably only the adult of a Bipinnaria, closely resembling that of Marseilles (second Memoir, Pl. I. *Figs.* 8, 9), if it is not the same species. In the Brachiolaria figured on Plates II. and III. of the second Memoir of Müller, the young Starfishes are evidently on the point of resorbing the arms. The larvæ present all the appearance of contraction and distortion usually accompanying this process, and Müller's figures agree entirely with the various attitudes which they assume during this resorption.

If we now turn to his fourth Memoir, which contains the fullest descriptions, we shall see that although in many of the figures of Müller the Starfish, or at least one side of it, has been drawn correctly, yet his statements and some of the figures which he gives cannot be reconciled with one another. On Plate II. *Figs.* 5, 6, of his fourth Memoir, we have the evidence, from his own drawings, that his Bipinnaria had two water-tubes; yet, in the subsequent stages, Müller says positively that it has only one water-tube, the one with the water-pore, — a statement entirely contrary to the earlier stages of his Bipinnaria. From what I have shown of the mode of development of these water-tubes, of their increase in size in proportion to the age of the larva, it is quite improbable, notwithstanding the statement of Müller, that one of them should disappear; he also says that they are not to be confounded with what he calls "wimpernder Schlauch," while our observations of Asteracanthion go to show that these two systems are but one.

The discovery of the water-pore in Müller's Bipinnaria was a great step towards solving the question of the origin of the madreporic body, which he rightly conjectures to be nothing but the water-pore. He also notices the rosette of tentacles, or, more properly speaking, the five radiating tubes from which the tentacles eventually branch. He fails, however, to notice that this rosette, like the cap of the Starfish, as he calls the back, is open; and although he has occasionally represented it as such, he has not perceived the true relation between the positions of these two areas. He says distinctly that the cloak-like envelope, or the abactinal area, originates upon the surface of the stomach, whereas it lies, in reality, upon the surface of the second water-tube, which he says does not exist in his Bipinnaria; while the water-system, or the ambulacral system, originates on the water-tube in such a way that the two open warped pentagonal surfaces, the actinal and the abactinal areas, make a very large angle with one another; Müller, however, did not notice that they were open and warped surfaces.

Van Beneden's observations, in which he says that the two branches of the Y-shaped water-tubes are separate in the young, and become united in the adult, are fully confirmed by my observations. Müller has called these small bodies, while they are still separate, problematic bodies; he says they disappear in older larvæ, and have nothing to do with the "Schlauch-System." It is evident, from my observations, that the Schlauch-System is only the advanced condition of the problematic bodies, which are isolated on each side of the body in the young larvæ (see Pls. II., III. of this Memoir, and Van Beneden's Brachina), and become united in a Y-shaped water-system (Schlauch-System), when they reach the condition of Bipinnaria of Müller. It would seem, from his figures, as if the abactinal pentagon closed, while the Bipinnaria is still visible. I am rather inclined to think that more advanced larvæ will be found to be Brachiolaria-like, as is the case with our Starfish and the Brachiolaria from Messina; and that this apparent closing up is due to the fact that the larva is not in its normal state, or that the drawings are made somewhat foreshortened. In the second Memoir of Müller, on Plate I., we see that the Y-shaped water-system (Schlauch-System) has been noticed in two of the larvæ (*Figs.* 4, 7), while in the intermediate stages, and in younger larvæ, it has escaped his notice. It is undoubtedly to Müller's want of acquaintance with the earlier and later stages of his Bipinnaria that we must ascribe the discrepancies in his observations. Many of the more important points in the structure of the young larvæ naturally escaped Derbès and Krohn, who were not familiar with the adult larvæ; neither of these observers tells us anything of the presence of the water-tubes, or of the first appearance of the young Echinoderm.

Bipinnaria asterigera. — Müller's views concerning the different organs of

Bipinnaria asterigera of Koren and Danielssen are undoubtedly correct. What they took for a respiratory opening, leading into the cavity, is the mouth; they had correctly seen the anus, as well as its connection with the intestine of the Starfish. Judging from the figures of Müller, and of Koren and Danielssen, there are evidently striking differences in the termination of the intestinal canal, from that of our Starfish. In Bipinnaria asterigera the anal opening is on the abactinal side of the Starfish, while in our young Starfish it is still on the actinal side. The position of the young Starfish, with reference to the stomach of the larva, seems still to require further investigation, as it is not possible to say, from the figures of Müller, or from those of Koren and Danielssen, what is its true relation, and whether it has the same oblique position which it occupies in our young Starfish. The investigations of younger specimens than those examined by Müller, or Koren and Danielssen, will at once settle this point, as well as determine the mode of formation of the mouth of the young Starfish, and the question of its separation from the Bipinnaria. From the figure given by Müller, in his third Memoir (Pl. VII. *Figs.* 5, 6, 7), I am led to think that the position is also an oblique one; and that, though the Starfish may separate from the Bipinnaria, yet it is undoubtedly the opening of the œsophagus into the stomach, which becomes the future mouth of the Starfish, as in our Asteracanthion. In his third Memoir Müller shows conclusively that the madreporic body is not the scar left by the junction of the young Starfish with the Bipinnaria, but corresponds to an opening leading into a short tube between two of the arms; and also points out the probability of its correspondence with the opening leading into one of the water-tubes which he had noticed in Auricularia. This supposition is fully confirmed by the observations we have made of the coincidence of the water-pore and of the madreporic body. The slit in the Starfish, noticed by Müller and by Koren and Danielssen, was probably owing to the fact that in their young specimens the spiral was not yet closed and flattened, as is the case in older Starfishes.

From the drawings of Sars, and of Koren and Danielssen, it would seem as if a large tube extended into the long appendage opposite the arms. If this is truly so, it leaves no doubt that the long, tail-like appendage of the Bipinnaria is homologous to the brachiolar appendages of our larvæ, only developed to a much greater extent, and with all the arms placed nearer together, immediately round the mouth. A comparison, after careful examination of the position of the Starfish in the Bipinnaria asterigera with the mode of development as noticed in Echinaster (Cribrella) A. flaccida, and A. Mülleri, will give the means of settling the true affinities of the singular ventral appendage of these larvæ, and of deciding whether they are, as I have suggested, the homologues of the brachiolar appendages,—a result which seems probable from the observations made by Professor Agassiz, of a circulation in this peduncle, in a species of Asterias (A. flaccida, *Ag.*) closely allied to Asteracanthion Mülleri, the mode of development of which is identical with that observed by Sars in Echinaster.

Professor Thomson, who has had occasion to study the sedentary mode of development of several Echinoderms, has given us the most accurate description of the structure of this peduncle, in a species which he calls Asterias violaceus. A glance at his figures and descriptions will suffice to show us the complete identity between the brachiolar appendages and this peduncle, in which there is a circulation arising from a branch of the water-tube, and at the base of which, at the point of junction of the three arms, we find a peculiar disk, having the same structure as the elliptical disk, noticed at the base of the brachiolar arms in our Starfish larvæ. But we cannot agree with Professor Thomson, that this peduncle is the first sign of an ambulacral tentacle, the ambulacral tentacles being developed at a totally different part of the water-tube.*

Different Types of Larvæ.—Müller did not suspect that his Bipinnaria and Brachiolaria were the larvæ of different species of Asteracanthion. The observations of Sars, who had traced the embryology of Asteracanthion Mülleri, in which the eggs attain their full development without leaving the mouth of the parent, seemed to preclude the possibility of these nomadic larvæ belonging to the same genus. He even went so far as to say that his Bipinnariæ belonged to the same genus as the Starfish of the Bipinnaria asterigera. This is undoubtedly an error, for the Starfish of the Bipinnaria asterigera, as figured by Müller, and by Koren and Danielssen, has already the characters of a Pteraster; and it is evident that the Bipinnaria of Müller, being a young Brachiolaria, which I have shown to be the larva of an Asteracanthion, cannot belong to that genus.

The larvæ which I raised by artificial fecundation from Asteracanthion

* [See also a most interesting paper by Thomson in the Journal of the Linnæan Society, Vol. XIII. p. 57, 1876.]

berylinus and Asteracanthion pallidus — species which have their representatives in Europe, and which have, up to the present time, been included in the same genus with Asteracanthion Mülleri — are free-swimming larvæ, resembling the Bipinnaria of Müller. These facts can, therefore, leave but little doubt that Müller and Van Beneden have observed the larvæ of Asteracanthion rubens *M. T.*, and of allied species, the larvæ of which have been called by them Bipinnaria, Brachiolaria, and Brachina, and are only different stages of one and the same generic type. The difference of the two modes of development of A. Mülleri and A. pallidus is so great, that these two groups of species have been separated into two genera by Professor Agassiz. [Verrill has subsequently placed A. Mülleri in a separate genus (Leptasterias), to which have been added Asterias tenera and A, compta. The former is probably what I have seen called A. flaccida. See also Memoirs Am. Acad. *Fig.* 34, 1864, for an account of its mode of development. Compare also the development of Pteraster militaris, M. Sars, Norges Echinodermer, 1861. (Pl. VI. *Figs.* 3–13).] The Brachiolaria from Trieste and Messina present very striking differences from the northern Brachiolaria. These larvæ are probably the young of Asterias tenuispinus, so common in the Mediterranean. In his revision of the Starfishes, Professor Agassiz has also separated this species from the true Asteracanthion, under another generic name. We have next the Bipinnaria asterigera, still another type of larva, belonging in all probability to another family, differing from both the other larval forms. As Bipinnaria asterigera can only be the larva of a Pteraster, a Ctenodiscus, an Astropecten, or of an Hippasteria, either of which belong to families distinct from the Brachiolaria type of larvæ, we find differences in form, modified by structural features, characterizing the larval conditions, as well as the adult stages of families of the same order; while structural peculiarities in the larvæ characterize the different generic divisions more plainly than in the more advanced conditions. It is evident, from the observations of Professor Agassiz and of Sars, that the Asterias violaceus of Thomson, the embryology of which he has traced in the Microscopical Journal, must be placed in the same genus with A. Mülleri, and may, perhaps, be identical with it, unless the true A. violaceus *L.* has also a similar mode of development. [This would most certainly prove that A. violaceus, at least what the English call A. violaceus, cannot be the male of the European of A. rubens, as has been suggested by several European writers on Starfishes.] There is still another type of Echinoderm larvæ, which in all probability are the larvæ of Starfishes, viz. the Tornaria type. [For the history of Tornaria, which has been proved to be the embryo of Balanoglossus, see my paper in the Memoir of the American Academy, Jan. 1873, where the relations of Balanoglossus and Tornaria to Echinoderms and their mode of development are fully discussed.] In this type there is not the excessive development of the ciliary chord into long, slender arms, characteristic of the Brachiolaria; there are only slight, wavy indentations, corresponding to the position of the arms of the Brachiolaria, as we find them in the younger stages of the larvæ (Pl. III. *Fig.* 4; Pl. II. *Fig.* 26). In fact, this type of larva, in its adult condition, seems to be a permanent embryonic type of the younger stages of the Brachiolaria. I would infer from this that the Tornaria will probably prove to be the larva of Ctenodiscus, Astropecten, or Luidia, or of some Starfish with pointed ambulacral suckers. Having had the opportunity to examine several of the Tornaria type of larvæ at Naushon, in different stages of development, I hope to return to this subject at a future time.

[The only important embryology relating to Echinoderms in general published since the distribution of copies of this Memoir in 1864, is that of Metschnikoff.* He has confirmed the explanation I had given of the mode of development of the Echinoderm upon the surface of the water-tubes, the spiral nature of the young embryo, the mode of development of the water-tubes as diverticula of the original imaginated cavity, and the resorption of the pluteus by the young Echinoderm in Starfishes; he has also been able to follow very carefully the mode of development of the water-system of an Ophiuran, and showed its entire agreement with the changes I have traced in the development of the Starfish as far as relates to the formation of the abactinal system and the ambulacral system. Although Metschnikoff has added some new points to the development of Echinoids, still the mode of formation of the original plates composing the test of the young sea-urchin is not yet clearly shown, beyond the very earliest stages. As far as relates to the development of Auricularia, we can form a better idea than formerly of the nature of the change from the Auricularia to the young Synapta; and certainly in a general way this development is different from the normal growth of some of the other

* Studien über die Entwickelung der Echinodermen und Nemertinen, Mem. Acad. St. Petersb. XIV. No. 8. 1869.

Echinoderms (Starfish, Echini, or Ophiurans). The changes in the relative position of the organs remind us strongly of the mode in which the Tornaria gradually passes into a Balanoglossus by a mere difference in the topography of the organs of the Pluteus and of the enclosed Synapta The mode of development of Holothurians seems to be intermediate between the pelasgic pluteus, with its gigantic arms (Starfish, Ophiuran, Echinus) and the sedentary or viviparous development of certain Ophiurans, Starfishes, and Echini. See also the excellent paper by Selenka on Holothuria in Zeitscrif. Wiss. Zool., Vol. XXVII.]

FIFTH CHAPTER.

ON THE PLAN OF DEVELOPMENT OF ECHINODERMS.

We have constantly insisted, during the whole of this Memoir, upon the radiate plan of our Starfish larvæ in their different stages of growth. We have, however, seen that this radiate plan of structure, at certain periods of their existence, is so far hidden by the apparent bilateral arrangement of the locomotive appendages as readily to escape notice. We have also had occasion, in discussing the development of these apparently bilateral appendages, to show that Müller's views of the bilateral nature of these larvæ were founded upon mistaken analogies. It now remains for us to examine, somewhat in detail, the theory put forth by Huxley, in his review of Müller's observations, concerning the articulate nature of the Echinoderm larvæ. The facts already stated respecting the development of these larvæ show that they have only a very remote analogy to some of the larval forms, quoted by Huxley in order to strengthen his interpretation of the investigations of Müller. Misled, perhaps, by the names which Müller has given to some of these larvæ ("Wurmförmige Larven"), he has allowed this analogy to influence him so far that he revives the old opinion of Oken, and refers the Echinoderms to the type of Articulates. [See my Memoir on Balanoglossus, for a later review of the views of Huxley, Haeckel, and others, who have urged the affinities of Echinoderms with worms.] Huxley has given us no observations of his own, bearing upon the subject, but endeavors to justify his assertion by reducing all these forms to one hypothetical type, having an elongated form, a straight intestine, with the mouth at one extremity, the anus at the other, and girded by a circular ciliated fringe, just like the larvæ of some Annelids. The region in front of the ciliated fringe he calls *prætrochal*, and the region behind the fringe *postrochal;* and then, by an ingenious process, he shows how all these different forms might be produced by the greater or less development of one or other of these region. He then attempts to prove, further, that there is an intimate connection between the point where the young Echinoderm is developed, and the position of the rows of vibratile fringes; Starfishes being, according to him, developed in the postrochal and the Echini in the prætrochal region. Any one who has observed these larvæ alive cannot fail to see that whatever may be the position of these vibratile fringes, the young Echinoderm, whether it be an Echinus, a Starfish, or an Ophiuran [also a Holothurian Selenka], is developed in exactly the same spot on the sides of the stomach, upon the outer surface of opposite water-tubes, one of them forming the actinal, the other the abactinal surface of the future Echinoderm. The hypothetical form of Huxley is indeed one which has never been observed, as in all larvæ of Echinoderms the mouth and anus are always on the same side, viz. on the lower surface of the larva. It is only during the first few days, after hatching from the egg, that the so-called mouth is placed at one end; this, however, is not observed beyond the time when this opening performs the double function of mouth and anus, and leads into a very short digestive cavity. By the time the true mouth begins to be formed, the future anus, which has served the purpose of mouth thus far, has already changed its position to the lower side. The mouth is, in fact, never formed at one extremity, but always in the centre of the lower surface, and only some time after the anus, which performs the functions of a temporary mouth. This has been demonstrated by Krohn and myself, with reference to the Echinus larvæ, and I trust that the preceding pages have shown it to be also the case with our common Starfish. [See also Selenka for Holothuria.] The division into rings, of what Müller calls the Wurmförmige Asteridenlarve, is only an optical delusion, due to the lines formed upon the abactinal surface during the closing of the pentagon.

The radical difference in the mode of formation of the œsophagus, stomach, and intestine, in the Echinoderm larvæ, as compared with the larvæ of Annelids, a number of which, including those most resembling Echinoderm larvæ, I have examined myself, will, perhaps, be the strongest proof that they do not belong to one and the same type. The digestive cavity of Annelid larvæ is formed by the liquefaction of the interior of the larva, while in the Echinoderm larvæ the digestive cavity is formed by the bending in of the outer wall of the larva itself. The superficial resemblance of Annelid larvæ to those of Echinoderms is due to the appendages surrounding the mouth, while the principal appendages of the Echini and Starfish larvæ are developed from the vibratile chord developed round the anus. Nothing is more characteristic of the Echinoderms among Radiates than the isolation of the digestive cavity by means of distinct walls. This feature is so strongly marked that a larva can be recognized as an Echinoderm larva before its radiate characters are developed. It is only later that the circular tube, the water-system, is formed, while the ciliary appendages, which have nothing to do with the formation of the Echinoderm, make their appearance later still long after the first rudiments of the Echinoderm (the water-tubes) are present.

It seems to me that the different modes of development in Holothurians, Echini, true Starfishes, Ophiurans, and Crinoids, different as they are apparently, may easily be reduced to a single type. [See the Memoirs of Metschnikoff on the affinities of Echinoderms, in Siebold's Zeitschrift for 1874. Since this paper was written Haeckel has put forth his views of the relationship of the Sponges and Cœlenterates, and of the Echinoderms and Worms. As the whole subject is intimately connected with the history of Tornaria and Balanoglossus. I would refer to my Memoir* for an analysis of the modifications which these views are likely to bring about regarding the classification of Echinoderms and of Cœlenterates; also to my Memoir on the Embryology of Ctenophoræ, Mem. Am. Acad. 1874.] We have in Ophiurans two different modes of development, — one by means of the Pluteus, the other by means of the viviparous mode of development observed by Krohn and Schultze. We have two similar modes of development in the Starfishes, — the one as observed by Sars and Agassiz in Echinaster, the other in which the embryo assumes the shape of a Bipinnaria or Brachiolaria; and, finally, in the Holothurians we have these two modes represented by the Auricularia type and the type of the "Wurmförmige Holothurienlarve." [See also for Echini Thomson's paper in Journal Lin. Soc. and A. Agassiz, Viviparous Echini from Kerguelen, Proc. Am. Acad. 1876.] The difference between these two modes seems to be one of time; in one case, the eggs are retained by the parent until they have passed through many of their changes, and are freed in a stage corresponding to that of our young Echinoderm after it has resorbed its Pluteus, its Brachiolaria, or its Auricularia. In the other case the egg goes through all these changes after it has left the parent, developing this complicated system of arms, which seems to be

* A. Agassiz Balanoglossus and Tornaria in Memoirs American Academy, 1873.

simply a means of locomotion for the young Starfish till it shall have acquired a sufficient size to be able to take care of itself, and use its suckers as organs of locomotion.

Have we not here, in Echinoderms, something analogous to what we have in Discophorous Medusæ? In Cyanea and Pelagia, for instance, where, in one case, the young Acaleph passes through a Scyphistoma stage before it reaches the Ephyra condition, while in Pelagia, on the contrary, the Ephyra is at once produced from the egg, without passing through the Scyphistoma stage.

I think it can be easily shown that there is, in reality, no difference between these two modes of development; it is merely a question of quantity. In Cribrella, in Pluteus, in Brachiolaria, or in Auricularia, the young Echinoderm is developed on the outer surface of the water-system. The water-tubes obtain a great prominence in Auricularia, in Brachiolaria, and in the Pluteus-like form of the Ophiurans and Echini, while in types of development like those of Echinaster they remain more rudimentary; the only appendages developed in this last type being those which correspond to later periods of growth in the Starfish larvæ, viz. the brachiolar appendages. The peduncle and its appendages, by means of which the young Echinaster fastens to the rocks, are strictly homologous to the brachiolar appendages of our Starfish larvæ. In fact, when the young Starfish has resorbed all the arms, and there is nothing left of them, except a few swellings on the actinal side, to mark their former position, the brachiolar appendages are in exactly the same position as that occupied by the peduncle of the Echinaster larva. Had we known nothing of the previous modes of development, and found those young Starfishes in the open sea in this stage, nothing would have been more natural than to have assumed that they had reached this condition by the same mode of development. The cavity noticed in the peduncle of the Echinaster larvæ is part of the water-system, corresponding to the branch of the water-system leading into the brachiolar arms of our Asteracanthion larva.

The same is the case with the two modes of development of Ophiurans and of Holothurians; they are shorter ways of arriving at the same point, whether they pass through what we shall call hereafter the Pluteus type of development or the Echinaster type; in either of the orders it is one and the same thing differently carried out. The larvæ of our Cribrella, which I have had frequent occasion to examine, have satisfied me that the process of development is the same, with the exception that it is shorter. The larvæ of Ophiurans examined by Professor Agassiz at Charleston would lead to the same conclusion with reference to the Ophiurans; while, from the drawings of Müller, it is easy to satisfy one's self, with the above data, that the two types of development of Holothurians examined by him are only modifications of each other. As the only larvæ of Holothurians which I have seen belong to the "Wurmförmiger" type, I am unable to state this from actual observation. It is evident that we have also in Comatula these two types of development. Professor Agassiz frequently observed that in a species of Comatula found in Charleston, S. C., the young embryos remain attached to the parents; while Thomson and Busch have found the larvæ swimming freely about.

[An important paper on the development of Comatula by Goette, in the Archiv für Microscopische Anatomie for April, 1876, gives us the early stages of its embryo. Goette shows conclusively that the type of the crinoidal development is echinodermoid. We have, as in Echini, Starfishes, Ophiurans, and Holothurians, an original digestive cavity, from which arises the water-system, as diverticula. This observation is in direct contradiction to that of Metschnikoff, who distinguishes the Crinoids from the other Echinoderms by the absence of these processes. Goette's observations of the early stages are, however, in complete agreement with the usual mode of development among Echinoderms. Unfortunately the subsequent stages are all figured from embryos preserved in osmic or chromic acid, and while I have the greatest respect for Goette's technical skill, the very fact that in so many general points he differs, both from Metschnikoff and myself, throws considerable uncertainty on the whole of his memoir. He begins by stating that the larval mouth (the subsequent anus of the other Echinoderms) is entirely obliterated. As he has not followed this from living embryos, we must be pardoned if, knowing, as we do, the difficulty of tracing the gradual changes in living embryos of the most transparent kind, we doubt many of his conclusions obtained from the study of opaque embryos acted upon by reagents. Although Goette has derived his knowledge of the present paper from the excellent abstract in Leuckart's Jahresbericht, he has not only credited me with a very indifferent treatment of the embryology of

Echinoderms, but also with several errors contained neither in the abstract nor in the original. He does not appear to know my paper on the Embryology of Ctenophoræ, nor on Balanoglossus, published in the Memoirs of the American Academy in 1873 and 1874, and distributed at the time; consequently, in what he now writes, the older views regarding the affinities of Echinoderms with Cœlenterata and Annelids, which had been discussed from a different standpoint, do not receive the least recognition.

The mode of development of these two types having been shown to be on one and the same pattern, modified in such a way that a like result is reached either by fewer stages or by a greater or less rapidity in the process, it remains for me to show that the larvæ we have had before us, in the complicated form of a Brachiolaria or a Pluteus, is really built upon the radiate plan. We find a good starting-point in the water-tubes, which, as I have shown, become the circular tube of the young Starfish, from which the ambulacral system is afterwards developed. This water-tube, it is true, is not circular; it is not continuous, and yet it is the homologue of the circular tube of Acalephs, the radiating tubes being developed only afterwards, when the pentagon of tentacles is formed. The mouth is placed within this circular tube; and the fact that the mouth of the larva is brought, by the contraction of the œsophagus, close upon the stomach, does not change its position with reference to this circular tube. The water-system contracts with it, changes its position, and surrounds eventually the new opening, by the flattening and closing of the Starfish.

The Brachiolarian and Plutean stages are the Acalephian stages of the Echinoderms, corresponding to the Hydrarium forms of the Acalephs, in their Polyp stage; while the arms of the Pluteus stage, with their cords of locomotive cilia, recall strongly the strange filiform appendages of portions of the spheromere, covered with locomotive flappers as in Euramphæa, and other Ctenophoræ. The resemblance of the larvæ of Echinoderms to Ctenophoræ had already been pointed out by Baer, and more recently by Professor Agassiz, who was not then acquainted with the observations of Baer. This comparison seems to have found but little favor with more recent investigators. Leuckart, in his Bericht for 1862, simply says that no further proof has been adduced by Professor Agassiz to show that the homology holds good. A writer in the Natural History Review for 1861 seems to consider the whole comparison so puerile as not to be worth even a moment's consideration; and the off-hand way in which he dismisses the whole subject shows his total want of appreciation of the arguments by which this view is supported. If the writer of the said article had ever seen the young of Brachiolaria, of Pluteus, or, still better, the young of Tornaria, swimming about amongst crowds of young Ctenophoræ, such as Idyia, Pleurobrachia, Mertensia, or Bolina, he would not have passed such a sweeping judgment on this comparison. The motions of a Tornaria are so similar to those of young Ctenophoræ, that I venture to say that many a skilful naturalist would be deceived as to their true nature, on first seeing them moving about together in the water. The Tornaria has no appendages developed into long arms as in the adult Brachiolaria or Pluteus. The appendages remain always abortive, the larvæ in their adult condition resembling young Ctenophoræ. From an examination of drawings given by Müller, Professor Agassiz was induced to make the same comparison already hinted at by Baer, and we have seen that it is sustained in every particular. Gegenbaur has also noticed the resemblance between young Trachynemæ and Echinoderm larvæ.

From what has been said, it is evident that the plan of radiation underlies this apparent bilaterality of the Brachiolaria and of the Pluteus. The throwing of the whole of the stomach and the alimentary canal on one side, the complicated system of arms arranged with perfect symmetry on each side of the axis, passing through the mouth and the anus, does not change, though it partially conceals, the radiate plan. We have Holothurians which always creep upon three of their ambulacra, where a dorsal and a ventral side, an anterior and a posterior region, are subordinate to the plan of radiation; and the same takes place to a less extent in Spatangoids. Among Polyps even, which are, as it were, the simplest type of radiate animals, an anterior and a posterior region are strikingly shown in the case of Arachnactis. The additional spheromeres are all added at one extremity of the mouth-slit, and yet the Actinia is made up of radiating spheromeres. The earliest stages of the larvæ of Echinoderms, before the appearance of the water-tubes, reminds us forcibly of the young Actinia soon after it has escaped from the egg, or of the first stages of growth of a Scyphistoma, after it has attached itself to the ground, previous to the formation of tentacles. Let us now consider what constitutes the difference in the structure of these animals in their primary stages of growth, as far as the different classes of the type are concerned. They are all built according to one and the same plan, yet this plan is so carried out as to be eminently echinodermoid in one instance, acalephian in another, and polypoidal in a third. In young Echinoderms, as in young Ctenophoræ, we find nothing of the remarkable preponderance of certain parts which gives these young their bilateral appearance in more advanced conditions. Their radiate character is extremely prominent at first, but becomes gradually obscured and hidden under the guise of this bilaterality, which is, after all, due only to the excessive development of certain spheromeres as compared with the others.

