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ON THE
EARLY STAGES OF TEREBRATULINA SEPTENTRIONALIS.

BY EDWARD S. MORSE, PH.D.,
PROFESSOR OF COMPARATIVE ANATOMY AND ZOOLOGY IN BOWDOIN COLLEGE.

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II. ON THE EARLY STAGES OF TEREBRATULINA SEPTENTRIONALIS (Couthouy.)
By EDWARD S. MORSE.

Read October 20th, 1869.

THERE is hardly a group among the lower animals (if we consider the relatively small number of species represented by it) that has attracted the attention of so many naturalists as the Brachiopoda. The names of Cuvier, Owen, Vogt, Huxley, Hancock, Gratiolet, Lacaze-Duthiers, Bouchard-Chantreaux, Müller, Davidson, Carpenter, King, d'Orbigny and a host of others, are sufficient evidence of the interest felt in a group whose organization links them so closely with the past.

The desire to interpret through a knowledge of its living forms the many species which are now extinct, as well as to ascertain the relations it bears to the other divisions of the animal kingdom; the contemplation of a group whose maximum development in genera and species was attained in the Devonian age, though its representatives are strewn through the rocks of all ages since the dawn of life upon the globe; the remarkable fact that among the earliest forms of organic life known, are genera whose species can hardly be distinguished from present existing forms, all explain the attractions its study has afforded alike to Zoologists and Palæontologists.

The splendid memoirs upon the Brachiopoda by some of the authors just mentioned, more particularly those of Albany Hancock,¹ Vogt and Gratiolet, offer but little encouragement to one entering the field with the expectation of gleaning anything new. While, however, the anatomy and histology of the adult animal of several species has been carefully worked up, little or nothing has been done toward elucidating the embryology, or the early stages of the class. Fritz Müller² has given in a short note a description and two figures of what he considers an early stage of a species of *Discina*, and Lacaze-Duthiers³ has made some extremely interesting observations on the embryo of *Thecidium*. Aside from these two papers, we know of nothing whatsoever relating either to the embryology or the early stages of the Brachiopoda. The importance and necessity of some information regarding the embryology of these animals has been urged by many writers, for it was believed that the relations between them and the Polyzoa, as urged by Agassiz, Milne Edwards, Huxley, Hancock, Dana and others, would be verified, when the development of Brachiopoda was known. In this path of inquiry the investigator will find an open field.

For a long time I have been interested in the relations of the class under consideration,

¹ On the organization of the Brachiopoda. Philosophical Transactions of the Royal Society, London, 1858, vol. CXLVIII, part 2.

² Archiv für Anatomie Reichart et Du Bois Raymond, 1860, p. 72.

³ Histoire de la Thecidie. Annales des Sciences Nat. 4th series, tome xv, p. 262.

and in an early paper entitled "Hæmal and Neural regions of Brachiopoda,"¹ and later, in a paper on the "Classification of Mollusca, based on the principle of Cephalization,"² urged the intimate relations existing between the Brachiopoda and Polyzoa. With the hopes of learning something about the early stages of one of our native species of Brachiopods, I visited Eastport, Maine, in the early part of June, 1869, and this communication embraces a summary of the incomplete observations there