The case of these larvæ is only an additional example of what we find so often in nature, that a plan of structure which seems to prevail is in reality only an external analogy produced by great predominance in certain parts, but subservient to the primary plan, even though the latter be perceived only on closer examination. This view solves a question which has hitherto perplexed all investigators of this subject, viz. how it was possible that a larva, which has always been considered as bilateral, should produce a radiate animal by a process of internal gemmation. It is, indeed, a bilateral larva, but built upon a radiate plan; a larva recalling a lower class of this branch of the animal kingdom, an acalephian larva giving rise to an Echinoderm, which, from its very beginning, is a radiate animal, having all its spheromeres developed at the same time, and equally.*

These transformations are, however, peculiar to the class of Echinoderms; they constitute neither a metamorphosis nor a case of alternate generation. The egg becomes the embryo larva, nothing essential is lost during the process, no intermediate individual comes into the cycle. It is the yolk which becomes the larva, the latter being, in its turn, transformed into the young Echinoderm. This larva is, in short, an Acalephian larva, reminding us somewhat of the twin individuals of free Hydroids, the Diphyes, though adapted to the mode of development of the Echinoderms. But in the latter we have no intermediate condition corresponding to the Polyp-like Hydroid in Acalephs from which the Medusæ or reproductive individuals arise, and in their turn, bring forth the Hydroid again, which completes the cycle by developing another set of Medusæ.

* For a closer comparison of young Ctenophoræ and Echinoderm Larvæ, see the Chapter on Ctenophoræ, Illustrated Catalogue of the Museum of Comparative Zoölogy, No. II.

If the views here taken of the plan of development of Echinoderms be correct, they introduce a new set of facts respecting their affinities with the Polyps and Acalephs, which cannot fail to have an important bearing on the question of the separation of the Echinoderms as a distinct type from the two latter groups. The Echinoderm plutean form, with its mouth. stomach, intestine, and with its water-system originally forming a part of the digestive cavity, bears, as it seems to me, the same relation to the Ctenophoræ which the Hydroid Polyps hold to the true Polyps. The Ctenophoræ may be considered, as it were, the prototype of the Echinoderms, as the Polyps are the prototype of Acalephs. We have in the Ctenophoræ a digestive cavity, from which branches the water-system, and that peculiar funnel opening outwards, through which the fecal matters of the Ctenophoræ are discharged, reminding us at once of the almost identical arrangement of an Echinoderm Pluteus, in the relations of the intestine to the stomach. The plutean forms certainly show that the plan upon which the Echinoderms are built does not differ from that upon which the Acalephs are built, and that we have between the Echinoderms and Acalephs the same connection, based upon identity of plan, as exists between the Acalephs and Polyps. We cannot, therefore, admit that the views so frequently urged and so universally admitted, in support of the separation of the Acalephs and Polyps as a distinct type (Cœlenterata), from the Echinoderms, have any real foundation in nature; and still less can we concur in them when we remember that the main argument in their favor rests upon the assumed total want of connection between the ambulacral system and the digestive system. This connection has been shown by Professor Agassiz to exist in the adult of many Echinoderms, while the facts above stated prove that it also exists in the early stages of the embryonic development, where, in fact, the water-system is formed from the digestive system. With this evidence falls the strongest argument for the validity of a classification by which the type of Radiates would be broken up, and the Polyps and Acalephs separated from the Echinoderms, as a distinct type, under the name of Cœlenterata. We are, therefore, justified in affirming that the type of Radiates constitutes an independent type of the animal kingdom, containing three equivalent classes, — Echinoderms, Acalephs, and Polyps.

PART II.

ON THE SOLID PARTS OF SOME NORTH AMERICAN STARFISHES.

HOMOLOGIES OF ECHINODERMS.

Comparatively little use has been made thus far, in the study of Starfishes, of the structure of their hard parts. With the exception of the short paper by Gaudry, the occasional references to them in sundry memoirs of Müller, Duvernoy, Agassiz, Perrier and others, only show that we know but little of the solid frame concealed under the mass of appendages covering a starfish. The study of these solid parts is instructive, as it throws new light on their homologies with other Echinoderms, and enables us to form a better idea of the relationship between Ophiurans, Echini, and Starfishes. The homology between these orders, as usually understood, can be stated in a general way as follows; the great development in Starfishes of what has been called the tergal system, covering the centre and arms, forming a system where no special regular arrangement could be traced, joined to the presence of distinct ambulacral and interambulacral plates, limited to the furrows occupying the lower face of the arm; also the absence of specialized genital plates, or anal plates, and the presence (in some genera) of a special ocular plate. The essential character in a general way of the Ophiurans as distinguished from Starfishes is the presence of genital plates, and the limitation of the tergal plates to a comparatively simple casing, consisting of few plates enclosing an ambulacral system, no interambulacral system having been traced; while in Echini the tergal system is reduced to a minimum, ocular and genital plates being present, and the ambulacral and especially the interambulacral plates greatly developed.

From the more careful examination of Echini a hypothetical Echinoderm was formerly established, which has served as the type to which the other Echinoderms were to be reduced, and with which they should homologize. In the absence of embryonic data, however, the fundamental facts derived from the study of young Echinoderms already point to a different interpretation of the Echinodermoidal homologies. Taken in connection with our knowledge of the hard parts of Starfishes as compared with those of Ophiurans and Echini, they throw much light upon many imperfectly known structural features of Crinoids. The living Crinoids, on account of their small number, have till recently seemed to promise but little help in explaining the fossil forms. The collections of the Challenger include, however, a variety of stalked Crinoids, and until the information to be derived from them is on hand it does not seem advisable to extend the comparison of the hard parts beyond the more common orders.

All young Echinoderms, while still in the Pluteus stage, or soon after its resorption, are strikingly alike. They all have an actinal and an abactinal area. The actinal area is occupied almost entirely by the ambulacral canals radiating from the central ring enclosing the actinostome, with their lateral ambulacral tubes existing as mere loops, the different tubes not being as yet encased in any limestone plates. The abactinal surface consists of the outer integument, in which rudimentary plates begin to appear, made up in the early stages merely of Y-shaped rods, more or less closely connected together, so as to form patches of reticulated network to become in the future the solid plates of the Echinoderm.

Thus far all Echinoderms are alike, and show no structural difference between the different orders. We shall greatly facilitate our examination of them by beginning our comparison at this early and uniform stage, so that we may see how far we can, by merely tracing the development, explain the mode of differentiation by which the orders gradually assume the structural features of the adults.

Before proceeding any further in this comparison, I must state that I have given already in detail* my reasons for considering the Echinoderms as more closely related to the Polyps and Acalephs in opposition to the view lately revived of their affinity to Worms. I have stated the objections mainly on embryological grounds, by comparing the development of the most Echinodermoid larva among Annulata, that of Balanoglossus, with other vermiform Echinoderm Plutei. Haeckel has recently strongly urged, on theoretical grounds chiefly, their annulate

* See A. Agassiz, Embryology of Ctenophoræ; Revision of the Echini; The History of Bananoglossus and Tornaria.

affinity, and has assumed the composite nature of Echinoderms, which he considers as a colony of five persons united at the buccal extremity in a somewhat similar way to that of a colony of compound Ascidians having a common cloacal opening.

He considers each arm of a Starfish, for instance, — and it will apply equally well to any Sea-urchin, — as made up of a series of distinct articulations, just as well marked as the articulation of any Annelid. To a certain extent this analogy is correct; we find a repetition of very similar parts, a remarkable vegetative capacity in all Echinoderms, which at first glance might seem to be of great importance as confirming their articulate affinities. Yet the earliest stages of the young Echinoderms in the Pluteus show beyond doubt that they have nothing in common with a community.

As well might we compare the simple chymiferous tube of an Acaleph with a single individual, and make a many-rayed Zygodactyla a community of individuals with a single central digestive cavity. The very fact that we can trace the passage between an Acaleph with a polymeral chymiferous system like Zygodactyla and a Siphonophore zoid in which we can trace but a single chymiferous tube, shows, at any rate, that the number of ambulacral tubes should not be taken as any proof whatever of a composite structure. When we come to the articulation of the arms, can we consider that as anything beyond the adaptation of the ambulacral system to the deposition of limestone plates, allowing certain limited movements? In the whole order of Echinoderms traces of this adaptation can be seen, as in some genera of Echini, which, like Astropyga and the Armored Echini, retain a more or less movable test, while in Holothurians the limestone deposition is reduced to a minimum, the latter showing the range of a dermal and closed ambulacral system, while the Ophiurans show the limits within which the articulation can be developed in the Starfishes proper (Crinoids not being in question at present). In consequence of this articulation and their presumed Annulose affinities, Haeckle does not hesitate to derive Echinoderms from worms, but as far as the orders of Echinoderms now known are concerned, it seems impossible to imagine, even with the light palæontology has thrown upon their appearance, how they have succeeded one another, much less whence they have been derived. We can readily see from the presence of several of the orders of Echinoderms in the older geological deposits, that, if any development from one order to another has taken place, it must have been during much earlier geological periods. As far as we now know, palæontology throws no light whatever upon such a transition, however possible it may seem from embryological data. Starfishes, Ophiurans, Echini, and Crinoids existed in the oldest-known Echinodermoid fauna, having all the typical features of Echinoderms of our day, or only so far modified as to be readily homologized with them. If there has been such a thing as a single ancestral Echinoderm, his primordial descendants early assumed different lines of development diverging to a great degree, and retaining their characteristics from the earliest-known geological period. This at least appears to be the case with Starfishes * and Ophiurans; while the different groups of Crinoids which have appeared and vanished are numerous as compared to those of the other orders.

The Echini again continued to develop until the secondary period with very little modification, and only after the Jurassic period did the marked changes begin through which they subsequently pass; changes fully equalling those of the Crinoids in their earlier geological history.† And yet, great as these changes have undoubtedly been, were we to measure them simply by palæontological evidence, we must remember that they are not greater in degree than the changes known to take place among the Echini of the present day during their embryological development. But while the successive appearance of the great types of Echini in geological time — in other words, their palæontological development — is in the strictest harmony with what we know of their embryological development,‡ we as certainly know nothing whatever of the causes which have brought about their sequence in time, in such striking agreement with

* The attempt made by G. O. Sars to prove Brisinga to be the living representative of the palæozoic Starfishes seems to be very far-fetched, and I must acknowledge I have been unable to see any such radical difference between Brisinga and ordinary Starfishes (Solaster, Crossaster, and Pycnopodia, for instance) as Sars insists upon in his Memoir on Brisinga. The type of Starfishes, as I have already shown, has been remarkably persistent from the earliest geological periods to the present day, and there is no indication that the Starfishes now living have undergone such changes as to make the agreement of Brisinga or other genera with the older forms a matter worthy of especial notice as survivals or representatives of the earlier types.

See also the view taken by Lütken in regard to the affinities of Protaster in his Ophiur. Add. III.; he does not agree with the view taken by Sars.

† See A. Agassiz's Revision of the Echini, Part IV.

‡ See Part IV., Revision of the Echini, by A. Agassiz.

the sequence in their phases of growth. All we can say at present is that the course of the embryological development of the Spatangoids is such that we can, as it were, read off upon it the sequence of echinoidal development since the Jurassic time in the developmental history of some genera of that group. In the one case, however, this development is accomplished in the course of a few years, in the other it stretches over a comparatively infinite period. We have no data for any such comparisons in the other orders of Echinoderms.

The case of successive modifications of the ancestral horse, which has so often been brought forward as conclusive regarding the genealogy of the group, although more familiar, is far less complete and much more limited in time than the succession to be traced from the palæontological evidence of Echini. But while natural selection gives a plausible explanation of like problems among Vertebrates, it fails utterly when applied to the majority of the Invertebrates, and we have completely failed thus far to find any causes for their palæontological development differing from those acting upon their successive embryological stages at the present day, of which we know absolutely nothing.

Let us return now to the comparison of the changes undergone by the embryo Echinoderm from its earliest post-Pluteus stages, until the structural features characteristic of the several orders are clearly differentiated. The actinal and abactinal surfaces of the embryo Echinoderms in the different orders are, as has been stated, identical; and it would be impossible to characterize them from early stages immediately following the resorption of the Pluteus, in the same way as from the adult. The abactinal surface consists, in all cases, of a central plate, round which are arranged radial and interradial plates, while the actinal surface is entirely occupied by the pentagonal rosette of the water-system, held by the abactinal system as it were in a cup, — a combination which is strictly crinoidal. It is only later that ordinal distinctions appear, but in such succession as to show that the homologies of the several orders as usually understood are not correct.

In the case of the young Starfish the radial plates of the abactinal system, which form the dorsal part of the arms, gradually extend towards the edge of and down on to the actinal side, enclosing the water-system little by little, and finally, as has been described, covering the ambulacral tube, leaving only openings for the passage of the tentacles. This is a stage which is passed through by Ophiurans and Echini as well as Starfishes, the only difference in the subsequent development being that the Ophiurans always remain in an embryonic condition, closely resembling the one just described. In the Starfishes the actinal plates formed by the bridges separating successive pairs of tentacles become resorbed along the central line, the edges forming inwardly by spurs the true ambulacral plates, and the plates which little by little develop so as to form the edge of the arms are likewise formed from the plates originally a part of the abactinal system. Those which are on the outside of the tentacles become the interambulacral plates, but differ in no way from the plates forming the sides of the arms. In the case of the Starfishes these side arm-plates are often very numerous; in the case of the Ophiurans they are reduced to a minimum, the upper arm-plate being, as in young Starfishes, very prominent and distinct, while the lower arm-plate is formed by the junction of opposing spurs of the interambulacral plates, as can readily be imagined from a comparison with Brisinga, where we find a spur from the interambulacral plates extending nearly one third across the arms. We must only remember that in Ophiurans the lower arm-plates represent the original plates derived from the abactinal side extending across the tentacles, while in Brisinga and Starfishes the median part of the plate has become resorbed, so that the tentacles passing between the ambulacral plates are inside of the interambulacral plates, while in Ophiurans they pierce the connected interambulacral plates (or the lower arm-plate).

Something analogous to what takes place in Ophiurans occurs in Echini. The plates which cover the water-system never become resorbed (as in Starfishes); there is no internal ambulacral system of plates developed, from the fact that new plates in the Echini are always developed near the basal plate (the apical system), while new plates in Ophiurans and Starfishes are invariably formed at the extremity of the arms. In Echini, therefore, the extremity of the water-system (the ocular tentacle) remaining connected with the original apical system, the water-system thus forms a loop, one end of which is attached to the so-called ocular plate, while the other connects with the circular canal at the mouth, and hence, both ends being fixed, the new plates must necessarily cover the water-system, while in Ophiurans and Starfishes, one end alone being fixed, it is possible, as in the case of Starfishes, for the water-system, owing to the resorption of the central part, to appear in a peculiar position. But in spite of this similarity in the position of the water-tube in Echini and Ophiurans, the latter are really more closely allied structurally to Starfishes than to Echini. This will readily account for the position of the water-system inside of the test in Ophiurans and Echini, contrasted to the Starfishes. We can also homologize Holothurians with Echini by supposing that in that group the limestone plates never form ambulacral and interambulacral plates, but that the abactinal system of the embryo, as it elongates, covers irregularly the water-system, the suckers of which pierce the plates as they do in the embryonic stages of other Echinoderms. In fact, the external limestone plates forming the test of a Sea-urchin, the reticulated network of the actinal and abactinal surface of a Starfish together with the ambulacral and interambulacral plates and the plates forming the disk of an Ophiuran, the upper, lower, and side arm-plates, as well as internal skeleton, are all directly derived from the simple system of limestone plates of the abactinal surface of the Echinoderm embryo. This system consists, in all cases, of a basal plate, five radial and five interradial plates. In Ophiurans the genital plates are formed from the angles of the five interradial plates; similar plates can still be traced in the young Starfishes, while in the full-grown Starfishes their presence is shown by the interbrachial partition, on each side of which the ovaries discharge. Thus there exists a complete homology between the genital plates of Ophiurans and the interbrachial partitions of Starfishes, a homology fully carried out in its details when we examine the relations held by the genital plates to the ovaries in Ophiurans and by the interbrachial partitions to the ovarian openings in Starfishes.

From the primitive number of plates existing in the disks of all embryo Echinoderms, it is evident that palæontologists have laid altogether too much stress upon the arrangement of the plates of the arms in Crinoids. The study of the solid parts of Starfishes, while valuable as accessories, would certainly furnish no very satisfactory data for a classification, at least if this were based entirely upon an examination of the hard parts of the abactinal system alone, as is so frequently the case in Crinoids.

HARD PARTS OF SOME NORTH AMERICAN STARFISHES.

ASTERIAS.

In the genus Asteracanthion (Asterias) the true character of the plates of the abactinal and actinal surfaces is far more difficult to trace than in other genera where the plates retain more or less homogeneous features. In Asteracanthion, although in the younger stages (as shown in Plate VIII.) the reticulation consists entirely of plates readily distinguished one from the other, yet in the adult the plates have become changed to a mere irregular network anastomosing in all possible directions (Pl. IX. *Fig.* 3), and thus rendering it quite difficult, if not frequently impossible, to trace the connection of the actinal and abactinal reticulation with the interambulacral plates.

In the majority of species of this genus the plates adjoining the interambulacral plates are cross-shaped (Pl. IX. *Fig.* 6), connecting with adjoining plates at three ends, in front, behind, and towards the abactinal surface; the other end connects with the interambulacral plates. These plates lose their regularity as they ascend towards the abactinal side on the edge of the arms, the prongs becoming gradually short processes, and finally simply rods or irregularly shaped plates all more or less imbricating (Pl. IX. *Fig.* 4). The spines are generally attached to the rods by a very shallow socket fitting into a rudimentary tubercle and ring. The spines of the interambulacral plates are movable, those of the actinal and abactinal less so, and frequently soldered to the reticulation.

Asteracanthion berylinus.

Asteracanthion **berylinus** * AG., A. AG. 1863. Proc. Amer. Acad. Boston.

Asterias **Forbesii** DES. 1848. Proc. Bost. Soc. Nat. Hist., III. p. 67.

Pl. IX.

The base of each of the interambulacral plates at its junction with the ambulacral plates is marked by a pore for the passage of a water-

* For the typography used to explain the synonymy, see A. Agassiz, Revision of the Echini, p. 26.

tube (Pl. IX. *Figs.* 5, 6) between this plate and the following reticulations, forming a part of the sides of the arms; similar pores are found arranged like the first row of pores in a line parallel to the longitudinal axis of the arms. The other water-pores are irregularly placed over the surface of the arms.

Near the mouth the interambulacral plates come together in the angle of the arms and form the mouth-papillæ so called. They are readily seen in a Starfish examined from the lower side (Pl. IX. *Fig.* 5) when denuded of spines. Seen from above (Pl. IX. *Fig.* 6, an interior view), the connecting plate between adjoining ambulacral systems is formed by the rising of the outer edge of the plate (the outer pore not being present) towards the limestone network formed by the junction of the interambulacral imbricating pieces which constitute the framework of the abactinal system.

This structure is best seen in large specimens of A. vulgaris, in which the alternate arrangement of the ambulacral plates commences at once at the base of the arms, and where the interbrachial fold at the angle of the arms is high and well set off from the pores left for the passage of water-tubes.

The spines placed on the junction of the interambulacral plates (a'', Pl. IX. *Fig.* 5) form the papillæ (Pl. IX. *Fig.* 6), near the actinal opening; they differ in no respect from the other spines.

The arrangement of the pores in double rows (Pl. IX. *Figs.* 5, 6) for the passage of the ambulacral suckers is, as is well known, only due to age, owing to the crowding of adjoining plates; in large specimens there is no trace of the original linear arrangement of the ambulacral pores beyond the plates nearest the actinostome or at the extremity of the arms. But while the ambulacral pores thus alternate, the plates themselves extend entirely across from the median line to the interambulacral plates; they are wedge-shaped, the broad and pointed ends of adjoining plates alternately extending to the median line of the arm or to the edge of the interambulacral plates (Pl. IX. *Figs.* 5, 6). See a note on the fecundation of A. berylinus and A. vulgaris in Archives de Zool. Expér., which suggests a plausible cause for the great number of varieties of the genus Asterias. A. Forbesii (berylinus) extends from Halifax, N. S., to Florida, while A. vulgaris (pallidus) has a more limited southern range, and extends farther north, from Labrador to Long Island Sound. In Massachusetts Bay the two species are about equally common.

Asterias ochracea.

Asterias ochracea Br. 1835. Prodrom.

Pl. XI.

The striking differences which apparently exist on a cursory examination of the species allied to A. ochracea are not found to be of sufficient importance, when analyzed, to warrant us in considering the genus Pisaster, as recognized by Professor Agassiz, anything more than a convenient systematic generic subdivision; the special points of difference are the great width of the ambulacral system, its elongated plates, the breadth of the furrow forming the median ambulacral ridge (seen from the interior) (Pl. IX. *Fig.* 5), the proximity of the openings for the passage of the ambulacral tubes on each side of the median ridge, with the corresponding slender interambulacral plates carrying only one row of long spines at the outer extremity. When denuded of spines the reticulation of the actinal surface of the arms adjoining the interambulacral plates forms a close pavement with small interstices (Pl. XI. *Fig.* 4); the tubercles carrying the spines are arranged in three or four rows at right angles to the longitudinal axis of the arm; they have a deep slit at the top of the boss; these tubercles are connected laterally by a comparatively low ridge. In the reticulation of the abactinal surface of the arms the primary spaces are quite large, but these are greatly subdivided by a secondary system (Pl. XI. *Figs.* 1, 2) (more or less prominent), consisting of smaller plates, most irregular in shape, which encroach upon the primary areas and subdivide them again, or materially reduce the area through which the water-tubes can be protruded. The reticulation of the actinal surface carries large club-shaped spines of moderate length, while the spines of the upper surface are shorter but similarly shaped, presenting the appearance of having been ground down so as to form nearly continuous walls on the separating ridge of the reticulations (Pl. XI. *Fig.* 1). The interambulacral papillæ are generally cylindrical, sometimes pointed or somewhat club-shaped at the tip, contrasting with the generally flattened and slightly spatulate interambulacral spines of Asteracanthion proper. The interbrachial partition (Pl. XI. *Fig.* 5) is naturally very well developed, owing to the great number of narrow interambulacral plates from which the brachial reticulations arise. The whole reticulation of the arms is far more solid than in any other group of species of Asteracanthion (Asterias); compare Pl. IX. *Fig.* 6, the corresponding interbrachial partition of A. berylinus, and also Pl. XI. *Fig.* 4, the prolongation of the plates separating adjoining ambulacral systems in A. ochracea and in A. berylinus (Pl. IX. *Fig.* 5). To show the difference in the thickness of the limestone reticulation of the abactinal and actinal systems compare Pl. XI. *Fig.* 3, and Pl. IX. *Fig.* 4, which are similar views of the interior of the abactinal systems of A. berylinus and A. ochracea, or compare the horizontal sections shown in Pl. XI. *Fig.* 5, and Pl. IX. *Fig.* 6. The range of Asterias ochracea is from Sitka to San Diego, California; it is the most common species of Starfish on the coast of California.

Echinaster sentus.

Asterias **sentus** SAY, 1825. Journ. Acad. Nat. Scien. Phila., V. 143.

Echinaster sentus VERR. 1867. Notes on Radiata.

Pl. X.

The meshes of the abactinal limestone network are larger than in Asteracanthion, especially near the centre of the disk, where the irregular polygonal spaces covered by the abactinal membrane are quite large (Pl. X. *Fig.* 3). The same loose structure extends a short distance along the abactinal surface (Pl. X. *Fig.* 4) and the sides of the arms; but towards the extremity the meshes become smaller, and on the actinal side, immediately adjoining the interambulacral plates, the limestone work is quite compact (Pl. X. *Figs.* 5, 6), and leaves only a few small openings for the passage of the water-tubes.

In addition to the water-tubes in the actinal surface of the arms, there is a row of very large tubes (Pl. X. *Fig.* 1′) passing between the interambulacral plates. The madreporic body differs considerably from that of Asteracanthion, and is not as well separated or as distinct from the general abactinal surface as is the case in that genus.

The interambulacral plates, forming the so-called teeth, are larger than the others; they form the extremity of the single lateral rows (Pl. X. *Fig.* 5), and do not make a partition or division-wall between adjoining ambulacra, as in Asteracanthion proper, the actinal part of the limestone network extending nearer the actinostome. The solid character of the actinal part of the limestone network covering the arms is well shown in an interior view (Pl. X. *Fig.* 6). This figure also shows how far the ambulacral and interambulacral plates become soldered together with the actinal limestone network. The small size of the first set of ambulacral plates is characteristic of the genus as well as of other Starfishes with two rows of suckers; the plates of the actinal are scarcely more prominent than the other ambulacral and interambulacral plates, forming a striking contrast to the immense development they take in Asteracanthion and allied genera. The interambulacral plates, as is well shown on Pl. X. *Fig.* 5, are remarkably uniform in size; the secondary ambulacral plates forming the brachial limestone network adjoining them are compactly soldered together. In this genus the spines of the limestone network are completely sheathed by the outer membrane covering the whole abactinal and actinal system (Pl. X. *Figs.* 1, 2); they are large, sharply pointed, generally placed only at the angles of the limestone polygons, and form irregular longitudinal rows, from the central part of the abactinal part of the disk, gradually diminishing in size towards the extremity of the arms. This species is particularly abundant in the West Indies and Florida, and extends northward to New Jersey.

CROSSASTER.

Crossaster M. T. 1840, Monatsb. d. Akad. Berlin, (emend.) A. AG.

The genus Crossaster, as originally established by Müller and Troschel in the Monatsbericht d. Akad. d. Wiss. of Berlin, was identical with Solaster of Forbes, which had the priority of a year. In the System d. Asteriden, Müller and Troschel adopted Forbes's genus. From an examination of the hard parts, it is evident that Solaster papposus and Solaster endeca should not be included in the same genus, having really nothing in common beyond the great number of arms. The accompanying descriptions will fully show my reasons for placing these two species in different genera. In order not to multiply names, I have retained the genus Crossaster, which is quite closely related to Pycnopodia, only limiting it to S. papposus, and have kept Solaster for S. endeca and its allies, which are more nearly related to Cribrella.

Crossaster papposus.

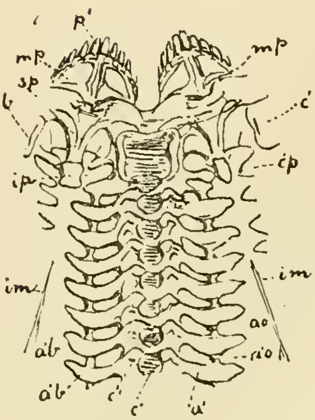
Crossaster *papposus* M. T. 1840. Monatsb. d. Akad. Berlin.

Pl. XII.

In Crossaster the membrane covering the abactinal system, like that of Pycnopodia, forms a mere film, but it is strengthened by a regular reticulation, with open meshes, carrying, at the points of junction of the horizontal limestone plates, prominent club-shaped processes, upon the tip of which are attached minute slender spines, forming more or less prominent tufts (Pl. XII. *Figs.* 3, 4). The interbrachial partition consists of a membrane, without limestone plates, extending towards the base of the arms, connecting the few limestone plates reaching from the actinal plate to the abactinal surface with the triangle formed by the rising of the actinal floor at the point of junction of adjoining arms (Pl. XII. *Fig.* 3). The actinal floor, with the exception of the plates of the interambulacral area, is entirely composed of a compact pavement formed of small irregularly shaped imbricating plates, gradually passing into the open reticulations of the abactinal surface, along the sides of the arms (Pl. XII. *Fig.* 2).

The ambulacral plates of this genus are broad and well separated; the ambulacral groove is broad and prominent (Pl. XII. *Fig.* 2); at the junction of the ambulacral and interambulacral plates the former are well separated; they are pointed, bulging in the central portion, leaving a wide opening for the passage of the sucker. The basal plates take an unusual development, forming a prominent ring round the actinostome; they are well separated by the interbrachial basal plates, forming the base of attachment to the limestone plates, which constitute the basal part of the interbrachial arch (Pl. XII. *Figs.* 2, 3). The actinal side of the interambulacral plates forms a series of slightly curved plates, at right angles to the ambulacral groove, carrying tubercles diminishing in size as they recede from the edge of the arms; these plates form a prominent row along the edge of the arms on the actinal surface (Pl. XII. *Fig.* 2); the tubercles of the interambulacral plates, arranged in narrow belts, carry slender spines, similar to those of the tufts of minute spines found on the abactinal surface. The basal interambulacral plates, like their corresponding ambulacral plates, are immensely developed, projecting far into the large actinal ring, and carrying, like all the interambulacral plates, long, slender spines; these form powerful papillæ,

Fig. 1.*



surrounding the mouth; though their use, as in all Starfishes, is evidently very limited, the principal work of digestion being done by the stomach itself, which folds over the substance to be introduced, and thus gradually dissolves it.

The accompanying woodcut (*Fig.* 1) shows somewhat more plainly than *Fig.* 3 on Pl. XII. the plates composing the parts round the actinostome and base of the arms.

This species is common to both sides of the Atlantic; it is found in Norway, Denmark, Great Britain, on the west coast of France, in Ireland, Greenland, and extends on the east coast of America as far south as Massachusetts Bay.

Pycnopodia helianthoides.

Pycnopodia *helianthoides* Stimps. 1861. Proc. Boston Soc. Nat. Hist., VIII.

Asterias **helianthoides** Br. 1835. Prodrom.

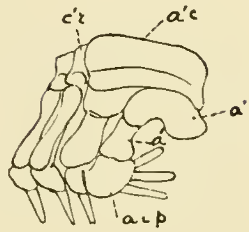
Pl. XIII.

In Pycnopodia the opening at the end of the large ambulacral plate near the actinostome is best seen in profile (*Fig.* 2); it differs in no way from the structure of the corresponding plates in Asteracanthion, though apparently, on first examination, the actinal plates forming the actinal ring seem quite peculiar, owing to the disappearance near the mouth of the interbrachial membrane, and the isolation of the interbrachial partition; this connects the actinal and abactinal reticulated surfaces by a mere film only. The large plate at the actinal ring, forming the base of the interbrachial partition (Pl. XIII. *Fig.* 6 *i p*), is entirely disconnected from the interambulacral system, as can easily be seen by an examination of the actinal extremity of the arm from the inside of

* Fig. 1. *Crossaster papposus.* — Internal view, seen from above, the abactinal surface of the plates at the base of one of the arms, round the actinostome, removed. *c′ c′*, attachment of muscular bands connecting adjoining ambulacral plates; *a o*, *a o*, openings for passage of ambulacral suckers; *a′b*, *a′b*, ambulacral plates with projecting spur; *i m*, termination of film forming the interbrachial partition; *c′p*, spur from interambulacral plates forming connecting floor of actinal surface; *c′b*, large muscular plate at base of the arm; *i p*, interbrachial plate to which the film forming interbrachial partition is attached (when it extends to that point) at the base of the arms; *s p*, spur of interambulacral basal plates forming the base of attachment of the interbrachial partitions; *m p*, interambulacral plates forming the so-called mouth-papillæ; *p′*, spines of *m p*.

the actinal ring, showing the plate rising up on the side of the two large ambulacral plates of the actinal ring. The interambulacral plates (Pl. XIII. *Fig.* 7) form small scale-like plates near the base of the arm, carrying slender pointed spines; they increase somewhat in size at a distance from the base. They are followed on the edge of the arm by two lozenge-shaped plates, with extended points, carrying large club-shaped spines forming a thin low wall for the support of the line of attachment of the abactinal membrane covering the abactinal surface of the arms. This membrane extends also over the central part of the disk; over the abactinal surface it is strengthened here and there by a few small limestone plates or rods, placed at the base of the large spines irregularly scattered on the surface of the abactinal region; these plates sometimes form in the disk a very irregular disconnected reticulation, the lines of which are composed of small irregularly shaped rounded plates. Within the space where the arms are united the ambulacral plates rise nearly vertically, but towards the extremity they gradually slope more and more, inclining towards the actinostome, so that the ambulacral plates form a hard flat area, occupying nearly the whole of the actinal surface of the arms.

Fig. 2.*

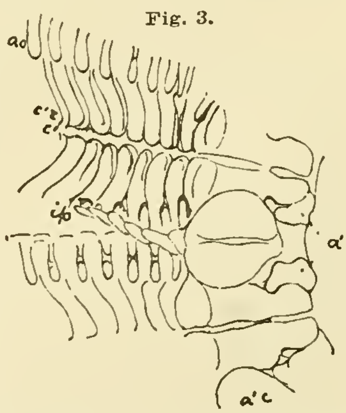


The genera Pycnopodia and Crossaster are specially interesting on account of the close relationship they have to Brisinga. In fact, compared with Brisinga, they prove conclusively that the latter genus,

* *Fig.* 2. — Profile view of actinal extremity of arm of Pycnopodia (the dermal covering of arm removed). *c'r*, small plates forming the ridge, covering the ambulacral groove, repeated along the whole length of the arm. *a'c*, the corresponding plate of the second interambulacral plate. The upper projecting part of this plate is the support of the basal plate of the interbrachial partition, and below it is seen the plate which strictly corresponds to it. This plate *a'c* also covers in part the plate *a's* of the basal ambulacral plate *a'*, at the base of which is situated the interambulacral plate *a i p* carrying the short spines forming the mouth-papillæ.

The relative position of the plates *a's* to the basal plate of the interbrachial partition is well shown in *Fig.* 3, which represents an inside view, seen from above, of a part of the actinal ring. *a's*, *a'c*, the same as in *Fig.* 2, *i p*, the interbrachial partition, reduced in this genus to a few scale-like plates, supported on spurs of the interambulacral plates. *c'*, longitudinal groove, line of junction of ambulacral plates. *c'r*, ridge of connecting plates forming groove *c'*. *a o*, opening for passage of ambulacral suckers.

Fig. 3.



far from being so exceptional in its structure as has been generally supposed, is structurally very intimately connected with Pycnopodia and Crossaster. We might readily transform a Pycnopodia or a Crossaster into a Brisinga by reducing the actinal and abactinal interbrachial spaces into a minimum, which would give us a Starfish with a small disk, in which the ambulacral plates adjoining the actinostome assume a great development, and thus the numerous arms would appear quite disconnected (as in Brisinga). The connection of the arms in Starfishes does not depend so much on the greater or less development of the ambulacral and interambulacral systems, as upon the greater or less increase of the limestone network forming the interbrachial spaces, which, although a feature greatly affecting the physiognomy of the Starfish, yet influences but slightly its internal structure.

The range of this species is from Sitka to Mendocino City, California. In the Gulf of Georgia and at Mendocino it is a very common species in shallow water and at low-water mark.

BRISINGA.

The genus Brisinga, with its long slender arms, the whole actinal side of which, with the exception of the large interambulacral plates forming the edge of the arm, is occupied by the ambulacral plates, shows us very distinctly how we can pass from the Starfish to the Ophiuran by the joining of the large interambulacral plates on the lower surface, and their becoming soldered together into one plate to form a lower arm-plate, so that the absence of interambulacral plates, which has always been cited as the great difference by which Starfishes and Ophiurans could always be distinguished, is readily explained; the lower arm-plates of Ophiurans being only modified interambulacral plates. We further find, on examining, in Brisinga, the secondary imbricating plates forming the arches which support the abactinal membrane covering the arms, each of which carries only a single spine, and is arranged in more or less regular curves, that we have some approach already to the side arm-plates so characteristic of Ophiurans, the separation of the so-called disk from the arms, — which, although so striking a feature of the genus, is less important than it seems at first sight, — being merely brought about by the reduction to a minimum of the lateral spreading of the actinal part of the secondary and interambulacral plates. In the case of Brisinga this forms at once an arch over the arms without expanding, as in other Starfishes, into a flat actinal floor of greater or less extent on the side of the interambulacral plate, from the extent and shape of which the various families are determined. This obtains its maximum of development in the extreme forms like Culcita and Palmipes; in one case the actinal and abactinal floors are well separated, in the other closely united by vertical shafts and walls. The analysis of the structure of Brisinga gives a most satisfactory explanation of the general homologies existing between Starfishes and Ophiurans, and reduces the gap hitherto unfilled between Starfishes and Ophiurans to a comparatively unimportant method of development.

As the madreporic body of Starfishes is placed in one of the interbrachial arches, and this arch reduced as it often is to a minimum (Solaster), or limited sometimes to the mesenteric support of the stone canal, we have a ready explanation of its position in the Ophiurans on the homologous plates in the interbrachial spaces, namely, the single plate in the continuation of the line of the interambulacral plates; at the same time the homology between the genital plates and the single interbrachial plate found in some Starfishes at the angle of the arms is fully carried out, as it is well known that it is on each side of the interbrachial arch that the ovarian openings are found. An examination of the base of the arms of Brisinga near its junction with the disk shows already quite a constriction, and of course a corresponding reduction in the length of the interbrachial arch. The great extension of the interambulacral plates across the space covering the ambulacral canal reduces it to its minimum at that point. The mode of articulation of the ambulacral plates of joints in the arms of Brisinga has been compared rather with Ophiurans than with Starfishes, but the articulation of the internal skeleton in Ophiurans is not specially different, although somewhat more perfect, from the articulation of the joints of arms in the Starfishes proper, and the homology between the internal skeleton of Ophiurans and the ambulacral system of Starfishes can be clearly established. If we imagine for each primary interambulacral plate but a single row of secondary interambulacral plates composed of a small number of plates, we shall of course have a side arm-plate and an upper arm-plate; the lower arm-plate being formed of the opposed interbrachial plates, which have become soldered together, and through which the tentacles have pierced their way.

The abactinal membrane of the disk of Brisinga is eminently Asterian; it is only slightly strengthened by a few minute limestone plates, as is the case in Crossaster and Pycnopodia, and in spite of the general resemblance, at first glance, of this well-defined disk to an Ophiuran disk, we have nothing whatever corresponding to the arrangement of the central plates so characteristic of the disk of Ophiurans. But we have in a great many genera of Starfishes the central part of the disk, showing in the young stages only, as regular an arrangement of the plates of the abactinal system as in any Ophiuran, though it is lost in the adult. Such a young stage is figured in Pl. VIII., a corresponding stage has also been recently figured by Lovén in his Memoir on the Echini (1875), and a similar structure of the disk will undoubtedly be found to exist in the very youngest stages of each genus, as it seems to be a general structure of the young of all Starfishes, as far as observed.

While Brisinga is a most important form, as showing the relationship between Starfishes and Ophiurans, there certainly is nothing in its structure or in its affinity to Protaster to warrant the palæontological importance ascribed to it by the younger Sars; and it cannot be considered, any more than several other genera of Starfishes now living,* as the representative at the present day of the oldest-known Echinoderm. I think we can show from the study of the hard parts of Starfishes that they have been a remarkably persistent type, and that the apparent changes of form due to the excessive increase or diminution of the interbrachial limestone deposit is a very secondary feature, which, though greatly modifying the external appearance of the Starfishes, yet does not affect the main structure, which, as has been stated, is remarkably uniform throughout the order. While fully admitting the many important points (so well brought out by Sars in his Memoir on Brisinga) wherein the genus differs from the other Starfishes, yet I must call his attention to the fact that many of the structural details which he strongly insists upon as specially characteristic of Brisinga † are common to the other Starfishes, and do not constitute features by which this family can be contrasted with the remaining Starfishes.

* Pycnopodia, Crossaster.

† For an opportunity of examining both dry and alcoholic specimens of Brisinga, I must thank Sir C. Wyville Thomson, and Dr. G. O. Sars. Brisinga endecaenemos is found in deep water off the Lofoten Islands, Norway. It has been collected by the "Challenger" in eighty fathoms, on the La Have Bank off Nova Scotia.

Linckia Guildingii.

Linckia **Guildingii** GRAY, 1840. Ann. Mag., VI.

Pl. XIV. Figs. 1 – 6.

A longitudinal section of one of the arms (Pl. XIV. *Fig.* 6) shows the great thickness of the irregularly shaped polygonal plates composing the limestone network of the abactinal surface. The plates (as seen in *Fig.* 4, Pl. XIV., when they are denuded of the finer granulation covering them, Pl. XIV. *Fig.* 1, and the intervening spaces) are very closely packed; the processes connecting plates laterally often do not exist in the median space of the arm, and appear only as short rods along the sides of the arms and on the outer edge of the lower surface (Pl. XIV. *Fig.* 3), where they are closely packed, forming in older specimens a compact pavement, and losing on this surface the imbricating arrangement to be traced only along the sides of the arms or to be seen in a transverse section. The fine granulation mentioned above extends over the whole actinal surface of the arms, concealing almost completely the three to four longitudinal rows of small plates immediately succeeding the interambulacral plates (compare *Figs.* 2 and 3, Pl. XIV.; see also *Fig.* 2′).

The top of the large papillæ (Pl. XIV. *Fig.* 6) attached to the interambulacral plates forms a close pavement when seen from the actinal side; these large papillæ pass very rapidly into the minute granules covering the lower side of the arms (Pl. XIV. *Fig.* 2). Toward the actinostome the papillæ flare inwardly, forming several rows placed one behind the other, and appear, when seen in section, as if there were a series of secondary interambulacral plates forming the mouth-papillæ, but on examination we find that the structure of the actinal interambulacral plates is that of other Starfishes. Seen from the interior on the actinal floor, the interbrachial plate is sunk far below the level of the ambulacral groove; the interbrachial arches are reduced to the thickening produced by the junction of the arms, which extend in wedge shape a short distance toward the actinal ring; the space in which the limestone canal is situated alone connecting by a low ridge with the actinal ring.

This is specially a West-Indian and Florida species.

Asterina folium.

Asterina **folium** LÜTK. 1859. Vidensk. Meddel.

Pl. XIV. Figs. 7 – 9.

In Asterina, as in the bulk of the pentagonal Starfishes, the great lateral development of the secondary interambulacral plates introduces some modifications in the structure and position of the hard parts in this genus. The plates forming the actinal and abactinal floors are irregularly lozenge-shaped, imbricating at the extremities of the adjoining points, leaving thus a greater or less free space for the passage of the water-tubes; the plates of the two floors at the ridges of the disk become soldered together, thus forming, as it were, a new system of plates, which in some genera are regularly arranged and often furnish characteristic specific distinctions. At the actinal ring the interbrachial arches exist only as columns rising directly from the actinal to the abactinal floors in the interambulacral spaces. As in all the species of the genus, the lozenge-shaped plates of the actinal and abactinal surface carry short slender spines, with a more or less regular fan-shaped arrangement on the abactinal side; the spines are less numerous on the actinal side, somewhat longer on the interambulacral plates, especially near the actinostome, forming mouth-papillæ of considerable prominence (Pl. XIV. *Figs.* 7 and 7′).

The simple structure of the short, pointed terminal tentacle at the extremity of the arm is well seen in this genus (Pl. XIV. *Figs.* 8′, 8); adjoining tentacles are, as in Asterias, long, slender, without a prominent sucking-disk. The water-tubes are specially large in this genus (Pl. XIV. *Fig.* 9).

This species has the same range as Linckia Guildingii.

Asteropsis imbricata.

Asteropsis **imbricata** GRUBE, 1857. Wiegm. Archiv., XXIII.

Pl. XV.

The abactinal limestone reticulation of this species consists of flat, irregularly star-shaped plates, from which diverge longer flat pieces, connecting the adjoining centres of radiating plates (Pl. XV. *Fig.* 2); the plates and their connecting links are all imbricating. Towards the central part of the disk the larger spaces between the rods are partially closed by shorter spurs, and are further separated by disconnected plates into elliptical areas, through which the water-tubes are protruded (Pl. XV. *Figs.* 1, 2); the network becomes closer towards the tip of the arms, and there are a great number of small areas for the passage of the water-tubes (Pl. XV. *Fig.* 3). In the living state the limestone skeleton is deeply imbedded in a thick epidermis, completely covering the upper and lower surface of the disk. Compare Pl. XV. *Figs.* 1, 1′, with the figures Pl. XV. *Figs.* 2, 3, showing preparations of the plates of abactinal surface from the exterior and interior. The interbrachial arches are reduced in this genus to a mere vertical column, consisting in portions of not more than a single plate placed close to the actinal ring, and leaving a large open space between it and the edge of the arm (Pl. XV. *Fig.* 6).

The plates of the actinal floor form a regular pavement, diverging from the interbrachial angle parallel to the axis of the arms; the actinal and abactinal systems of plates form, at their junction on the edge of the arms, a double row of large plates forming a binding at the periphery (Pl. XV. *Fig.* 4), one row placed on the actinal side, the other on the abactinal side (see Pl. XV. *Figs.* 4 and 2). There is a well-marked abactinal orifice near the centre of the disk (Pl. XV. *Fig.* 1).

In Gymnasteria, otherwise closely related to Asteropsis, there is no special difference between the plates of the actinal and abactinal systems; they are more distinct, and not arranged quite so regularly as to form a pavement.

In the greater number of the pentagonal Starfishes we find the same general distinction between the pavement-like plates of the actinal side, extending to the junction of the actinal with the abactinal system, although we do not always find so regular a peripheric series of plates. This is the case in Culcita (see *Figs.* 4, 5). Where the actinal plates acquire a great thickness, forming a lower floor through which the passages between the plates and beams make an intricate system of openings placed at different levels (*Fig.* 4), while the abactinal system is reduced to a comparatively simple series of rods having the general arrangement of triangular network with the longer or shorter rods separating them set on edge and imbricated (*Fig.* 5). The whole limestone system is, as in Asteropsis, entirely imbedded in the thick epidermal layer in which the plates have been deposited, so that but a trace of the limestone network appears when seen either in a natural condition or merely in dried specimens. The interbrachial arch of Culcita is reduced to a few vertical plates rising close to the actinal ring from the interbrachial interambulacral plate.

Fig. 4.*

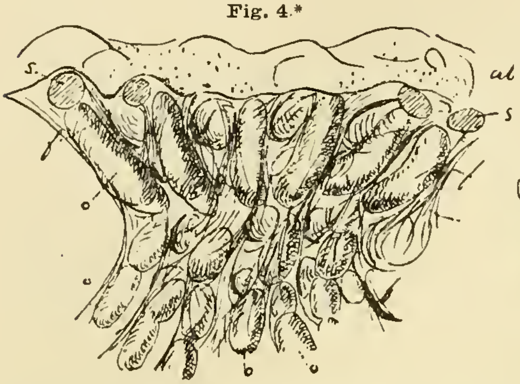
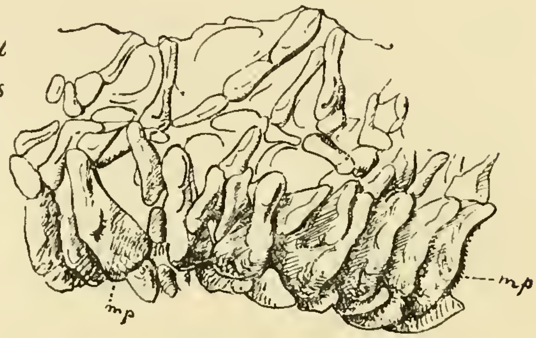


Fig. 5.†



This species of Asteropsis occurs on the West Coast, from Vancouver's Island to San Francisco.

The general arrangement of the limestone plates of the European Asteropsis pulvillus does not differ materially from the one here figured. The European species carries spines on the edge of the marginal as well as of the interambulacral plates, and the interbrachial arch is more fully developed, separating adjoining arms more completely.

Pentaceros reticulatus.

Pentaceros reticulatus Linck, 1733. De Stellis Marinis.

Pl. XVI.

Figs. 1, 2, 4, 5, on Pl. XVI., show the extent to which the limestone network of the actinal and abactinal surfaces is hidden by the spines and granules covering the plates and rods of the two surfaces. Seen from the abactinal side, the network consists of a central plate more or less hexagonal, with projecting angles connected together by short stout rods, overlapped by the plates, so as to form an open triangular network, covered by minute granules, and in their interstices giving passage to the thickly clustered water-tubes (Pl. XVI. *Fig.* 1). The same granulation covers the plates and rods as well as the greater

* *Fig.* 4 is an interior view of the actinal plates of a Culcita, as seen in an alcoholic specimen, of which the abactinal floor has been removed to show the intricate system of passages lying between the limestone rods. *a b*, abactinal system; *s*, section across a limestone rod; *f*, interior muscular sheath connecting limestone rods; *o*, passages between adjoining plates.

† *Fig.* 5, edge of a Culcita, to show the gradual passage of the open reticulation of the abactinal surface into the closely packed vertical wedges *m p*, forming the outer edge of the disk of a Culcita.

part of the spines scattered over the abactinal area, leaving but a short piece of the end of the spines bare. The meshwork of course becomes closer towards the extremity of the arms ; the plates and rods are of considerable thickness, as is seen in their section along the edge of the arm (see *Fig.* 5, Pl. XVI.).

The junction of the actinal and abactinal systems forms a double row of large contiguous plates carrying a heavy spine (see *Figs.* 4, 5, Pl. XVI.). The pavement-like plates of the actinal surface are arranged in rows parallel in a general way to the longitudinal axis of the arms (Pl. XVI. *Fig.* 4), and also in indistinct rows at right angles to this (Pl. XVI. *Fig.* 2). They are well covered by a coarser granulation than that of the abactinal surface, the central part of the plate carrying a cluster of three to five larger granules, becoming in some cases nearly fixed spines; these granules, on the actinal surface of the interambulacral plates, become a large flat pointed movable spine, with smaller flat lateral spines, rounded at their extremity. Round the edge of the interambulacral pieces forming the jaws they increase materially in size, becoming very prominent mouth-papillæ (Pl. XVI. *Figs.* 2, 3).

In all the pentagonal Starfishes the fact that the jaw pieces are simply the modified interambulacral plates of the last joint is very apparent, as well as that the interbrachial plates forming the base of the interbrachial arch are also only a modified part of the interambulacral plates formed by the soldering together of the inner lateral spaces of the opposite interambulacral plates of the joint of the jaw.

The interbrachial arches are composed of comparatively few large solid plates; their breadth varies materially in different specimens, either nearly filling the whole space between the actinal ring and the angle of the arms, or limited to a shorter wall next to the mouth. The ambulacral system is composed of tall plates rising well above the actinal floor, forming a broad median groove, seen from the abactinal side (Pl. XVI. *Fig.* 5); when seen in profile (Pl. XVI. *Fig.* 7), large elliptical spaces are left for the passage of the powerful ambulacral suckers (Pl. XVI. *Fig.* 2). The interambulacral plates are large, distinct, and of great thickness, with their actinal face well developed (see *Figs.* 4, 7, Pl. XVI.); the last joints of the plates of the actinal ring are prominent, raised high above the interbrachial plates. The jaws are large, projecting far into the central actinal space (Pl. XVI. *Figs.* 4, 5, 7); the papillæ when extended meet, nearly closing the actinostome, only leaving (Pl. XVI. *Figs.* 2, 3) a small pentagonal opening.

The interambulacral spines, when the suckers are drawn in close, completely cover the ambulacral furrow (see *Fig.* 2, Pl. XVI., where they are closed over a portion of the ambulacra at the base of one of the arms).

Pentaceros reticulatus is found on both sides of the Atlantic, at Cape Verde Islands, and in the West Indies, extending north to South Carolina. Several other West India species of Echinoderms are also found at Cape Verde Islands and on the main coast opposite.

In the pentagonal Starfishes the plates forming the so-called jaws are huge interambulacral plates extending far towards the centre of the mouth, where they nearly meet, to form, with the papillæ, the so-called jaws and teeth of Starfishes. So far we have not been able in any way to homologize the teeth of Echini with any of the solid parts of Starfishes or Ophiurans; the auricles of the regular Echini and the peculiar spur of the interior of the test near the mouth of some Spatangi being the only processes which appear to have analogous position. For a comparison of the Starfish mouth parts with those of Ophiurans compare the figures here given with those of Lyman in the Bull. Mus. Comp. Zoöl., Vol. III., from which it is evident that in Starfishes and Ophiurans the mouth parts are strictly homologous, and are formed by the terminal oral interambulacral plates. Comparing profile figures of the oral extremity of one side of an arm in Culcita (*Fig.* 7), Acanthaster (*Fig.* 6), and Solaster (*Fig.* 8), we cannot fail to be struck with the great size of the terminal oral interambulacral plate *a i p*, carrying the mouth-papillæ *m p*.

In the views of the arms, seen from the interior (the abactinal system being removed), the great development of the oral terminal plate (*a′c*) is well shown. In *Fig.* 6′, Acanthaster, *Fig.* 8′, Solaster, and *Fig.* 9, Anthenea, the lettering corresponds to the profile figures. The only additional notation introduced is *i p* for the interbrachial partition, and *i p b* for the spur forming the basal plate of the interbrachial partition. The mobility of the arms of Starfishes depends entirely upon the comparative width of the ambulacral and interambulacral plates compared in their length, upon the solidity and extent of the interbrachial partition, and the extent to which the abactinal system corresponds in its articulation

Fig. 6.*

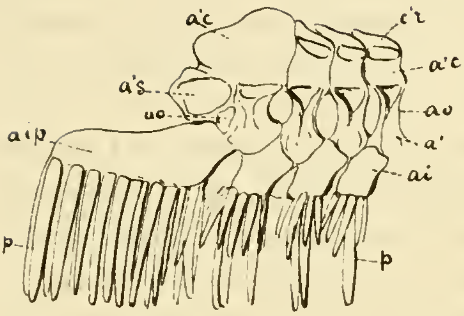


Fig. 7.

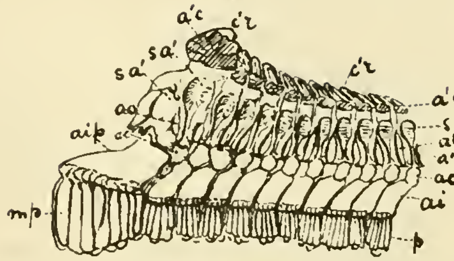
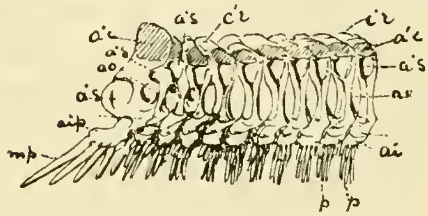


Fig. 8.



to the number of plates of the ambulacral system. Genera where there are large marginal plates, as in Astropecten, and the pentagonal Star-

Fig. 8′.

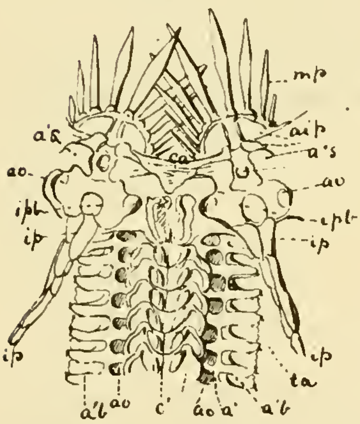


Fig. 6′.

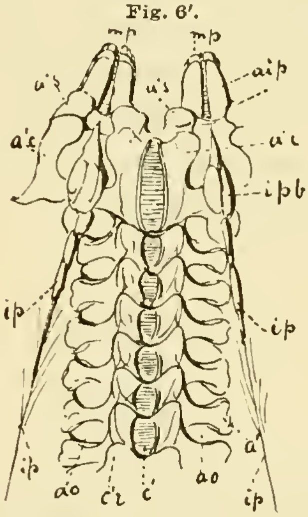
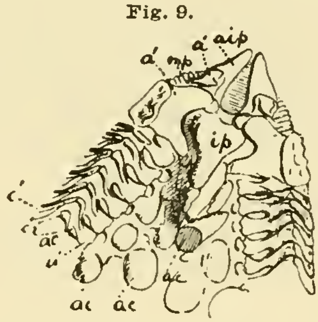


Fig. 9.



* In *Figs.* 6, 7, 8, *c′ r* are the small plates or spurs forming the ridge covering the ambulacral groove; *a′ c*, the corresponding plates of the ambulacral plates *a′*; *a o*, the opening for passage of ambulacral tentacle; *a i*, the interambulacral plates carrying papillæ *p*. The large terminal plate *a′ c* at the actinostome encroaches upon the corresponding ambulacral plate, so as to cover it by a spur *a′ s*, so much so that, when seen from above, this plate appears to be directly connected with the terminal interambulacral plate *a i p*, but the profile view clearly shows in all these genera that the terminal plates, although of different proportions, do not differ in their arrangement from those forming the body of the arm. The spur *a′ s* of the terminal oral plate *a′ c* sometimes forms a secondary cup-shaped plate along the edge of the arms; in *Figs.* 7, *s a′*, and 8, *a′ s*, this plate is quite prominent, while in *Fig.* 6 it is less developed.

fishes, or Starfishes in which the abactinal system is stiffened by heavy interbrachial partitions extending from the oral ring to the angle of the arms, or Starfishes where the abactinal reticulation is extremely solid, as in Ophidiaster, are all capable of but slight movements. On the contrary, Starfishes in which, as in most of the Asteracanthidæ, the reticulation is loose, the interbrachial partitions reduced often to a film, or to a mere arch of limestone plates, and in which the ambulacral plates are high, are much more flexible. The extremes are found in such forms as Anthenea and Brisinga. In some genera the arms are rendered more stiff by long flat spurs extending on the inner side of the actinal surface from the sides of the ambulacral plates towards the edge of the arms (see *a′ b*, *Fig.* 1, and *a′ b*, *Fig.* 8′). These spurs are also highly developed in Cribrella (*Fig.* 10), where, as in the preceding figures, they conceal the interambulacral plates, which are small compared with the ambulacral plates of Culcita, Anthenea, Acanthaster, and the like. The interambulacral plates retain their preponderance even towards the extremity of the arms quite near the tip, where the ambulacral and interambulacral plates become separated from the abactinal system proper (see *Fig.* 11, the tip of an arm of Culcita).

Fig. 10.

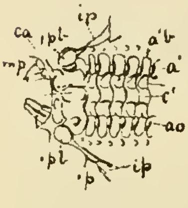
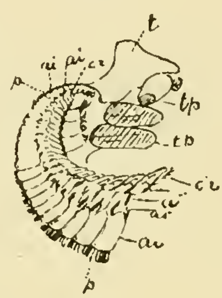


Fig. 11.



Solaster endeca.

Solaster *endeca* Forbes, 1839. Mem. Wern. Soc.
Asterias endeca Lin.

Pl. XVII.

In Solaster endeca the arrangement and general structure of the ambulacral and interambulacral plates are identical with those of Crossaster; the plates are, however, more closely articulated, and the basal ambulacral plates attain a still greater prominence even than in Crossaster. The mouth-papillæ are also more powerful. The fundamental difference between these genera, Crossaster and Solaster, lies in the structure of the abactinal floor (compare Pl. XVII. *Fig.* 1, and Pl. XII. *Fig.* 4). The actinal floor between the arms is composed of small, somewhat elongated plates, arranged in more or less regularly diverging rows, quite similar to those of Crossaster. The interbrachial partitions can hardly be intended for the support of the abactinal floor, either in this genus or in Crossaster. In Solaster it forms a broad band when it connects with the abactinal surface, and is gradually changed into a mere chord at the point of attachment to the interbrachial basal plates. These partitions are all exactly similar to the one supporting the stone canal. At the base of the arms the sides of adjoining arms come together, forming rounded angles, and do not, in the specimen examined, form an interbrachial partition for the support of the abactinal floor (see Pl. XVII. *Fig.* 3). The reticulation of the sides of the arms and of the abactinal region is compact, composed of small meshes forming diagonal lines across the arms, and more or less irregularly radiating lines from the centre of the disk. All the plates of the actinal floor carry tufts of small spines (Pl. XVII. *Fig.* 2), arranged usually in parallel rows, corresponding to the long axis of the plates; so that on the actinal side the spines of the interambulacral plates are at right angles to the arms; on the plates forming the triangular interbrachial space, the spines diverge from the actinostome, while those of the plates at the angles of the arms, of the arms themselves, and of the abactinal surface, form more or less circular tufts arranged on the lines of the plates of these surfaces.

Solaster endeca and Cribrella sanguinolenta are both found on the two sides of the Atlantic, occurring in Norway, Denmark, Great Britain, the northwest coast of France, Iceland, Greenland, Labrador, and as far south as Massachusetts Bay; C. sanguinolenta extending as far south as Long Island Sound.

Cribrella sanguinolenta.

Cribrella sanguinolenta LÜTK. 1857. Vidensk. Meddel.
Asterias sanguinolenta O. F. MÜLL. 1776. Zool. Dan. Prod.

Pl. XVIII.

The genus Cribrella is most closely allied to Solaster. It has, like Solaster proper, a compact system of limestone network, forming, when denuded of spines, small meshes on the abactinal surface (Pl. XVIII. *Fig.* 1), while the actinal surface and a part of the edge of the arms are covered with larger plates, forming longitudinal rows parallel to the longer axis of the arms, with more or less irregular shorter rows at right angles to the axis (Pl. XVIII. *Fig.* 4). The arrangement of the spines on this network is very similar in the two genera, consisting of short sharp spines placed on the abactinal surface, either in clusters or in semicircular fan-shaped rows as they approach the edge and lower surface of the arms; the sharp spines often become quite blunt in larger specimens. On the actinal surface the spines are longer and sharper, usually arranged in lines parallel with the longitudinal axis of the plates upon which they are carried (Pl. XVIII. *Fig.* 2). They gradually increase in size towards the ambulacral furrow; the spines of the interambulacral plates are still longer, and those which form the actinal papillæ attain the greatest development (Pl. XVIII. *Fig.* 3). The above features this genus has in common with Solaster, differing from it, however, in not having in the interbrachial angles the sharp line of demarcation between the arrangement of the plates and rods forming the actinal and abactinal surfaces. The genera differ also greatly in the structure of the interbrachial arch. In Cribrella the arch is well developed (Pl. XVIII. *Fig.* 7), starting from the angle of the arms and extending the whole way, between the two floors, towards the actinal ring, while in Solaster the arch is limited to a free loop, swinging between the abactinal surface and its basal interbrachial plates at the actinal ring in the interambulacral space. The last actinal joint of the ambulacral system is large, the ambulacral plates distant, and the interambulacral plates prominent, with a wide actinal face, upon which are placed numerous spines of different sizes, arranged in rows at right angles to the ambulacral furrow (Pl. XVIII. *Fig.* 2).

On the actinal surface two to four water-tubes pass through the free space enclosed by the limestone rods; the water-tubes on the actinal surface are less numerous, but longer.

Astropecten articulatus.

Astropecten articulatus M. T. 1842. Syst. d. Ast.

Asterias **articulatus** SAY, 1825. Journ. Acad. Nat. Scien. Phila.

Pl. XIX.

On account of the great prominence of the marginal plates of the actinal and abactinal surfaces in this genus, the limestone network is reduced to a small surface. This is particularly the case on the actinal surface, where the reticulation corresponding to the actinal surface of the arms is reduced to a few minute plates between the interambulacral and marginal plates placed at the angle of the arms near the base of the jaws (see *Figs.* 4, 7, Pl. XIX.). The remainder of the lower side of the arm is occupied by the marginal plates; these project beyond the marginal plate of the abactinal surface; forming, when seen from above, what appears like a second row of marginal plates (see *Fig.* 3, Pl. XIX.). The abactinal limestone network extends over the disk and over the narrow elongate space left on the upper side of the arms between the marginal plates (Pl. XIX. *Figs.* 1, 3, 6). The marginal plates are firmly soldered together, leaving no space between the floors where they are placed, with the exception of a single large opening for the passage of water-tubes along the line of junction of two plates, across the arms; the whole space in the arms between the plates being thus reduced to a narrow flattened space, of which the larger part is occupied by the ambulacral plates (Pl. XIX. *Fig.* 5).

The interbrachial arches are reduced to a thin partition at the angle of the arms, where the abactinal marginal plates attain their greatest height. The abactinal limestone network is, when seen from above, found to be closely covered by short club-like spines, often with a broad base and constriction in the middle below the head, attaining their greatest diameter a short distance from the base of the arms, passing gradually into mere granules towards the extremity of the arms and the centre of the disk; these spines are attached to the abactinal limestone network (Pl. XIX. *Fig.* 3) by a very shallow sucker, shaped like a saucer, with edges slightly turned up. On the tip of these spines are arranged concentrically a number of minute spines more or less cylindrical, with rounded ends, often completely filling the interval between adjoining spines, so that they appear to form at first glance a smooth surface (Pl. XIX. *Fig.* 1) over the whole space lying between the marginal plates. The grooves between the adjoining marginal plates are lined by similar, but even more delicate spines, which appear to perform the same functions as the delicate spines on the fascioles of Echini, namely, to sift the foreign matter contained in the water admitted to the water-tubes.

Seen from the actinal side, the abactinal floor consists of small circular plates (Pl. XIX. *Fig.* 6) corresponding to the flat saucer-like plates of the centre of the disk; seen from the opposite side, these gradually pass into the flattened plates closely soldered together, which extend into the arms, leaving only, however, on each side of the solid central band, a number of passages for the water-tubes (see Pl. XIX. *Fig.* 6). The general surface of the marginal plates of the abactinal side is covered by short rounded spines passing mainly into granules similar to those covering the abactinal surface of the arms; they are in addition provided with one or two long flat triangular movable spines similar to those covering the outer edge of the actinal side of the marginal plates, which are arranged in irregular diagonal lines across the plates, varying in size, generally flattened and triangular; but we find with them, along the edge of the furrows separating the plates, slender spines similar to those of the grooves of the abactinal side.

The interambulacral plates carry flat spatula-shaped spines placed at right angles to the longitudinal axis of the arms; these plates, when denuded, are seen to be in contact with the marginal plates, except near the actinal ring (Pl. XIX. *Fig.* 5). Spines similar to those carried by the interambulacral plates, only shorter, cover the actinal side of the jaws (Pl. XIX. *Fig.* 2).

The ambulacral plates seen from the interior of the arm occupy, with the base of the interambulacral plates, the whole space between the marginal plates; the median furrow formed by the junction of adjoining plates is deep; the ambulacral plates themselves are narrow, elongate, spreading somewhat at their junction with the interambulacral plates, leaving a wide space for the passage of the ambulacral feet.

It is not uncommon in this genus to find the ambulacral and interambulacral plates soldered together, either wholly or in part, so that it becomes difficult to trace the line of contact.

In Astropecten and Luidia the interambulacral plates of the last basal joint of the adjoining arms are connected together, forming a prominent point at the angle of the arms; but those plates which carry the mouth-papillæ are not, as in other families of Starfishes, at a lower level than the adjoining interambulacral plates. The jaws are on the same level, in direct continuation of the other interambulacral plates, only somewhat more prominent (see Pl. XIX. *Figs.* 7, 8).

Astropecten articulatus and Luidia clathrata extend from New Jersey to the West Indies. Luidia clathrata is one of the most common Starfishes of the sandy coasts of North and South Carolina.

Luidia clathrata.

Luidia clathrata Lütk. 1859. Vidensk. Meddel.

Asterias **clathrata** Say, 1825. Journ. Acad. Nat. Scien. Phila.

Pl. XX.

The genera Astropecten and Luidia are most closely allied, not only by their possessing but two rows of pointed ambulacral suckers (Pl. XX. *Fig.* 2), but also by the structure of the limestone network of the two surfaces of the spines and other appendages covering them. As in Astropecten, the actinal limestone network is limited to a small triangular area close to the mouth in the angle between two arms; this area reminds us of the interbrachial space on the actinal side covered by small plates in such genera as Solaster and Crossaster; with the latter they are closely connected. The rest of the actinal surface of the arms is covered by the narrow elongated marginal plates which correspond in number to the ambulacral and interambulacral plates (Pl. XX. *Fig.* 4).

The actinal marginal plates are, as in Astropecten, separated at the surface by deep grooves edged by minute spines less numerous along the main lines of the grooves than in the grooves of Astropecten, but much more crowded at the openings near the interambulacral plates, forming a regular sieve from plate to plate. The spines when removed leave upon the face of the plates markings exactly similar to those found as bands upon Echini, and known as fascioles. The spines carried upon these minute granules are similar in every respect to the spines of the fascioles of Echini. Their function is evidently identical, namely, that of filtering and clearing the water before it reaches the water-tubes. Their use is much more apparent than in the Spatangoids, where the bands of fascioles are really of use only when lining the edges of the sunken ambulacra of such genera as Hemiaster, while their extension from the tip of one ambulacral rosette to the other seems to be a remnant of a structure having at the present day in Echini but little if any use, while in Spatangoids it still performs its function of accumulating minute muddy particles floating in the water, which would to a certain extent impede the access of clean water to their lobed ambulacral tentacles. I have not observed these fascioles in other genera besides Astropecten and Luidia. The presence, however, in some genera of minute spines arranged in tufts on a solid basis projecting above the general surface shows us a regular transition from the closed area formed by them on the abactinal surface between the marginal plates in such genera as Astropecten and Luidia, to a somewhat looser arrangement in Solaster endeca and Cribrella. This arrangement is still further modified in Crossaster papposa and Pycnopodia, and leads to such spines as are found in Asterina and Palmipes, where the tufts consist of a smaller number of minute spines more uniformly scattered over the surface, thus forming an approach to the usual distribution of spines in Asteracanthion. Finally we pass to genera where the spines are long and few in number, and do not, as in the genera of the Asteriadæ proper, perform the part of sieves.

In place of the single row of large marginal plates along the abactinal edge of the arms, we find in Luidia a series of much smaller plates, corresponding in number, as on the actinal side, to the number of ambulacral plates. There are sometimes four or five rows of such plates, forming regular longitudinal and transverse rows (Pl. XX. *Fig.* 3), followed towards the median band of the arm by more irregularly arranged plates. These plates form the base of prominent pillars, somewhat constricted in the centre, flaring at the extremity, surmounted at the tip by short spines or merely granules articulating in a shallow socket. These spines are so closely packed as to leave but very narrow passages between adjoining rows (see Pl. XX. *Fig.* 1), generally mere slits edged by minute spines, so that longitudinal and transverse passages run the whole length of the arms for the passage of water, which must be all carefully sifted before it enters either through the passages protected by the fascioles or through those screened by the minute spines of the abactinal surface.

The plates of the abactinal limestone networks are completely soldered (Pl. XX. *Fig.* 6), leaving but few irregular rows of holes for the passage of the water-tubes to the abactinal side, where they are completely sheltered under the floor formed by the minute spines of the abactinal surface of the arms.

In no other genera of Starfishes do we find so great a simplicity in the structure of the plates of the actinal ring as in Astropecten and Luidia. Usually the ambulacral and interambulacral plates of the arms differ in no essential way except at the actinal ring formed in most Starfishes by such a modification of the last joint as to make it somewhat difficult to trace the homology of all the parts. This last joint is extremely simple in Astropecten, being but slightly modified and differing from the others mainly in length. Thus the homology I have attempted to trace between the jaws can there be seen in its simplest form (Pl. XX. *Figs.* 4, 5, 8). The plates of the extremity of the arms are soldered together when seen from above (Pl. XX. *Figs.* 9 – 11), forming a prominent knob with a deep groove on the actinal side for the passage of the ambulacral tentacles.

The spines of the actinal side increase slightly in length towards the outer edge of the arms, where there is found a prominent row of larger flattened spines fringing the edge of the arms.

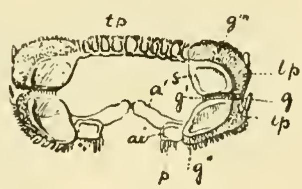
The actinal face of the jaw-plates is prominent and thickly studded with irregularly arranged minute spines, forming a marked feature at the actinal angle of the arms, between adjoining ambulacral rows (Pl. XX. *Fig.* 7).

The madreporic body is often irregular in outline (Pl. XX. *Fig.* 12), and is frequently completely hidden by the surrounding spines of the abactinal surface.

FASCIOLES OF STARFISHES.

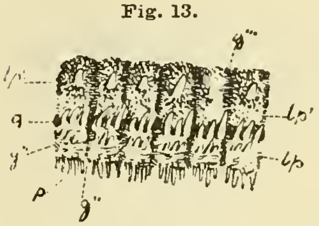
The description of the accompanying figures of Luidia and of Astropecten will explain the disposition of the minute spines of those genera which I have homologized with the fascioles of Echini. *Fig.* 12 represents a transverse section of an arm of Astropecten, a' being the ambulacral, ai the interambulacral, plate, with its spines p. lp is the plate on the edge of the lower side of the arm, and lp' the corresponding plate of the upper edge of the arm, tp being the small columnar plates surmounted by tufts of minute spines forming the close covering of the central part of the abactinal side of the arm. The surfaces s of the upper and lower plates on the edge of the arm are the articulating surfaces which rise somewhat above the surrounding edge of the plate, leaving a flat space g'' on the lower arm-plate, g''' on the upper arm-plate, and from g to g' between these two plates, through which water from outside can circulate as in a groove all round the articulation, and thus find its way between the columnar plates of the abactinal surface of the arm. The small papillæ which

Fig. 12.



cover these marginal plates, but more especially the minute spines crowded upon the surfaces of the grooves g, g', g'', and g''' form an effective sieve, and in thus freeing the water from its impurities before it circulates through the channels between the abactinal plates, act exactly like the fascioles of Echini. Only in Starfishes we can much more readily see their great use in the economy of the animal, while their action in the Echini is much less efficient. In a profile view of a part of the edge of the arm of Astropecten (*Fig.* 13), the openings, left for the passage of the water, which are lined by these so-called fascioles are very plainly defined. lp and lp' are the lower and upper marginal plates, with the deep grooves g'' between the lower plates and the furrows g''' between the upper plates, these furrows being completely arched over by the minute spines acting as meshes of a sieve. At the angle of the junction between the shallower horizontal grooves and the deeper vertical grooves a prominent opening g is formed for the passage of the bulk of the water, which is thus admitted to be sifted. The lettering of *Fig.* 13 is the same as in *Fig.* 12.

Fig. 13.



In Luidia the only difference in the mechanism of the fascioles is the greater number of openings through which the water is admitted to circulate between the columnar plates covering the abactinal surface and a part of the arms. In *Fig.* 14 we have a section of the arm of a Luidia, corresponding to *Fig.* 12 of an Astropecten. The lettering is the same, only, there being a larger number of upper marginal plates, the passages between them (g, g', g'', g''', g'''') are more numerous. The lower marginal plate alone is as prominent as in Astropecten. The articulation forms a continuous ring round the arm, broken by the columnar plates surmounted with their tufts of minute spines. These tufts are so thick as to form a uniform shield almost solid and unbroken on the abactinal surface of the arms. Seen from below (*Fig.* 15), the deep groove g' of the lower marginal plate edged with minute spines, the fascioles, is well shown. A view of the edge of the arm of Luidia (*Fig.* 16, corresponding to *Fig.* 13 of Astropecten) shows the small rectangular areas into

Fig. 14.

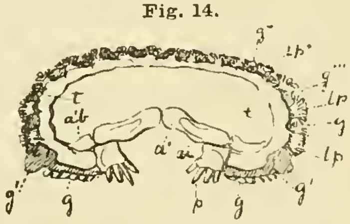
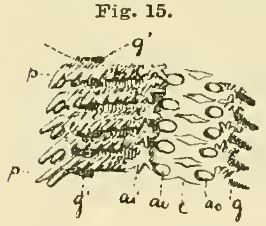


Fig. 15.



which the edge of the arm is divided by the deep furrows, allowing the passage of the water; at their crossing, the furrows form larger, more prominent openings; the edges of all these rectangular spines are crowded with fascioles. The genus Cribrella is interesting as showing the gradual transition of the interambulacral and marginal papillæ into tufts of such minute spines that the difference between them and true fascioles is hardly appreciable. In fact, in Solaster we have already certain parts of the surface covered by such minute spines that we must consider them as rudimentary fascioles and as probably acting as such. *Fig.* 17, a cross section of Cribrella, shows a close approximation to the cross section of Luidia as far as the tufts of spines are concerned; these need to be but slightly more crowded to form a most effective sieve. Seen in profile in a section (*Fig.* 18), the tufts of spines, the interambulacral papillæ, are seen to be somewhat more crowded into tufts than is the case in such genera as Asteracanthion. A similar arrangement is also found in Solaster (see *Fig.* 8), where the spines of the interambulacral plates, with the exception of those of the so-called jaws, are arranged in closely crowded tufts.

Fig. 16.

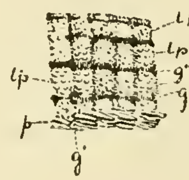


Fig. 17.

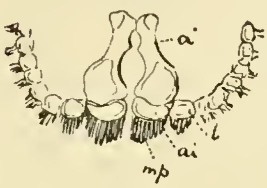
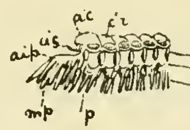


Fig. 18.



NOTE.

The arrangement of the Starfishes into families from the study of their hard parts does not differ materially from the families adopted by Perrier in his Revision of the group.* He himself has in a general way made use of the characters furnished by the skeleton to limit the families he has recognized. The modifications we should suggest go so far as to transfer Pycnopodia from the Asteriadæ proper, and Crossaster from the Echinasteridæ, placing them in close proximity to Brisinga, while Solaster (limited) and Cribrella would be placed with the Asterinidæ.

The disposition of the digestive cavity and its appendages does not appear to furnish systematic characters of great value. The anatomy of the ovaries of the coecal appendages of the digestive cavity proper with

* Asteriadæ, Echinasteridæ, Linckiadæ, Goniasteridæ, Asterinidæ, Astropectinidæ, Pterasteridæ, Brisingidæ.

its abactinal pouch is remarkably uniform in groups apparently differing so widely as the extreme pentagonal Starfishes, and the long slender-armed genera like Ophidiaster, Asteracanthion, or even the apparently abnormal group to which Brisinga, Pycnopodia, and Crossaster belong.

I do not give a list of our North American Starfishes, much less a Synonymic Catalogue, as it would be most incomplete and premature. Quite a number of species collected by Mr. Pourtalès in deep water between Florida and Cuba are at present in the hands of Professor Perrier for determination; of these several are undoubtedly new to our fauna. Numerous additions have recently been made by Professor Verrill, while engaged on the dredgings made in connection with the United States Fish Commission. In addition the "Challenger" expedition, while cruising in the Atlantic from Halifax to Bermudas, hence to New York, and then to St. Thomas, added quite a number of remarkable forms to our American species. As these collections are either in process of identification or about to be worked up, any general list now given would soon become antiquated. The Starfish fauna of North America, as far as now known, can be made out with sufficient accuracy from the articles by Professor Perrier on the "Stellérides du Musseum in the Archives de Zoologie Expérimentale" for 1875 and 1876, although the Synonymy he has adopted for several of our species will probably be modified when larger material than is now available has been collected. The principal localities of specimens in the Museum collections are added.

EXPLANATION OF THE PLATES.

To avoid useless repetitions in the description of the Figures, the same letters are used, throughout these Plates [I.–VIII.], to denote identical parts. It will greatly facilitate the reading of this memoir to become familiar with the notation here adopted.

Explanation of the Lettering on Plates I.–VIII.

a, anus.
b, dorsal or water pore, madreporic opening.
c, alimentary canal.
d, digestive cavity, stomach.
d', abactinal water-tubes in angle of rays of young Starfish.
d'', water-tubes of lateral line of rays of young Starfish.
d''', water-tubes of median line of rays of young Starfish.
e, eye of Starfish at base of odd tentacle (t').
e', median anal arms of Brachiolaria.
e'', dorsal anal arms of Brachiolaria.
e''', ventral anal arms of Brachiolaria.
e'''', dorsal oral arms of Brachiolaria.
e^5, ventral oral arms of Brachiolaria.
e^6, odd terminal oral arm of Brachiolaria.
f, brachiolar arms.
f', branch of water-tube ($w\,w'$) leading into *f*.
f'', odd brachiolar arms.
f''', surface-warts at base of odd brachiolar arm (f'').
h, hole of cul de sac of water-tube *w*.
l, central abactinal plate of young Starfish.
l_1, l_1, l_1, . . interbrachial abactinal plates of young Starfish.
$_2$, l_2, l_2, . . brachial plates of young Starfish.
m, mouth.
m', pistol-shaped oral pouch of œsophagus.
m'', anal pouch of œsophagus.
n, opening for passage of ambulacral sucker.
o, œsophagus.
p, spines on edge of ray of Starfish.
p_1, spines of exterior rows along abactinal surface of rays.
p_2, spines of middle row on abactinal surface of rays.
p_3, central spine of abactinal surface of Starfish, on central plate (l_1).
p_c, plate at junction of adjacent rays (ovarian plate).
p', p'', different forms of pedicellariæ.
r, abactinal surface.
r', first set of five limestone rods which appear on abactinal surface, and which eventually become the brachial plates (l_2).
r'', second set of five interbrachial limestone rods, which eventually become the interbrachial plates (l_1).
$r'''_1 - r'''_5$, rays of young Starfish; r'''_1 being ray next to madreporic body, when Brachiolaria is seen from the dorsal side.
s t and *s*, actinal region.
t, *t*, *t*, . . tentacles of the young Starfish.
t', odd tentacle.
t'', ambulacral tube.
u, lateral ambulacral plates, surmounted by spine.
u', median ambulacral plates with very small spines.
v, vibratile chord, anal part.
v', vibratile chord, oral part.
w, water-tube, developing abactinal area.
w', water-tube of Brachiolaria leading to madreporic opening (*b*), developing actinal area.
$w\,w'$, portion of water-tube of Brachiolaria formed by junction of *w* and w'.

In all the figures of the Brachiolaria (Plates I.–IV.), the attitude which has been given to them is not a natural attitude. This has been done purposely, for the sake of making the comparison with the memoirs of Müller easier. The only figure of a Brachiolaria which is in its natural attitude is that of Pl. VIII. Fig. 8. The young Brachiolaria does not, however, move with the anal part below, till the latter is loaded down by the development of the Starfish, and we see them swimming about, before that time, almost in every possible attitude.

Plates I., II. Embryology of Asteracanthion berylinus *Ag.*

Pl. I. Figs. 22–28, Pl. II. Figs. 2–19, Scyphistoma stage; Pl. II. Figs. 20–24, Tornaria stage; Pl. II. Figs. 25–28, Brachina stage.

PLATE I.

Fig. 1. A mature egg, surrounded by spermatic particles, soon after the artificial fecundation. The egg has assumed a spherical shape, and contains the germinative vesicle and dot. There is no trace of any interval between the yolk and the outer envelope.

Fig. 2. The germinative vesicle has disappeared, but the germinative dot remains.

Fig. 3. The germinative dot is no longer visible; the yolk has contracted, and is separated by a slight space from the outer envelope. The egg has all the appearance of having already gone through the segmentation; the whole yolk being made up of small spherical cells, resembling very minute spheres of segmentation, although the segmentation has not yet commenced. Two hours after fecundation.

Fig. 4 shows the first trace of segmentation, consisting in a depression on one side of the yolk.

Fig. 5. The yolk has become flattened on opposite poles; the Richtungsbläschen are visible on one side of the yolk.

Fig. 6 shows the yolk divided into two united ellipsoids, the whole yolk rotating slowly, always in one direction, from right to left. The Richtungsbläschen are at one pole of the axis of segmentation.

Fig. 7. The two segments of the yolk have entirely separated. The Richtungsbläschen are likewise isolated at one pole of the axis of segmentation.

Fig. 8. First trace of a further segmentation; one half of the yolk is partially divided.

Fig. 9. The two yolk segments are about to separate into four.

Fig. 10. The four yolk segments are all distinct, and almost transformed into regular spheres.

Fig. 11. Different view of Fig. 10, showing the position of the segments.

Fig. 12. The yolk about to separate into eight spheres.

Fig. 13 shows eight spheres of segmentation, all of which are more or less spherical; the spheres are arranged in two clusters of four, on opposite sides of the envelope.

Fig. 14. This view of the egg shows the tendency of the spheres of segmentation to arrange themselves on the circumference.

Fig. 15. The yolk is divided into sixteen spheres.

Fig. 16. The shell of segmentation is composed of thirty-two spheres; owing to the position from which the egg is viewed, only half the shell of segmentation is visible.

Fig. 17. The thirty-two spheres are again subdivided.

Fig. 18. The spheres of segmentation are still smaller than in the preceding figure.

Fig. 19. These spheres have become so small, that the walls of the spherical shell formed by them can be readily distinguished

Fig 20. The walls have become still more distinct in consequence of the close packing of the small spheres, which are now somewhat polygonal, owing to their pressure upon each other.

Fig. 21 represents an egg ten hours after segmentation; the spheres are still more polygonal; the rotation of the yolk is quite rapid, and the embryo is ready to break through the outer membrane; the shell envelope is very distinct from the inner contents, and has a uniform thickness.

Fig. 22. An embryo after its escape from the egg; the wall is no longer of the same thickness throughout, but has become very much thickened at one pole (*a*), while the spheres of segmentation are somewhat indistinct.

Fig. 23. The embryo has been slightly flattened at the pole (*a*), where the wall is thickest; the planula, if we may so call it in its present condition, reached this stage at the end of about eleven hours.

Fig. 24. The wall of the flattened pole has been pressed in so as to curve slightly inward (*a*).

Fig. 25. The depression (*a*) has become much deeper, and the spheres of segmentation have entirely disappeared, twelve hours after fecundation. The depression at *a* assumes here somewhat the aspect of a digestive cavity.

Fig. 26. Seventeen hours after fecundation; the embryo has lost its spherical shape and has become somewhat pear-shaped; a transverse section is still circular. The depression made by the thickened walls has increased in depth; the opening (*a*) performs the functions of a mouth and anus; *d* indicates the bottom of the digestive cavity.

Fig. 27. Twenty hours after fecundation; the depression has the appearance of a small pouch (*d*) hanging in a pear-shaped body with circular section, showing no deviation from the absolute radiate type; the opening (*a*) still performing the double functions of mouth and anus. Currents of water circulate in this cavity, as they would in the digestive cavity of any Polyp or Acaleph in about the same stage of development.

Fig. 28. Twenty-two hours after fecundation; the embryo has become somewhat more cylindrical, losing its pear-shaped form, but is still circular when seen in a transverse section. The cavity (*d*) has slightly expanded at the closed extremity, and is comparatively deeper and wider; the walls of the body are much reduced in thickness, except at the perforated region. The body is somewhat translucent, and slightly tinged with ochre color. The opening (*a*) still serves as a mouth, although, in more advanced stages, a second opening is formed, which is the true mouth, at which time the present mouth then becomes the anus.

PLATE II.

In Figs 1, 3, 9 – 17, the digestive cavity alone is represented.

Fig. 1. The digestive cavity of Fig. 2, seen by itself from above, has expanded into a large reservoir at the extremity, the walls of which are quite thin.

Fig. 2. The embryo of Fig. 1 seen in profile; the cavity is no longer in the axis, but is bent to one side. The larva has also lost its symmetrical outline, and the dorsal part of the perforated extremity projects somewhat beyond the opening of the present mouth (the future anus).

Fig. 3. The digestive sac of a larva somewhat more advanced than Fig. 2, in which the present mouth (*a*) (the future anus) has been brought to the lower side.

Fig. 4. The larva of Fig. 3 seen in profile; the pouch at the closed extremity of the bent digestive cavity is now nearer the lower side than in Fig. 2, having approached the slight depression (*m*) placed in the middle of the larva.

Fig. 5. A larva somewhat more advanced, seen in profile, in which the pouch has actually come in contact with the wall of the lower side at *m*. The dorsal region of the perforated extremity projects still more beyond the opening of the present mouth (*a*) (the future anus) than in the preceding stage (Fig. 4). The digestive cavity is not yet divided into distinct regions.

Fig. 6. The same larva as Fig. 5, seen from above, forty-two hours after fecundation; large epithelia-cells have appeared on the surface.

Fig. 7. A somewhat more advanced larva, seen in profile; the digestive cavity is no longer a simple bent tube, as in Fig. 5; it is strongly contracted near the extremities, one of them projecting upwards (*w*). At the point of contact of the digestive cavity with the outer wall at *m*, a second opening has been formed, connecting by a short tube with the pouch of the digestive cavity. This second-formed opening (*m*) is the true mouth, while the first-formed opening (*a*) now becomes the anus, after having, up to this stage, performed the functions of mouth and anus; end of the second day.

Fig. 8. The same larva as Fig. 7, seen from above, to show the position of the lobes (*w*, *w'*) formed on each side of the pouch of the digestive cavity (*d*), which in Fig. 7 appear like projecting angles (*w*).

Fig. 9. Isolated digestive cavity of a more advanced larva, showing still more plainly the transverse contractions of the digestive cavity by which the œsophagus (*o*), the stomach (*d*), and intestine (*c*) are gradually formed, and also the greater projection of the earlets of the pouch, which have become quite elongated laterally; the opening (*o*) in the centre is the tube leading to the mouth.

Fig 10. The same as Fig. 9, seen in profile; the tube (*o*) now connects very freely with the mouth (*m*), formed in the depression, mentioned in Figs. 4, 5, and with the digestive cavity; the currents now change their course, and circulate in the opposite direction. While the larva was in the state represented by Fig. 6, the currents of water enter at the mouth, the future anus (*a*), circulate in the pouch (*d*), as well as in the earlets formed from the thickening of the wall, and then issued again from the same opening (*a*). Now the water enters through the mouth (*m*) (the last-formed opening), passes through the narrow conical tube (*o*) into the digestive cavity (*d*), communicating with the earlets (*w*, *w'*), and out through the anal opening (*a*), which was the first formed, and formerly performed the functions of mouth.

Fig. 11. Isolated digestive cavity, seen in profile, showing the tube leading from the mouth (*m*) to the digestive cavity (*d*), and earlets (*w*, *w'*), more developed than in Fig. 10.

Fig. 12. The same seen from above.

Fig. 13. Oral end of an isolated digestive cavity, in which the earlets, formed by the pouch, are more

distinct from the digestive cavity than in any of the former stages. There is a slight constriction at their base of attachment, the first indication of their final separation from the alimentary canal.

Fig. 14. Isolated digestive cavity seen endwise, to show the tube leading from the mouth to the digestive cavity, at right angles to the pouch of the earlets.

Fig. 15. Isolated digestive cavity seen from above, in which the earlets (*w*, *w'*) (the future water-tubes) are so far differentiated as to be quite distinct from the digestive cavity. The walls of the earlets are exceedingly attenuated, and are scarcely connected with the main digestive cavity.

Fig. 16. The same as Fig. 15, seen from below, to show the position of the mouth and anus on the same side of the larva.

Fig. 17. Part of the same larva seen in profile: on account of the obliquity of the earlets, one of them (*w'*), as it increases in size more rapidly than the other, soon reaches the outer surface of the larva and opens into the surrounding medium by means of a small aperture (*b*). The walls of the tube (œsophagus) leading from the mouth to the first swelling of the digestive cavity (*d*) (the stomach), and of that part of the tube leading from the stomach to the anus, have a very different thickness. They are sufficiently distinct in their character to enable us to distinguish readily three regions; forty-eight hours after fecundation.

Fig. 18. The two small bodies (*w*, *w'*), the former earlets of younger stages formed from the pouch at the closed end of the digestive cavity (the problematic bodies of Müller), have entirely separated from the digestive cavity from which they were formed; seen from above, the three divisions of stomach, intestine, and œsophagus are plainly marked out.

Fig. 19. The same larva in profile.

Fig. 20. The same figure from below, shows the presence of short crescents of vibratile cilia (*v*, *v'*) placed in opposite directions near the mouth and anus; sixty-five hours after fecundation.

Fig. 21. A somewhat more advanced larva, seen in profile; the anal crescent (*v*) of vibratile cilia is seen as a small wart between the mouth of the anus, the oral crescent (*v'*) projects beyond the general outline. The division into œsophagus (*o*), stomach (*d*), and intestine (*c*) is quite prominent. The stomach has a tendency to approach the anal dorsal extremity.

Fig. 22. The same as Fig. 21, seen from below, to show the triangular shape of the mouth (*m*). The greater size of the problematic bodies (*w*, *w'*) (the water-tubes), which increase independently at an unequal rate, and also the position of the oral and anal vibratile crescents.

Fig. 23. The same larva seen in a profile, to show the position of the mouth in a strongly marked depression; the great increase in size of the oral part of the œsophagus; the swelling out of the stomach, and the bending of the intestine back towards the mouth, so as to make a small angle with the trend of the stomach; at the end of the third day after fecundation.

Fig. 24. Larva seen from above. The only difference in this stage from the preceding is in the greater increase of the vibratile crescents, forming two small plastrons, and of the water-tube. The intestine also bends so as to make almost a right angle with the stomach, which is pushed out further towards the anal extremity.

Fig. 25. More advanced larva, seen from the left profile, in which the oral pouch has assumed its characteristic pistol-shape. The stomach and intestine make a sharp angle with each other, the latter being much longer than the stomach proper. In its present aspect it closely resembles a retort, the stomach being the receiver, the intestine the tube. The anal and oral vibratile crescents have greatly extended, the one on the oral and the other on the dorsal side, to the extremity of the body.

Fig. 26. The same as the preceding, seen from below; the oral plastron is quite large, projects beyond the sides of the body; slight indentations can already be traced in the anal plastron, indicating the position of the future arms (*e'*). The water-tubes have increased in length, and extend half-way from the base of the stomach to the oral plastron.

Fig. 27. A larva six days after fecundation, seen from the right profile, the water-tubes extend beyond the opening of the mouth. The tube leading from the water-pore (*b*) (dorsal pore) to the water-tube (*w'*), is quite distinctly seen.

Fig. 28. The same larva as Fig. 27, seen from below; the intestine, as in Fig. 26, is thrown to one side of the axis of the larva. The water-tubes extend also along the sides of the stomach towards the anal extremity; the sinuosity of the anal ciliary chord indicates the position of the future anus.

Plates III.–VIII. Embryology of Asteracanthion pallidus *Ag.*

PLATE III.

Owing to the transparency of these larvæ, it is not easy to ascertain whether they are seen with the mouth downwards or upwards, unless we ascertain the position of the madreporic body. In all these figures, whenever the water-tube *w'* is on the left of the figure, the mouth is turned upwards.

Fig. 1. The youngest larva of this species, seen from the mouth side, corresponding to Pl. II. Fig. 20; a comparison of these two figures will show the great difference between the larvæ of these two species of Starfishes. In the former, the chords of vibratile cilia appear much earlier, and the oral plastron is well defined; while, in the other species, it is not before it has reached the condition of Pl. II. Fig. 26, that the oral plastron is as well developed.

Figs 2–10. Brachina stage.

Fig. 2. A larva seen from the left profile, corresponds to the stage of Pl. II. Fig. 27, of A. berylinus; with the exception of the size of the water-tubes, the larva of this species is much stouter, shorter, and the anal portion is the most prominent, while the larva of the A. berylinus is quite slender and elongated.

Fig. 3. The same larva as Fig. 2. seen from the dorsal side.

Fig. 4. A more advanced larva, seen from the dorsal side; the undulations of the ciliary chord indicate the future arms, the water-tubes extend beyond the mouth, and have already begun to bend towards each other.

Fig. 5. The same larva seen from the left profile, to show the bent attitude frequently assumed by the larva when disturbed.

Fig. 6. This larva, seen from the mouth side, is more developed than any raised by artificial fecundation from the eggs of A. berylinus. The water-tubes have greatly increased in diameter; they have united beyond the mouth, and extend on each side of the stomach so as almost to meet, but without uniting. The mere indentations of the previously figured larvæ correspond to accumulations of pigment cells, and to the thickening of the vibratile chord, accompanied by the formation of rudimentary lobes, which indicate plainly the position of the median arms (e'), the dorsal anal (e''), the ventral anal (e'''), and dorsal oral arms (e''''). The greatest accumulation of pigment cells, and the thickening of the vibratile chord, is found at the rudimentary median arms (e'). The anal ventral pair of arms (e''') is especially well marked.

Fig. 7. The preceding figure seen in profile, the mouth to the right, shows the great development which the oral position of the water-tube has taken; also the mode of formation of the oral ventral pair of arms (e^5), as well as the first sign of the odd brachiolar appendage (f'').

Fig. 8. Larva seen from the dorsal side. The arms have increased greatly in size since the stage represented in Fig. 6. The oral portion of the water-tube has become very pointed; it extends into the odd oral arm (e^6), which has also elongated, and stands out prominently beyond the oral plastron.

Fig. 9. The same figure seen in profile, with the mouth downward. The vibratile chord is a deeply undulating line, following the edge of the arms, which extend beyond the general outline. The water-tube, it will be seen, forks also at the oral extremity; one branch extending into the odd arm (e^6), the other toward the angle made by the base of this arm and the pair of oral ventral arms (e^5). The great increase in size of this odd arm will be seen when compared to Fig. 7 of this plate.

Fig. 10. Larva seen from the mouth side. Thus far the arms had altered but little the character of the outline of the larva. In this figure, however, some of them are sufficiently developed to be capable of extensive motion. The median arms (e') especially are far in advance of the others. All the anal arms develop so as to become more slender at first, and assume their true character sooner than the oral arms, which, during the early stages, are always more heavy, and take their final shape later than the anal arms. At the angle, where the oral ventral arms and the odd arm come together, at the base of the oral arms, slight swellings are formed (f), which are the first trace of the pair of brachiolar arms ($f\,f$), the odd brachiolar arm being only seen in the profile view (Fig. 12, f'), though it can be traced as a double outline of the odd arm (f''). We can already see a constriction in the water-tube as it passes into the odd arm, and from this (nearer the mouth) are sent off two small pouches ($f'\,f'$), which enter into the brachiolar pair of arms (f). The first trace of the actinal area of the future Starfish is also plainly visible (t) on the water-tube (w'), on the left of this figure.

Fig. 11. A more advanced larva than Fig. 10, seen from the mouth side, in which the oral arms have assumed all the characters of the anal appendages. The brachiolar arms are quite well developed; the intestine and the stomach are slightly crowded to one side by the greater increase of the actinal area (t) of the Starfish; the ambulacral pentagon of the future Starfish is still more marked (t) than in previous stages. Brachiolaria stage.

Fig. 12. The same as Fig. 10 seen in profile, with the mouth downwards.

PLATE IV.

Fig. 1. Seen from the mouth side. A larva with its arms fully developed and in full activity; no further changes take place in the general aspect of the larva, with the exception of those of the anal part where the Starfish is developing, and those of the brachiolar arms. All the arms are nearly equally advanced, with the exception of the median arms (e'), which still retain their greater size. The odd terminal arm (e^6) has also greatly increased in length, as well as the brachiolar arms ($f\,f$), which are capable of motion, and into which the branches of the water-tubes can easily be traced. Brachiolaria stage.

Fig. 2. The same larva, seen from above, on a somewhat smaller scale, shows in what way the stomach and the intestine have been pushed to one side, by the great development of the actinal part of the Starfish, on the right of the figure ($s\ t$). The shape of the mouth (m) is particularly well seen, in a dorsal view, at this stage of growth.

Fig. 3. The same larva on a different scale, seen endways, from the oral end, to show the connection between the pair of brachiolar arms ($f\,f$) and the oral ventral pair (e^5), as well as the position of the odd brachiolar arm (f'') at the base of the odd terminal arm (e^6).

Fig. 4. An adult larva seen from the right, actinal profile; the arms are in the position which they take when moving rapidly, arched towards the median arms, the brachiolar arms alone being curved in the opposite direction from the others. Here the crescent-shaped ambulacral pentagon, as well as the lobed pentagonal outline of the abactinal area are plainly seen.

Fig. 5. A magnified profile view of the brachiolar arms.

Fig. 6. The brachiolar arms seen from the ventral side of the larva, to show the position of the single disk and of the double row of disks at the base and on each side of the odd brachiolar arm, somewhat less magnified than Fig. 5.

Fig. 7. The anal part of the larva soon after the shrinking of the arms has begun. The whole of the terminal anal part of the larva has gradually been absorbed, so that the disk of the Starfish occupies the whole of the space between the median arms, seen from the ventral side; the oral extremity of the Brachiolaria is unchanged and not represented.

Fig. 8. The shrinking has gone so far that the whole of the anal part has been affected, and the oral extremity alone, with the brachiolar and the terminal arms, retain their original shape and proportions.

Fig. 9. A different view of the anal part of a larva from that of Fig. 7; in a slightly more advanced condition than that of the preceding figure, showing the great height of the abactinal region of the young Starfish; the oral extremity of the Brachiolaria is omitted, as it remains almost unchanged.

PLATE V.

Development of the Starfish proper.

The Figures on this Plate show the gradual development of the actinal and abactinal regions of the Starfish, and the figures represent simply the anal part of the Brachiolaria, which is alone affected during this development.

Figs. 1 – 7 correspond to a Brachiolaria, having reached a state about as advanced as that of Pl. III. Fig. 10.

Fig. 8 is a Starfish developed on the Brachiolaria of Pl. IV. Fig. 11; while Figs. 9 – 14 are stages of development which are only found on Brachiolariæ having their full complement of arms, and in which, except these changes of the Starfish, but slight modifications take place.

Figs. 1, 2, 10, 12, represent that profile of the anal part of the Brachiolaria, in successively more advanced stages, which shows the water-tube upon which is developed the actinal area.

Figs. 3, 5, 11, represent the opposite profiles of the anal extremity of the Brachiolaria, showing the water-tube, upon which is developed the abactinal area.

Figs. 4, 14, represent the ventral side of the anal extremity of the Brachiolaria, showing the extremities of the actinal and abactinal areas of the Starfish.

Figs. 6 – 9, 13, represent the dorsal side of the anal extremity of the Brachiolaria, in the successive stages of growth of the young Starfish, showing the opposite extremities of the actinal and abactinal areas of the Starfish.

Owing to the partial transparency of the Brachiolaria, either the actinal or the abactinal area is always projected upon the other, when the larva is seen in profile. In the dorsal or ventral views, the angle made by the actinal and abactinal areas becomes visible.

Fig. 1. Actinal profile of the anal part of the water-tube (w') of the Brachiolaria, previous to the appearance of the pentagon of lobes. In stage of Pl. III. Fig. 7.

Fig. 2. Somewhat more advanced actinal profile, showing the ambulacral pentagon, as well as the position of the five rods of limestone, opposite the angles of the actinal pentagon, seen through the thickness of the larva on the surface of the other water-tube (w). In Stage of Pl. III. Fig. 8.

Fig. 3. The same larva seen from the opposite profile, to show the abactinal area; small Y-shaped rods have appeared at the extremities of the simple rods.

Fig. 4. The same larva seen from the ventral side of the Brachiolaria, to show the relative position of the pentagons of the two areas; only two of the rods of the abactinal side are seen, while the edges of three of the actinal folds (t) can be perceived, one above the other, on the foot-like projection formed by the folding of the water-tube w'.

Fig. 5. A more advanced Starfish, in stage of Pl. III. Fig. 10, from the abactinal profile; the Y-shaped appendages of the original rods have increased in number; smaller independent Y-shaped rods have made their appearance in the intervals between the larger ones, in the spaces corresponding to the middle of the pentagon of the actinal side. The angles of the actinal pentagon are formed of a double fold, the sides of which are concave; the stomach is almost concealed by the great accumulation of limestone granules on the abactinal area.

Fig. 6. The anal part of a larva from the dorsal side, to show the apparent dividing into elliptical compartments of the water-tubes (w, w'), made by folding and the bending of the extremities of these tubes (Pl. III. Fig. 10).

Fig. 7. The same larva from the dorsal side, to show the manner in which the first fold (t) is made on the exterior surface of the water-tube (w'), and the greater size of the right water-tube extending over the digestive cavity to the madreporic opening (b).

Fig. 8. A Starfish from the dorsal side of the Brachiolaria (Pl. III. Fig. 11); shows the lobes formed by the two arms which are in view, with the large cluster of rods in the centre of the lobe, and the small cluster in the space opposite the angle of two lobes.

Fig. 9. The same view of a more advanced embryo, somewhat older than Pl. IV. Figs. 1, 2; the lobes of the arms have become indented, the arms themselves are separated by a deep cut, the Y-rods extend so as to form almost a continuous network over the whole abactinal area. The actinal pentagon has assumed the shape of prominent loops projecting beyond the foot-like, oblique fold of the water-tube.

Fig. 10. The same embryo, seen from the actinal profile; the tentacular loops stand out independently from the surface of the water-tube; the stomach and nearly the whole length of the intestine are enclosed by the abactinal area.

Fig. 11. Seen from the abactinal profile in stage of Pl. VII. Fig. 8; tubercles have formed upon the surface, the Y-shaped rods extend into them, the lobes of the edge of the disk are deeper, the second set of clusters of limestone cells have greatly increased.

Fig. 12. The same embryo from the opposite profile; the inner tentacular folds have become tipped with a triangular point. The thickness of the abactinal surface prevents the network of cells on the edge of the arms from being seen.

Fig. 13. A view of the embryo from the dorsal side of the Brachiolaria; the madreporic body (b), the opening of the water-pore, is placed at the edge of the upper arm (r_1'''), the tubercles on the edge of the arms are well shown by the great accumulation of small Y-shaped rods.

Fig. 14. The same from the ventral side of the Brachiolaria (Pl. VII. Fig. 8). This figure shows, perhaps better than any other, the relative position of the extremity of the two pentagonal warped surfaces. The rough outline of the Starfish is due to the manner in which the tubercles of the abactinal surface project above. The Starfish in this condition is at the point of resorbing the larva, and of closing the actinal and abactinal areas.

PLATE VI.

THE YOUNG STARFISH AFTER THE BRACHIOLARIA HAS BEEN RESORBED.

Fig. 1. A young Starfish, seen from the actinal side; the anal and oral clusters of arms of the Brachiolaria appear like small knobs, placed on opposite sides of the new mouth. The future rays are mere lobes, and are not symmetrical.

Fig. 2. The same embryo, seen from the abactinal side, to show the arrangement of the network of limestone meshes.

Fig. 3. A more advanced embryo, in which all traces of the appendages of the larva have entirely disappeared. Each side of the pentagon of suckers is a rosette made up of seven loops; the limestone particles are deposited so as to project at the angle of the arms between these loops. The mouth is movable, the pentagon is not closed, and the Starfish is not yet symmetrical; the shape of the different rays is not identical.

Fig. 4. The same embryo, seen from the abactinal side, showing the arrangement of the successively formed rows of rounded spines and of the plates. The two ends of the open pentagon have approached nearer than in Figs. 1, 2; the outline is not yet regular.

Fig. 5. Magnified view of one of the ambulacral tubes, with its rudimentary tentacles.

Fig. 6. The young Starfish, in which the two pentagons have almost closed, and been brought into parallel planes. There has been a great increase in the size of the cut between adjoining rays; the spines also have grown longer and more pointed; the limestone points of the angle of the rays have advanced nearer the centre. The Starfish is not quite symmetrical, nor are the arms exactly alike.

Fig. 7. The same embryo, from the actinal side, shows the great increase of the ambulacral system, the tentacles being distinct pouches on each side of the main tube. The basal tentacles of one system are much further apart than all the others, and this is the last indication that the ambulacral pentagon is not closed.

Fig. 8. A more magnified view of the actinal side, when the ambulacral pentagon is entirely closed, and the Starfish has become symmetrical, and all the basal suckers are equally distant.

Fig. 9. The ambulacral system of one arm, when confined by the circle of limestone which has been formed round each ambulacral system; the first two pairs of tentacles begin to develop disks; they become club-shaped; the three terminal tentacles are still closely connected, and show no sign of any disk.

Fig. 10. An abactinal view of one ray and the centre of a young Starfish, in which the spines project far beyond the edge of the disk. The arm-plates and the interradial plates have become connected by a narrow bridge. The limestone rods are so much thickened by additional deposits, that they form elliptical cells which have entirely lost the polygonal character of the younger stages.

Fig. 11. One arm and a portion of the centre, from the abactinal side of the most advanced of the young Starfishes which have been raised by artificial fecundation. The spines are very prominent, long, somewhat spreading, and becoming even fan-shaped. The limestone cells are gradually assuming the character of the limestone cells of the adult, small cells within larger ones; the cut between the rays is very deep.

Fig. 12. The same young Starfish as Fig. 11, seen from the actinal side; the three pairs of tentacles have suckers; the deposit of limestone of the actinal area having the same cellular structure as that of the abactinal area, though formed by the increase of small cells instead of rods. This Starfish also shows the position of the madreporic body, immediately on the edge of the disk of the lower side; the eye is very prominent at the base of the odd terminal tentacle. The young Starfish (Figs. 11, 12) is about four months old.

PLATE VII.

Fig. 1. Two rays and the centre of the Starfish (Pl. VI. Fig. 10), seen from the actinal side. All the tentacles are encased separately by the limestone deposit of the actinal region. The tentacles have grown so long that they extend beyond the edge of the arm. The pair of terminal tentacles has, as yet, increased but little in comparison to the other pairs. The odd terminal tentacle has, at its base, a bright carmine spot, the eye, which appears about this time. The

mouth, limited by the limestone deposit, takes the shape of a pentagonal opening; the ambulacral tube is concealed.

Fig. 2. The same Starfish as Pl. VI. Fig. 11, seen in profile, to show the great development of the abactinal area, and the Echinus-like arrangement of the spines in the young Starfish. The odd tentacle is seen turned up, between two of the spines, with the eye at its base.

Figs. 3 – 5. Spines of the young Starfish in different stages of growth.

Fig. 6. An enlarged view of the terminal tentacle, to show the position of the eye at the base of the odd tentacle.

Fig. 7. An enlarged view of the meshwork of limestone cells, to show the mode of formation of additional cells, by means of Y-shaped rods.

Fig. 8. A greatly magnified figure of a full-grown Brachiolaria in its natural attitude, at rest, with the Starfish almost ready to resorb the larva; the obliquity of the planes, in which the actinal and abactinal pentagons are situated, is especially well seen in the pointed anal extremity of this Brachiolaria. No letters have been added to this figure, as the different parts can readily be distinguished by comparing it with Pl. IV. Figs. 1, 2, 4.

PLATE VIII.

Fig. 1. Young Asteracanthion about one year old, seen from the abactinal side.

Figs. 2 – 4. Magnified views of spines (p), and of rudimentary pedicellariæ (p', p'').

Fig. 5. Odd terminal tentacle of a Starfish in the stage of Pl. VIII. Fig. 10, at the extremity of the arm with the eye-speck (e).

Fig. 6. One of the abactinal water-tubes (d') at the angle of the rays.

Fig. 7. One of the abactinal water-tubes (d'') along the edge of the rays.

Fig. 8. Abactinal view of the arm of a young Starfish, probably two years old.

Fig. 9. Actinal view of an arm of a young Starfish in its third year.

Fig. 10. Abactinal view of a young Starfish, in which the rudimentary pedicellariæ have made their appearance, also having median and lateral lines of abactinal water-tubes along the arm. Probably three years old.

PLATE IX.

Asteracanthion berylinus.

Fig. 1. Living specimen, seen from the actinal side.

Fig. 2. Living specimen, seen from the abactinal side.

Fig. 3. Preparation showing the calcareous network, abactinal side.

Fig. 4. Abactinal calcareous network seen from the interior.

Fig. 5. Preparation showing the connection of the solid parts, seen from the actinal side.
- ($a\,i$) Interambulacral plates, with two rows of pores at base.
- (a') Ambulacral plates, showing the alternating arrangement of the ambulacral pores penetrating between the ambulacral plates.
- (a'') Base of interbrachial partition.
- (c) Ambulacral groove.
- (l) Lateral imbricating pieces forming the calcareous network of the abactinal surface.

Fig. 6. The same, seen from the interior. Lettering as in Fig. 5.
- (c) Dorsal groove of ambulacral system.
- ($i\,p$) Interradial partition formed by soldering of the imbricating pieces attached to the interambulacral plates.

Fig. 7. Longitudinal section of preparation of arm, to show the formation of the interradial partition by the soldering of the imbricating lateral pieces of the interambulacral plates.

All Figures natural size.

The color of this species, as of all the species of the genus Asterias, varies greatly; it ranges from dark chocolate (on the abactinal side) to light violet. The actinal side is of a much paler shade of the same color. The general tint of the abactinal side depends also greatly upon the state of expansion of the water-tubes and the development of the light-colored pedicellariæ clustered around the spines.

PLATE X.

Echinaster sentus.

Fig. 1. Living specimen seen from actinal side.
Fig. 1′. Portion of arm of Fig. 1, somewhat more magnified.
Fig. 2. Same from the abactinal side.
Fig. 2′. Water-tubes of part of abactinal surface.
Fig. 2″. Madreporic body.
Fig. 3. Calcareous network of abactinal side.
Fig. 4. Internal view of abactinal surface.
Fig. 5. Calcareous network of actinal side (same as Fig. 3).
Fig. 6. Inner view of actinal calcareous network.

All Figures natural size, except Figs. 1′, 2′, 2″, which are somewhat enlarged.

The color of this species varies from a dark reddish-brown to a pale violet, sometimes more or less yellowish-brown or purple. The water-tubes are light pink or violet.

PLATE XI.

Asterias ochracea.

Fig. 1. Single arm and disk, seen from the abactinal side.
Fig. 2. Single arm, seen from the abactinal side, with the spines of the limestone network removed.
Fig. 3. Interior view of limestone network.
Fig. 4. Actinal view of the disk and arm, to show the narrow ambulacral plates, the marginal interambulacral plates, and the adjoining actinal limestone network.
Fig. 5. Inner view of the same, showing the huge spaces left between the pillars forming the marginal support of the limestone work adjoining the interambulacral plates.
Fig. 6. Portion of half of the arm, to show the arrangement of the ambulacral and interambulacral plates, seen from the actinal side near the base of the arm-plates forming the median groove on top.
Fig. 7. Profile view of a similar portion of the arm (as Fig. 6) toward the central part of the arm, seen from the interior of the arm.

All Figures natural size, except Figs. 6 and 7, which are somewhat magnified.

This is often a very brilliantly colored species. Brandt has separated as species the extreme variations in color. The most common coloring is a dark orange, passing in some specimens to an almost pure yellow, or in the other direction to a rich chocolate color. We find also frequently violet as the prevailing tint. The ridges, on the abactinal network, are invariably of a lighter tint than the ground-color.

PLATE XII.

Crossaster papposus.

Fig. 1. Seen from the actinal side, with the spines of the interbrachial surface, and of the lower surface of the arms. (The abactinal surface has been removed.)
Fig. 2. Seen from the actinal side, with the spines removed to show the structure of the plates carrying the spines along the edge of the arms, round the actinostome, and of the limestone plates strengthening the interbrachial membrane; the limestone network of the inner surface of the abactinal surface is seen through the opening of the actinostome.
Fig. 3. Fig. 1, seen from the interior (from the abactinal side), showing the portion of the membrane extending as a division wall between arms, and forming the support as well as the connection between the actinal and abactinal surfaces; this membrane is often a mere film strengthened with limestone plates only at its outer and inner extremities, where it connects by more numerous and stronger plates the two surfaces of the interbrachial space. The plates near the actinostome are frequently drawn out into a long comma-shaped support on the abactinal part of the connecting membrane.

Fig. 4. Same as Fig. 2, seen from the abactinal side, to show the network of the abactinal surface and the projecting knobs forming the support of the clusters of spines of that surface.
Fig. 5. Longitudinal section through the median line, seen in profile.

All figures natural size.

The coloring of this species is of all shades, between a brilliant red and a light orange or a dark violet.

PLATE XIII.

Pycnopodia helianthoides.

Fig. 1. Portion of disk, seen from abactinal side, with papillæ fully expanded (from life).
Fig. 2. Same as Fig. 1, seen from the actinal side.
Fig. 3. Actinal view of central part of the disk, showing the connection of the arms around the central opening.
Fig. 4. Limestone network of part of the abactinal membrane, with the pillar separating adjoining arms seen from the interior.
Fig. 5. Profile view of the extremity of one arm.
Fig. 6. Interior view of the arm; the abactinal membrane is removed, showing the mode of connection of adjoining arms at actinostome, ambulacral vesicles all removed.
Fig. 7. Same as Fig. 6; seen from below, the soft parts all being removed.
Fig. 8. Profile view of Fig. 6.
Fig. 9. Section across Fig. 6.
Fig. 10, 10″. Profile views of two of the large spines of the abactinal surface.
Fig. 10′, 10‴. The same spines, 10, 10″, seen from above.

Figs. 1 – 5 are natural size; all others slightly enlarged.

The color of the abactinal surface varies greatly in this species, from a brilliant carmine to yellow, violet, or bright vermilion, with the intermediate shades of orange.

PLATE XIV.

Linckia Guildingii.

Fig. 1. Seen from above.
Fig. 1′. Enlarged tip of one of the arms.
Fig. 2. Fig. 1, seen from the actinal side.
Fig. 2′. Magnified portion of arm of Fig. 2.
Fig. 3. Preparation of actinal side, showing the limestone plates after the granulation is removed.
Fig. 3′. Magnified view of opening of actinostome of Fig. 2.
Fig. 4. Preparation of abactinal surface, showing the limestone plates of that surface.
Fig. 4′. Enlarged view of madreporic body.
Fig. 5. Interior view of abactinal surface of one of the arms, showing the small openings left between the nearly united plates.
Fig. 6. Section across one of the arms, to show the depth of the ambulacral furrow, with its single line of ambulacral pores.

Linckia is generally of an ashy-violet color, with darker spots scattered over the abactinal surface of the arms.

Asterina folium *Lütk.*

Fig. 7. Actinal view prepared to show the plates of that surface.
Fig. 7′. Enlarged view of plates, forming edge of actinal opening, in Fig. 7.
Fig. 8. Somewhat enlarged view, natural attitude, with suckers expanded.
Fig. 8′. Enlarged view of arm, showing ocular tentacle, at base of pointed terminal ambulacral tube.
Fig. 9. Water-tubes of abactinal surface somewhat enlarged.

Figs. 1 – 7, natural size; others somewhat enlarged.

The abactinal surface of Asterina is of a pea-green color. The actinal surface is more yellowish. Specimens frequently occur of a yellow color on both sides.

PLATE XV.

Asteropsis imbricata.

Fig. 1. Seen from above; in two of the arms the water-tubes of the abactinal surface are represented as fully expanded, while they are drawn in on the others.

Fig. 1'. Actinostome with the tentacles drawn in, taken from life; the plates, except the marginal ones, are all imbedded and hidden in the membrane of the actinal surface.

Fig. 2. Preparation showing the irregular limestone plates and needles of the abactinal surface.

Fig. 3. Portion of abactinal surface, seen from the interior, showing the original reticulation, which is lost in the exterior view from the abactinal side.

Fig. 4. Fig. 2, seen from the actinal side, to show the arrangement of the limestone plates.

Fig. 5. Interior view of the actinal floor, showing the broad ambulacral groove, the connection of the ambulacral plates round the actinostome, and the position of the pillars connecting the actinal and abactinal surfaces.

Fig. 6. Same as Fig. 5, seen in profile, to show the interbrachial arches and the great height of the ambulacral plates.

Fig. 7. Section across the arm near the tip; the ambulacral plates almost touch the abactinal surfaces.

All figures are natural sizes.

On the actinal side Asteropsis is of a brownish color, with yellow edge along the ambulacral furrows. The abactinal surface is most brilliantly colored with large patches, irregularly arranged, of vermilion, bright green, blue, yellow, with prominent carmine spots enclosing the areas for the passage of the water-tubes.

PLATE XVI.

Pentaceros reticulatus.

Fig. 1. Arm and portion of the disk with water-tubes fully expanded and ambulacral tubes extending beyond the edge of the arms near the tip, seen from the abactinal side.

Fig. 2. Same as Fig. 1, seen from the actinal side, the two rows of tentacles drawn in and ambulacral furrow almost closed near the face.

Fig. 3. Actinostome natural size, with the ambulacral tentacles at base of furrow fully expanded.

Fig. 4. Actinal view of the lower surface, showing the limestone plates of the margin of furrow supporting the papillæ, and the plates covered by the granulation of Fig. 2.

Fig. 5. Interior view showing the ambulacral system, the connection of the ambulacral plates round the actinostome, the thick abactinal surface with the nearly solid interbrachial limestone arches.

Fig. 6. Central portion of the abactinal surface of the disk, natural size, showing the massive reticulation of the surface.

Fig. 7. Section through the centre of the ambulacral system, seen in profile, with the interambrachial arches.

Figs. 3 and 6 somewhat enlarged; others, natural size.

The general coloring of this species is yellowish or pinkish brown, sometimes bright carmine. The ridges separating the spaces for the passage of the water-tubes are a darker shade of the general color. On the actinal edge the plates are of a darker brown color, while the actinal surface itself is faintly colored gray.

PLATE XVII.

Solaster endeca.

Fig. 1. Limestone network of the abactinal surface.

Fig. 2. Dried specimen, with spines bordering the ambulacral furrows and covering the actinal surface.

Fig. 3. Interior view of the actinal floor, showing the narrow furrow of the ambulacral system, its connection round the actinostome, the absence of a prominent interbrachial arch separating the central arm-spaces.

Fig. 4. Same as Fig. 2, only denuded of spines to show the plates of the actinal surface supporting them.

Fig. 5. Longitudinal section through the median line of the ambulacral furrow.

All Figures natural size.

This species is generally, on the abactinal side, a dirty orange yellow, passing into red; more yellowish and lighter in shade on the actinal surface.

PLATE XVIII.

Cribrella sanguinolenta.

Fig. 1. Seen from the abactinal side, to show the minute spines covering the whole disk and arms.

Fig. 2. Fig. 1, seen from the actinal side.

Fig. 3. Enlarged view of spines round the actinostome and base of the arms.

Fig. 4. Actinal view; specimen denuded of its spines to show the close system of limestone plates forming the actinal surface.

Fig. 5. Interior view of the abactinal surface, showing its close reticulation.

Fig. 6. Longitudinal section across the central line of the ambulacral furrow, somewhat enlarged.

Fig. 7. Interior view of the ambulacral system of one of the arms and its central connection, somewhat enlarged.

Figures 3, 6, 7 are somewhat enlarged; all others, natural size.

This species varies in color from brilliant orange-yellow to dark purple or dull violet.

PLATE XIX.

Astropecten articulatus.

Fig. 1. Dried specimen, from the abactinal side.

Fig. 2. Fig. 1, seen from the actinal side.

Fig. 3. Abactinal view of denuded specimen.

Fig. 4. Actinal view of denuded specimen.

Fig. 5. Interior view of actinal floor, showing ambulacral system, the interbrachial arches, the connection of ambulacra round the actinostome.

Fig. 6. Interior view of the abactinal surface.

Fig. 7. Actinal region of specimen somewhat larger than Fig. 4.

Fig. 8. Longitudinal section through arm, showing the great thickness of the marginal plates.

All Figures are natural size.

The marginal plates are of a light brown color with darker edges; the abactinal surface of nearly the same shade, somewhat lighter than the plates. The color is sometimes arranged in darker rectangular patches along the edge of the arms on the abactinal side. The marginal plates are also bright yellow, enclosing a violet abactinal surface.

PLATE XX.

Luidia clathrata.

Fig. 1. Abactinal view from life.

Fig. 2. Same, seen from the actinal side, showing the two rows of pointed tentacles.

Fig. 3. Same view as Fig. 1, denuded specimen.

Fig. 4. Preparation showing the plates of the actinal surface.

Fig. 5. Interior view of actinal floor, showing ambulacral system and mode of connection round actinal opening.

Fig. 6. Interior view of abactinal surface.

Fig. 7. Actinal view of central part of disk, with tentacles contracted, showing the spines along the edge of ambulacral furrows and at their junction.

Fig. 8. Longitudinal section of arm.

Fig. 9. Terminal knob of arm seen from above.
Fig. 10. A terminal knob, seen from the actinal side.
Fig. 11. The same, seen from the end.
Fig. 12. Madreporic body.

All Figures natural size, with the exception of Figs. 9 – 12, which are somewhat enlarged.

The coloring of this species is quite dull; it has a grayish hue, with large square patches of brown arranged along the margin of the arms. The color of the abactinal surface is frequently in lines, one in central part of the arms, the others along their margin. The ambulacral tentacles are yellow.

ERRATA.

On	page	6, 13th	line	from bottom	for *Blütschli* read *Bütschli*
"	"	25, 9th	"	"	for *pallidus* read *berylinus*
"	"	33, 7th	"	"	for r_1'' read r_1'''
"	"	33, 8th	"	"	for r_5'' read r_5'''
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"	"	61, 12th	"	from top	for *furrows* read *four rows*
"	"	74, 9th	"	"	for *Zeitscrif.* read *Zeitschrift*
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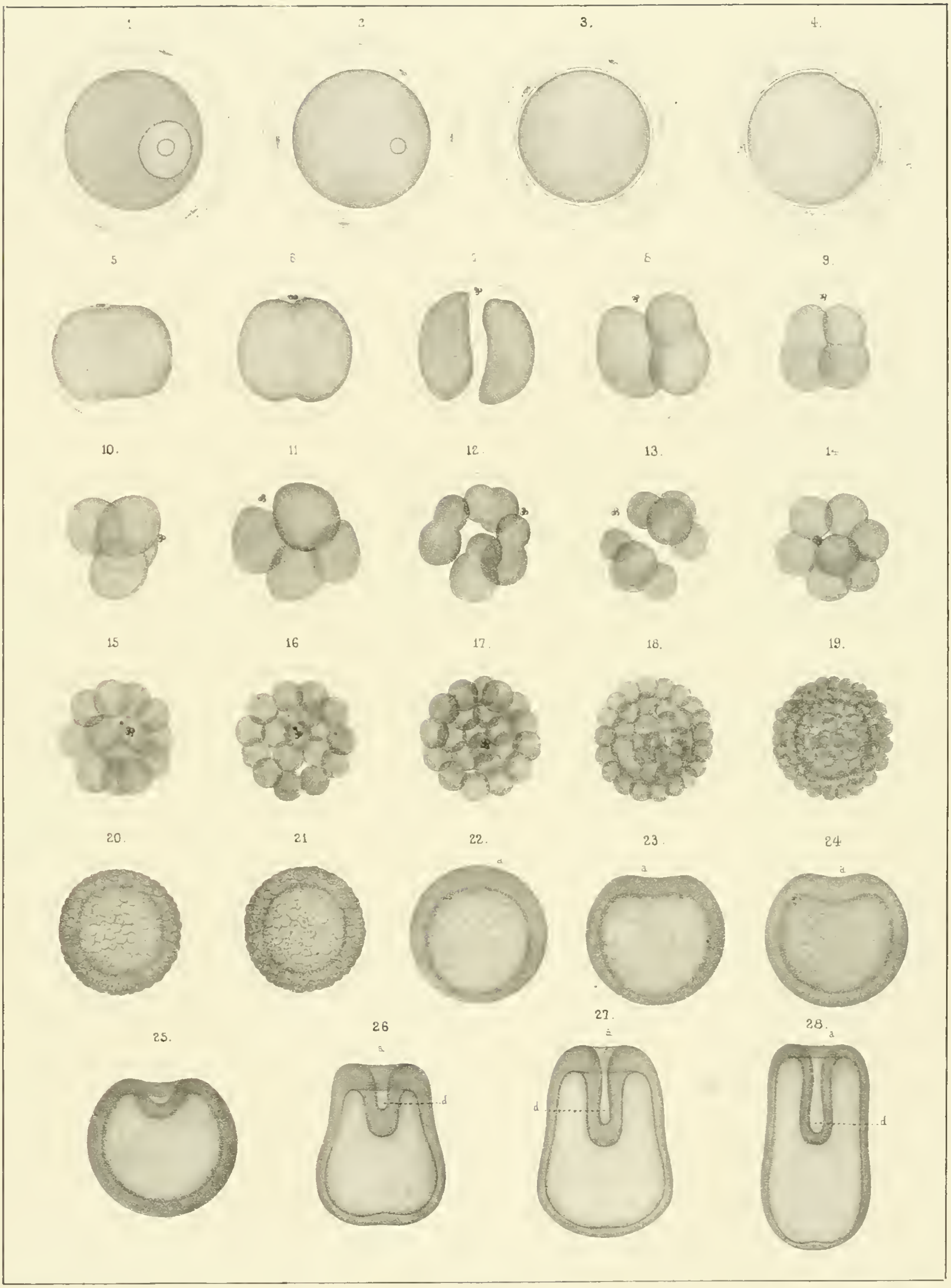

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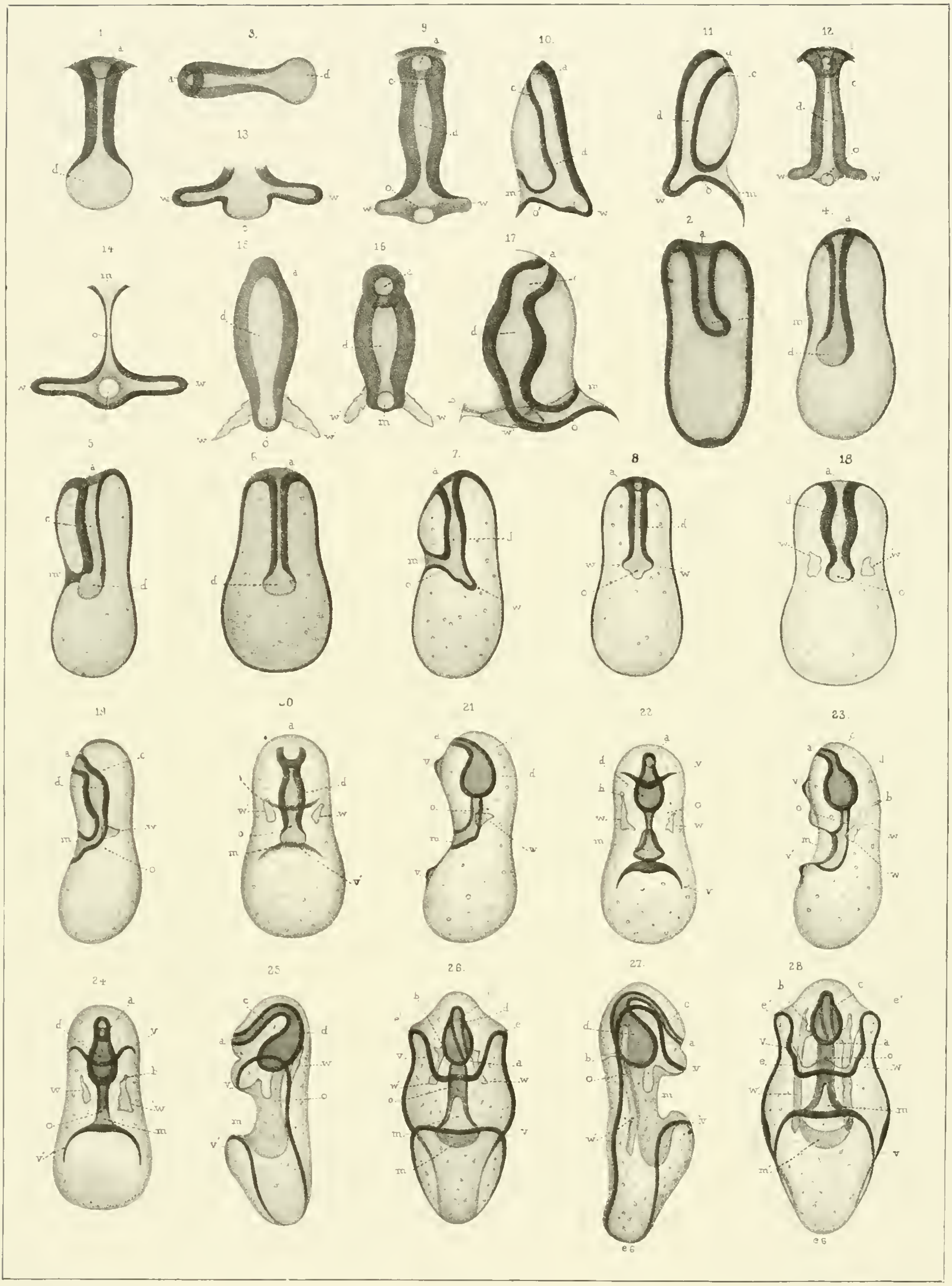

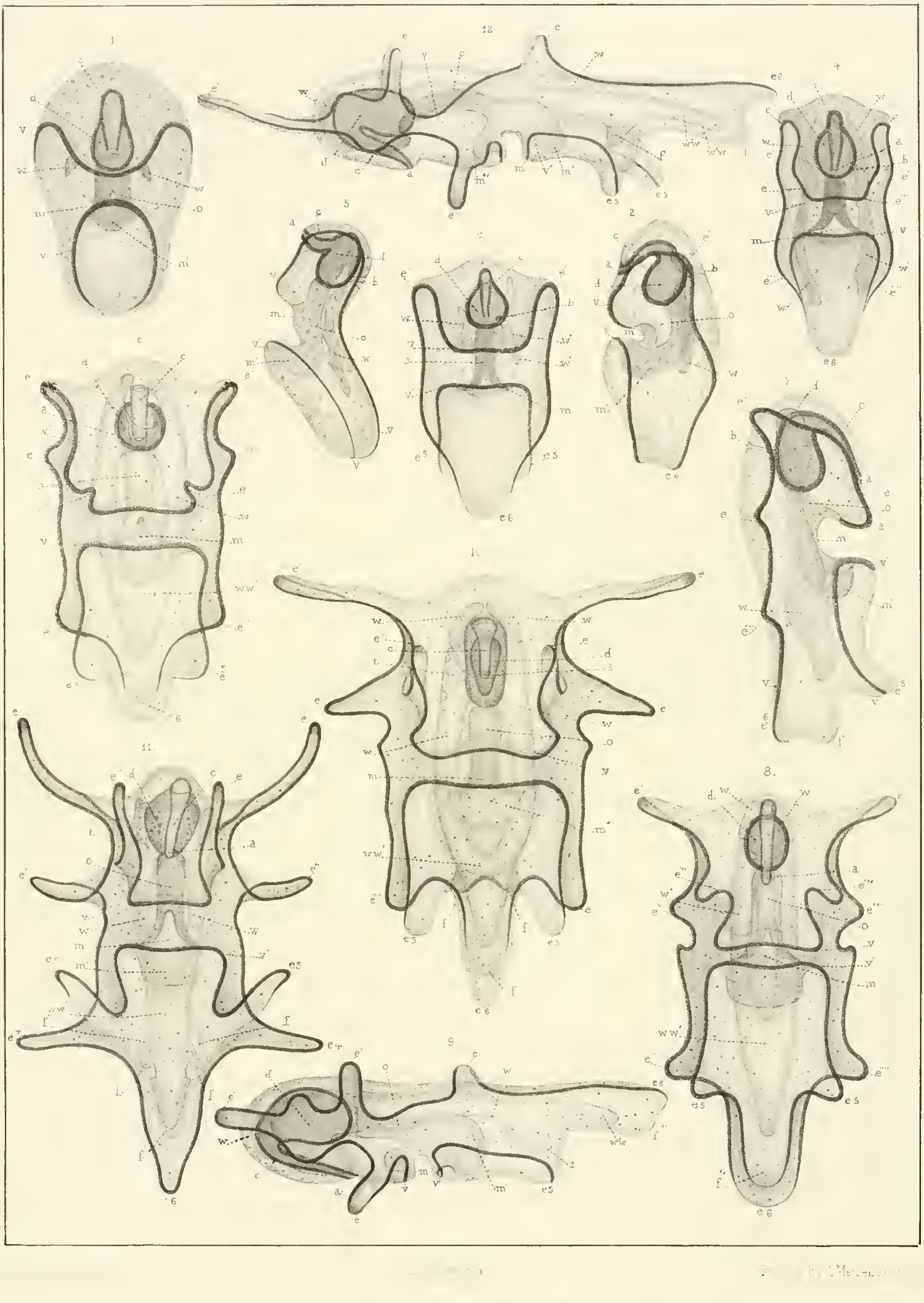

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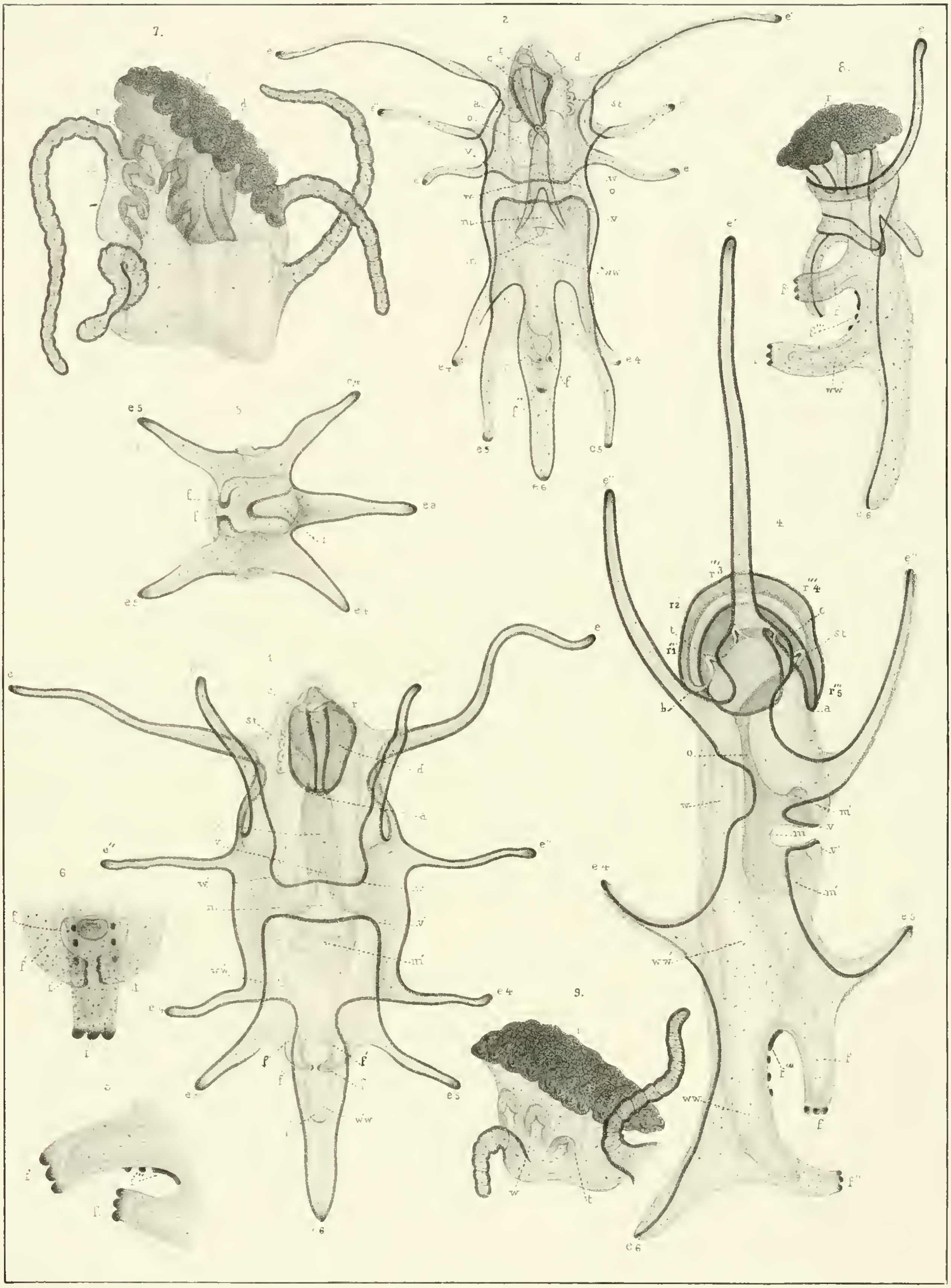

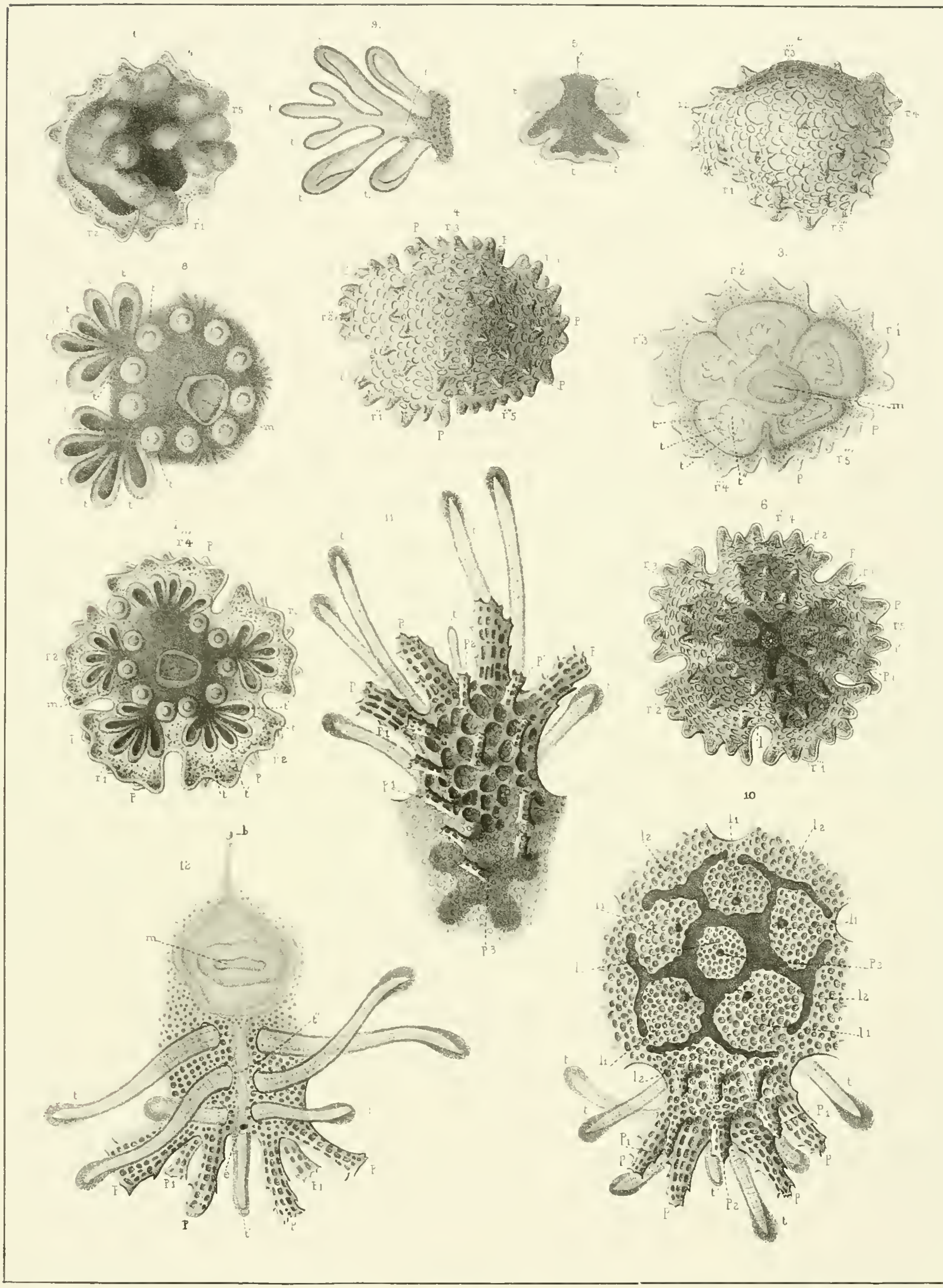
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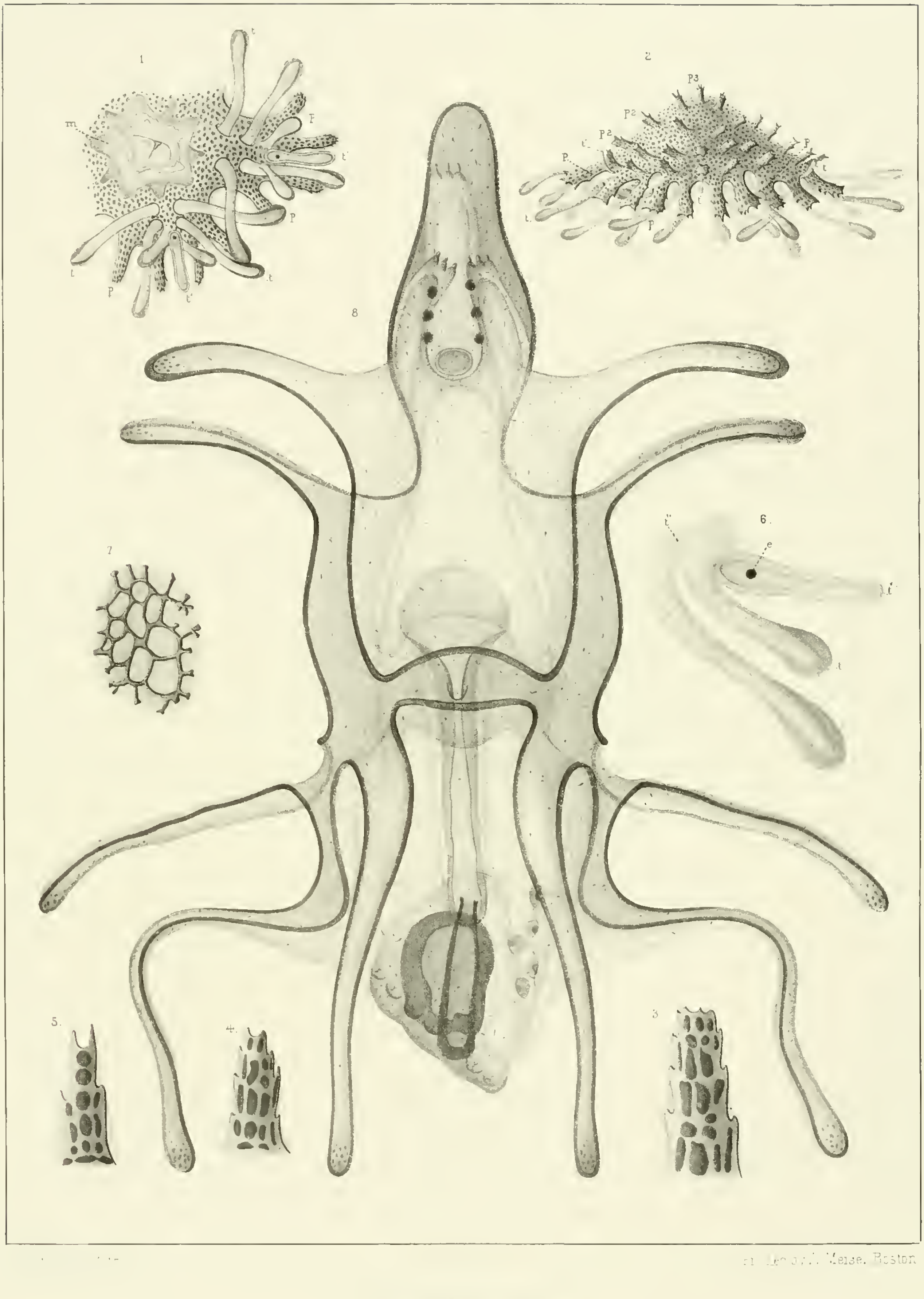
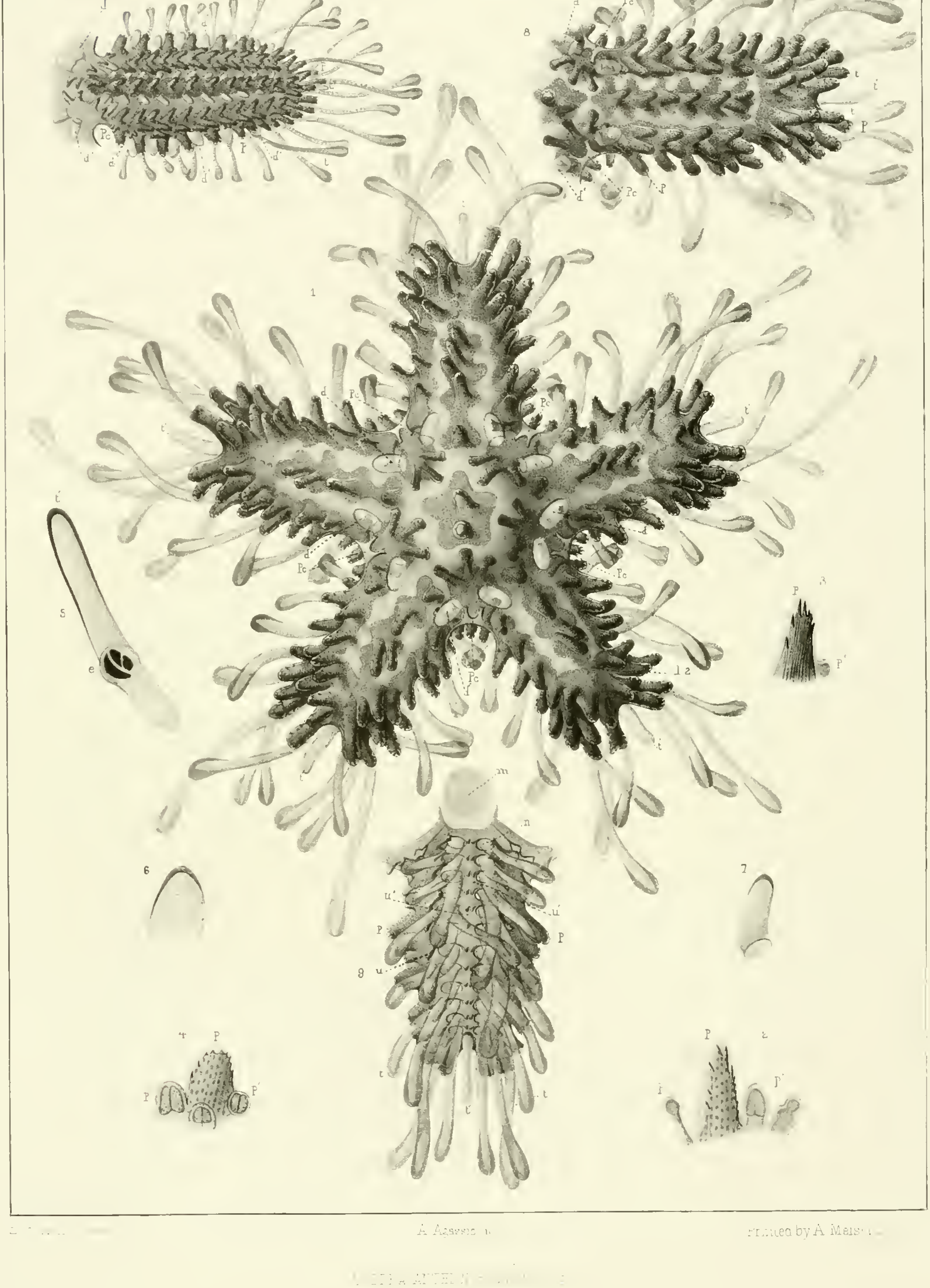


Meisel, Boston



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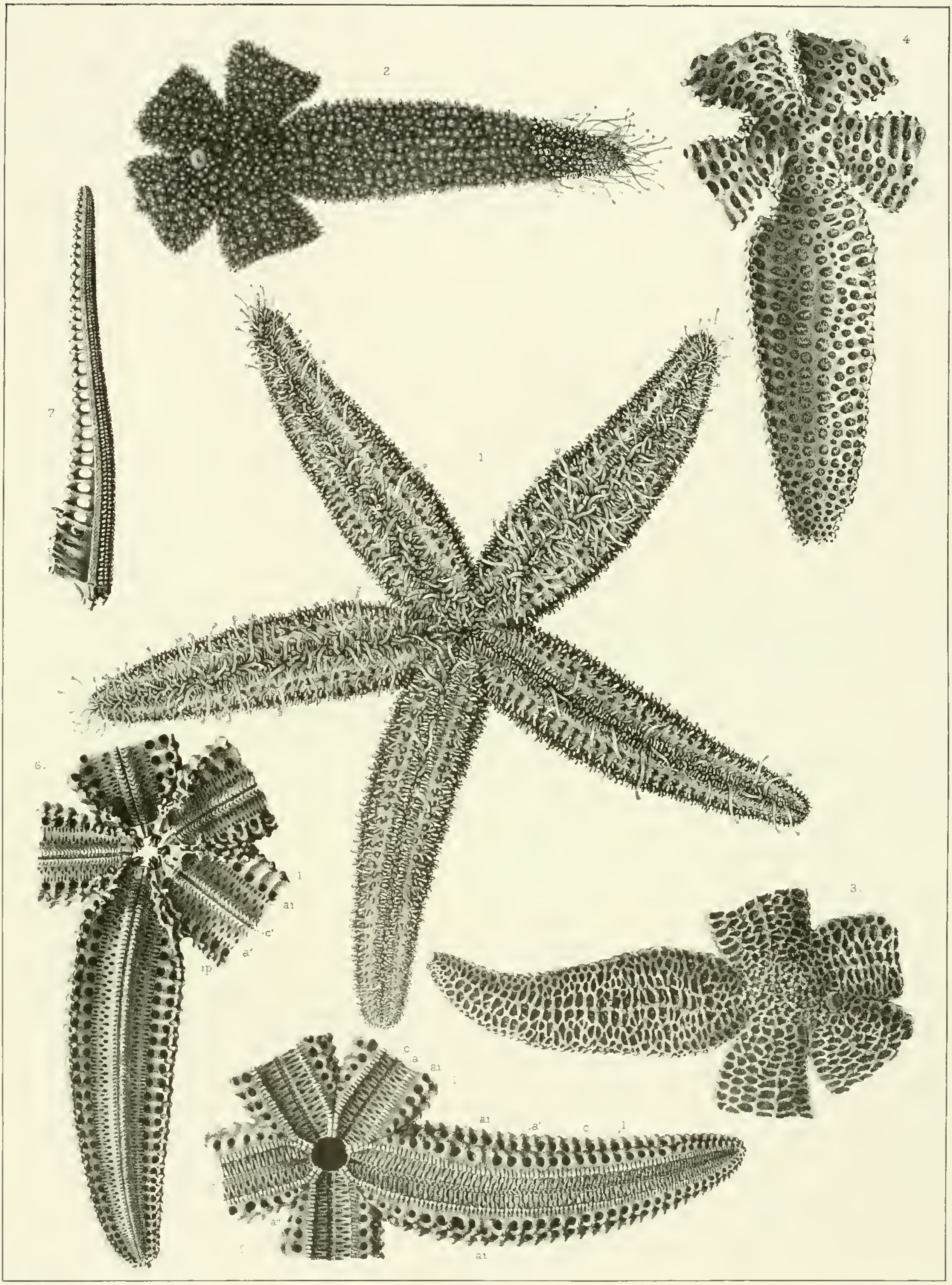

A Agassiz and B from nature

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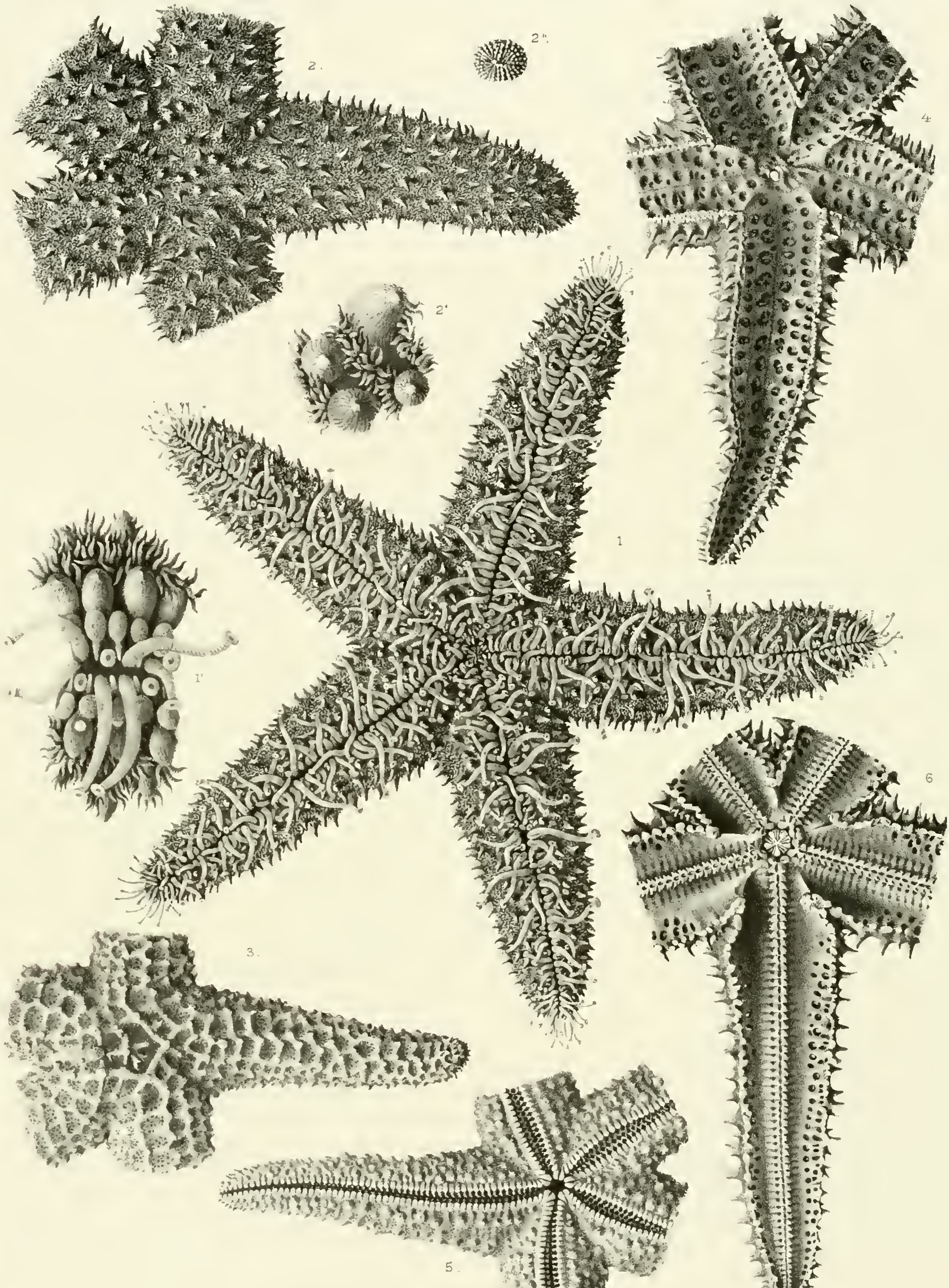
Astepacanthion berylinus Ag



A. Agassiz and Burkhardt from nat. Burrill on stone Print by A. Meisel

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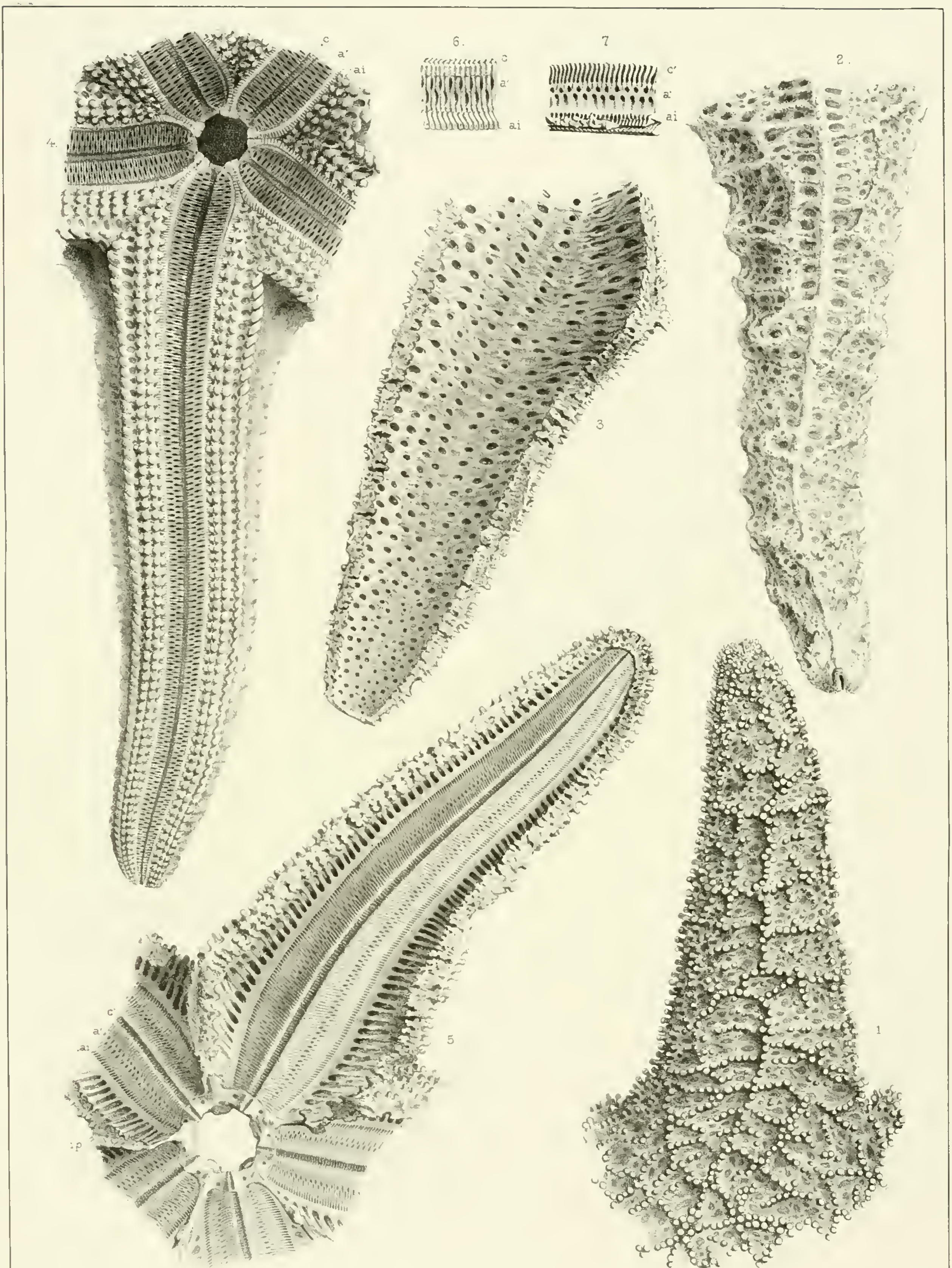
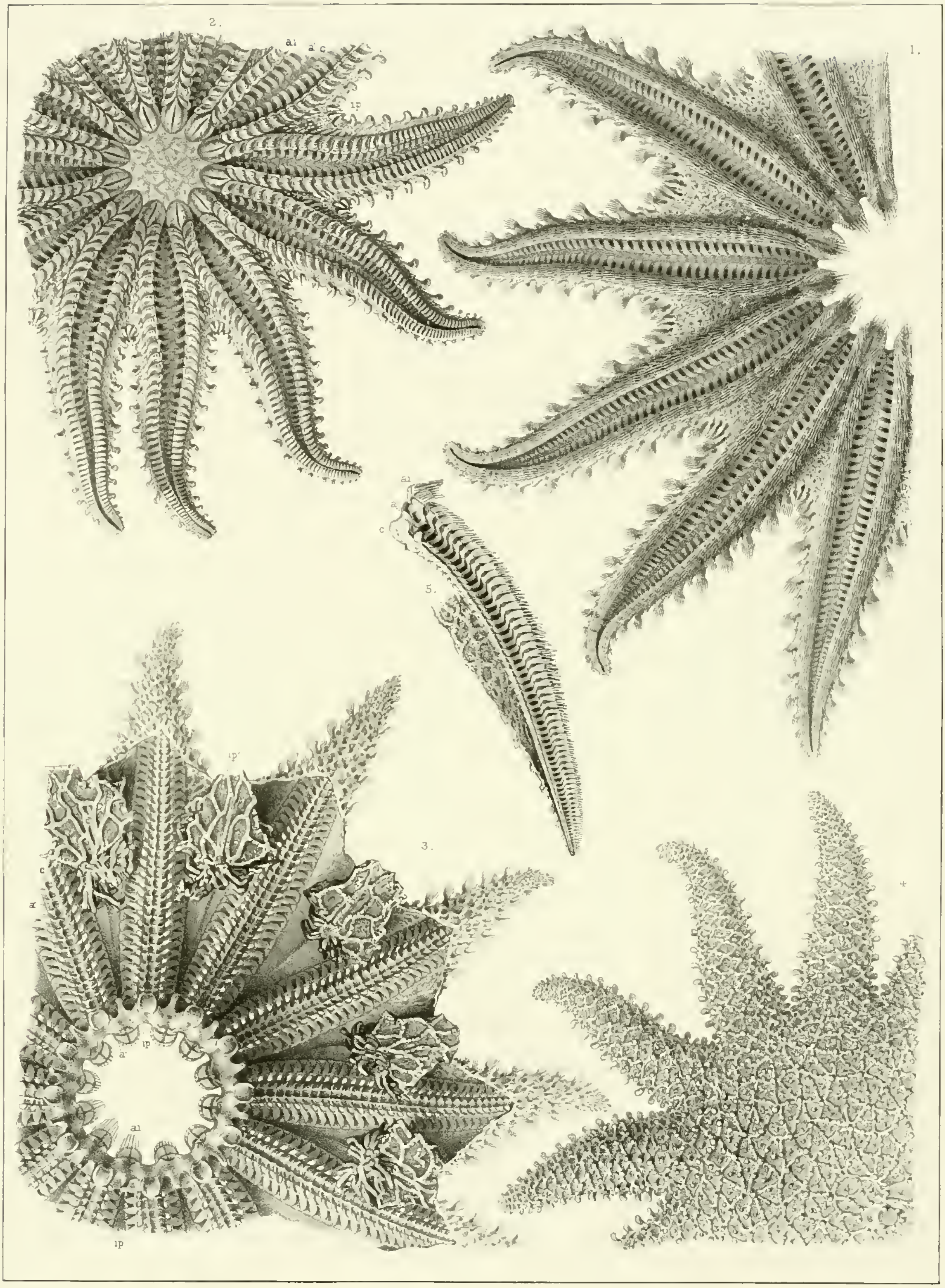


Burrill on stone

Print by A Meisel

Asterias ochracea Br



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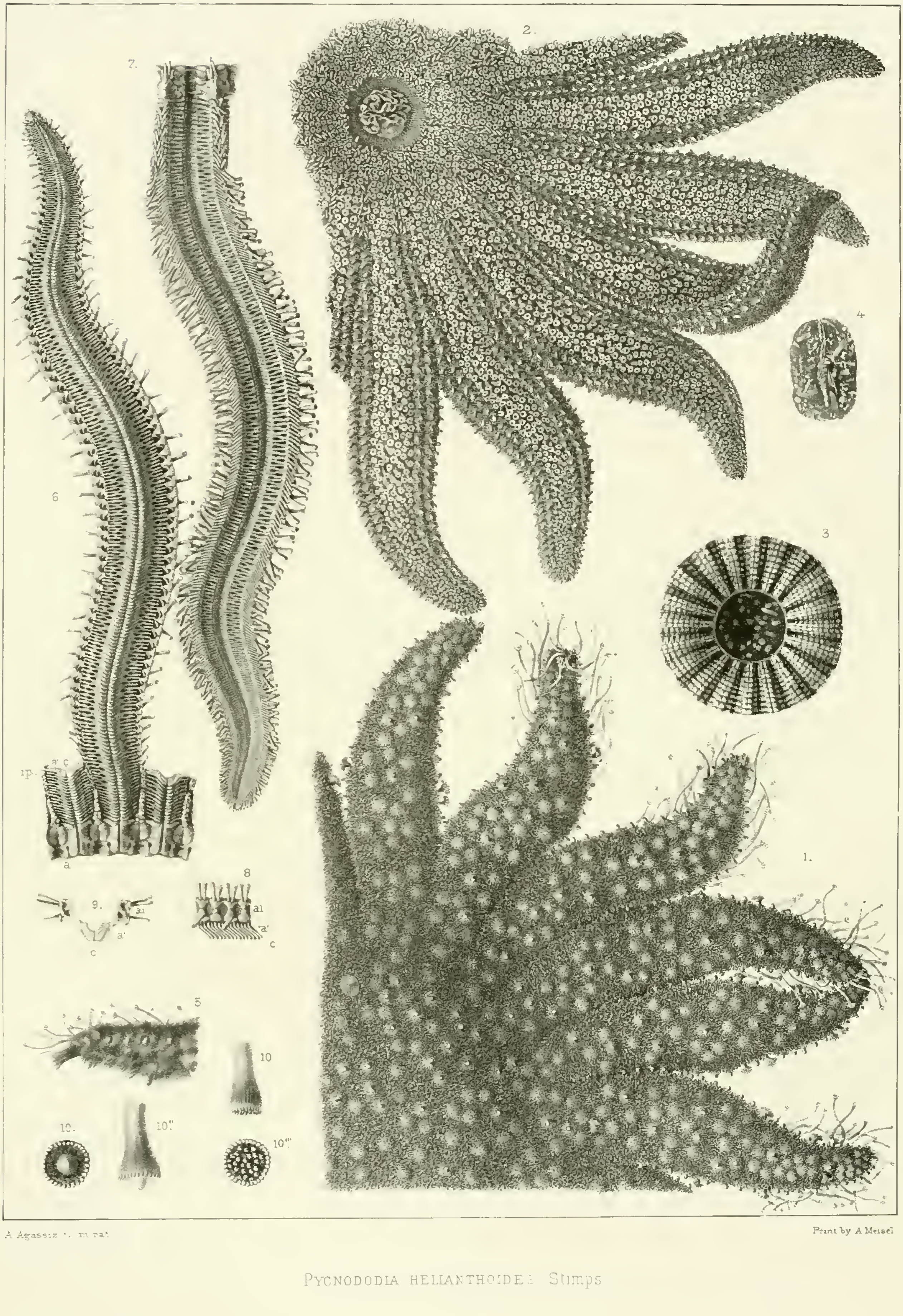

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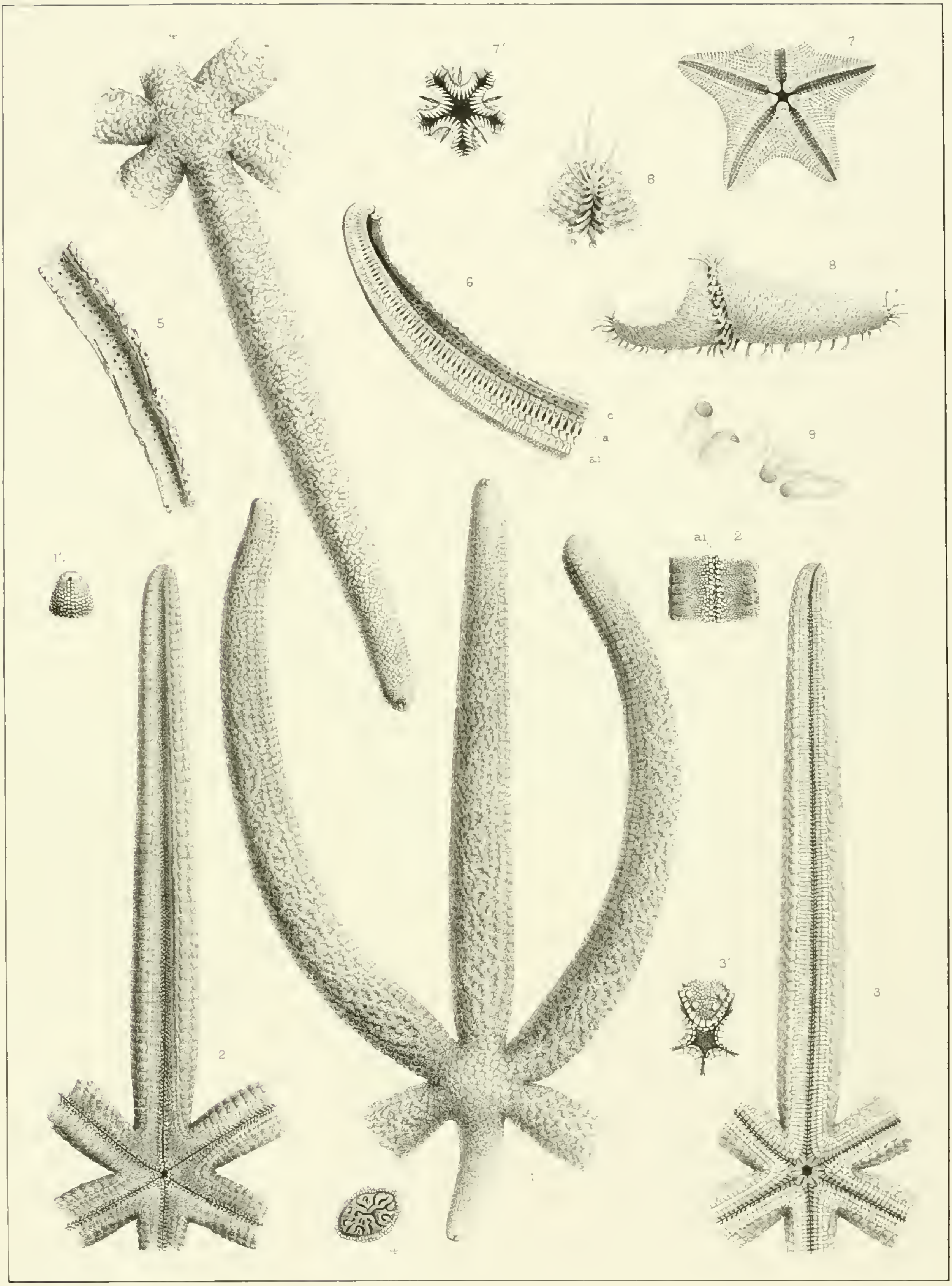
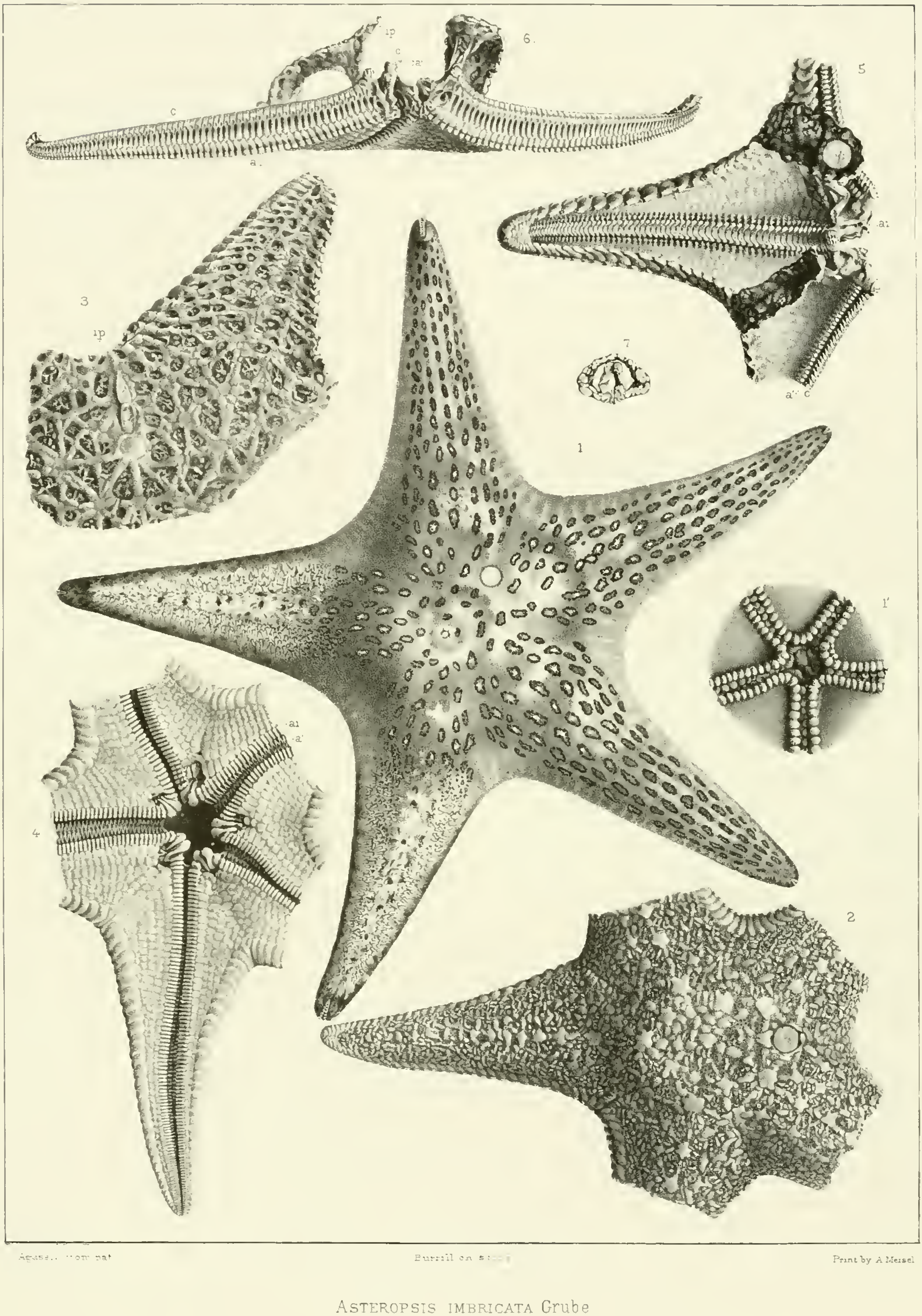
Print by A. Meisel

PYCNODODIA HELIANTHOIDES Stimps.



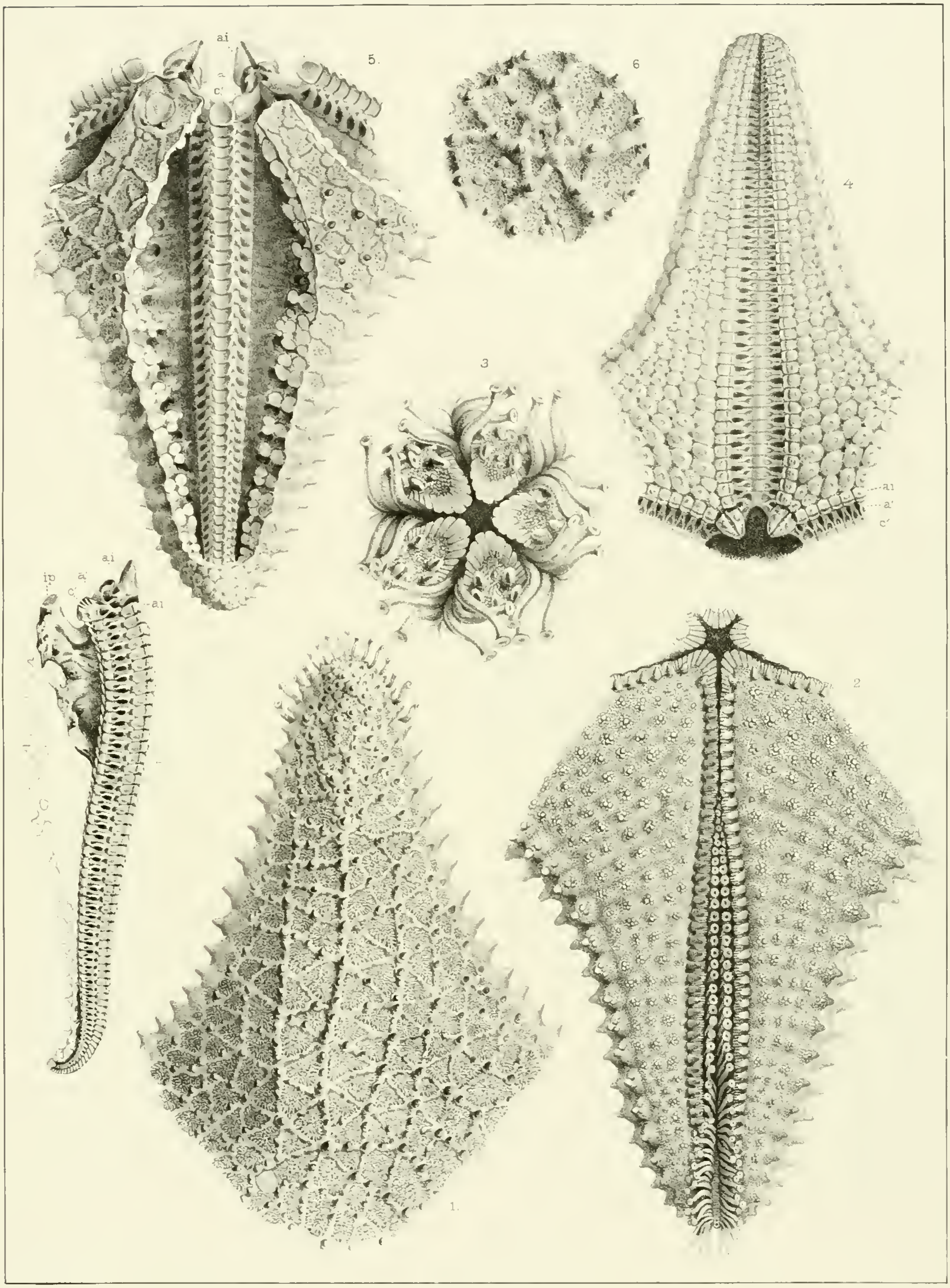
Agass… from nature   Print by A. Meisel

1-6 LINCKIA GUILDINGII Gray 7-9 ASTERINA FOLIUM Lutk



Agassiz, from nat. Burrill on stone Print by A Meisel

ASTEROPSIS IMBRICATA Grube



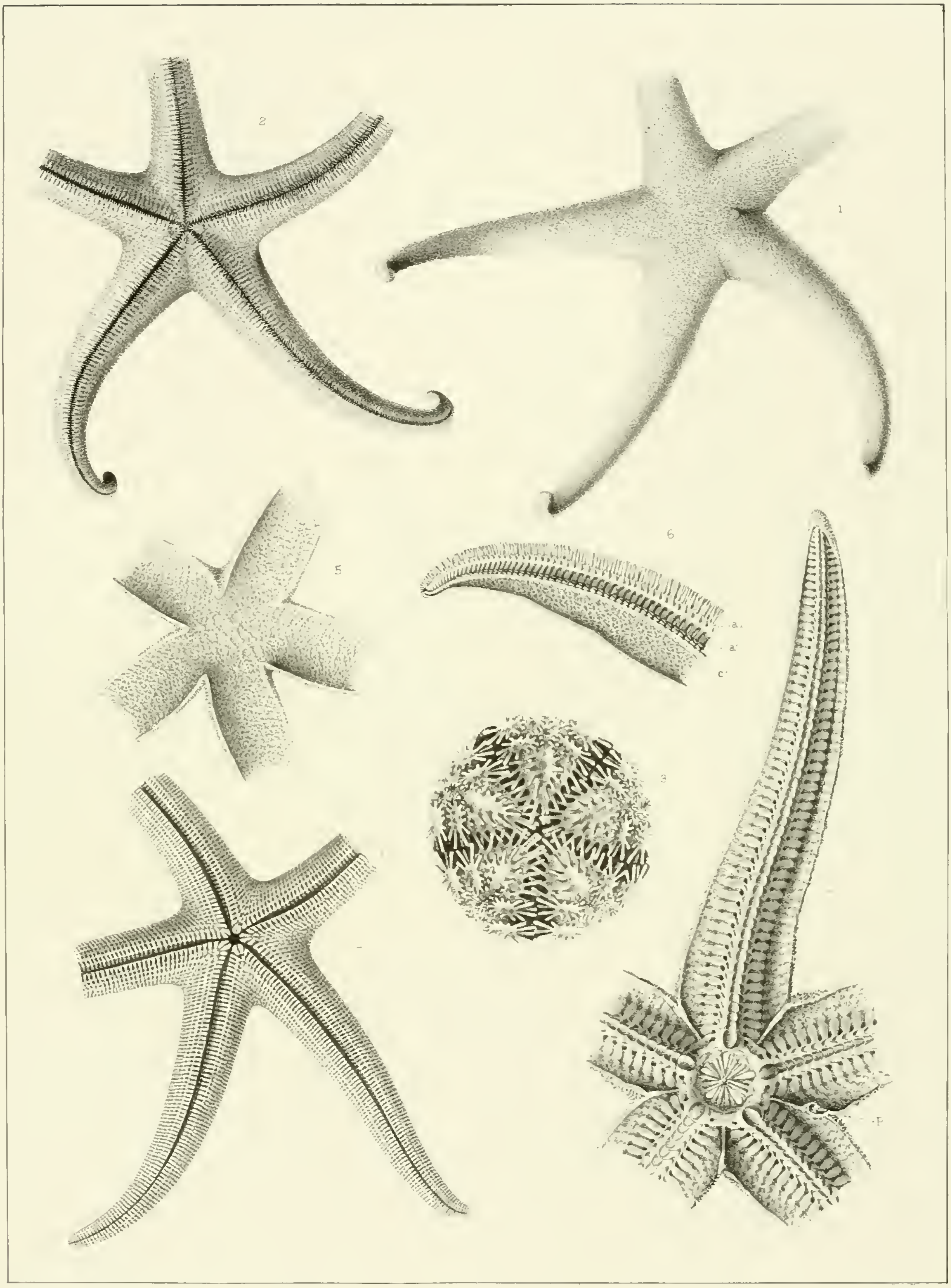
A Agassiz and Burkhardt from na.   Burrill on stone   Print by A Meisel

PENTACEROS RETICULATUS Link

Burrit, from nat. on stone

Print by A. Meisel

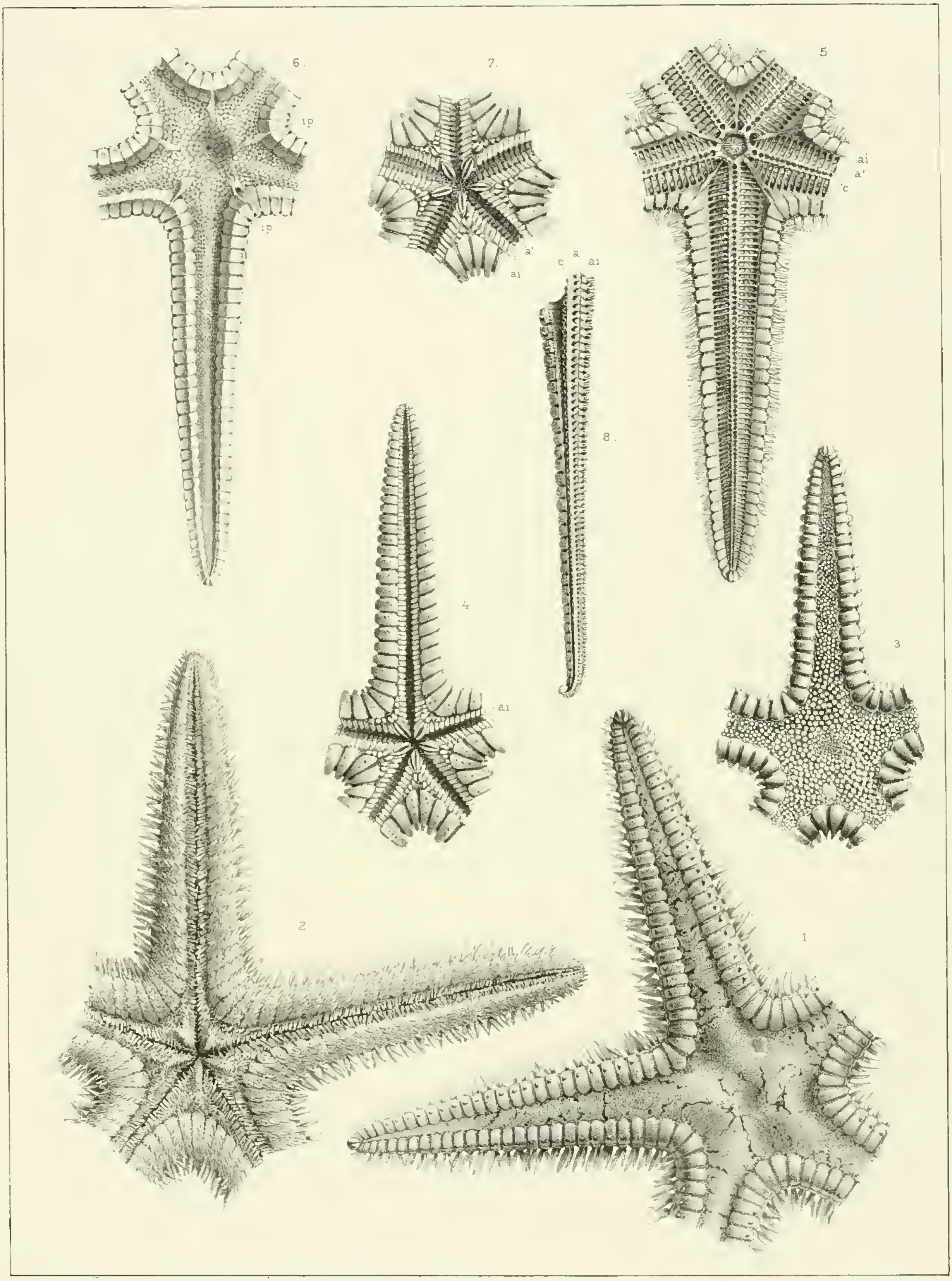
SOLASTER ENDECA Forbes.



A Agassiz and [illegible] from nature

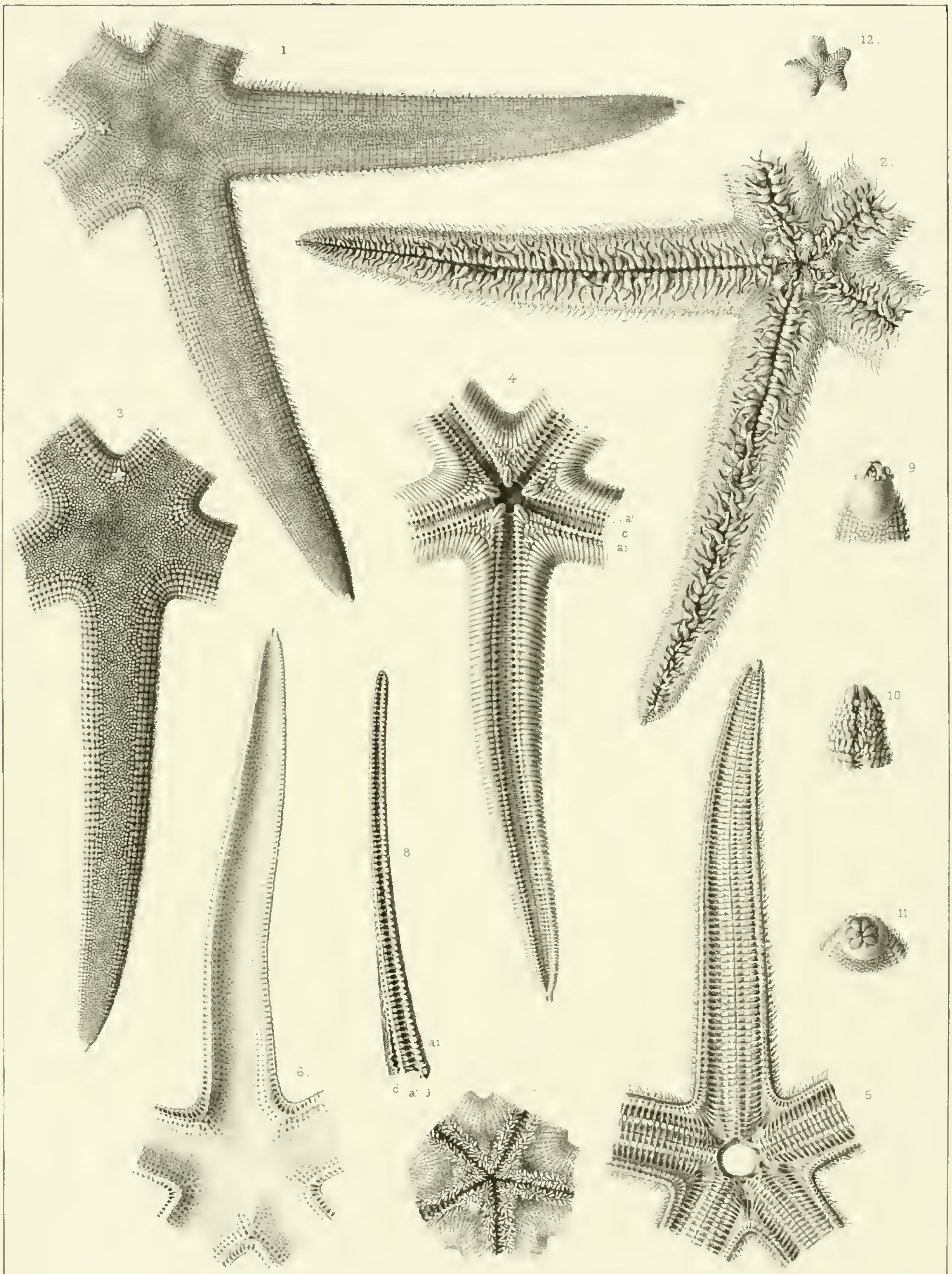
Print by A Meisel.

CRIBRELLA SANGUINOLENTA Lütk



Burrill on stone Print by A Meisel

ASTROPECTEN ARTICULATUS M T



A Agassiz and Burrill from nature

Print by A Meisel

Luidia clathrata Lutk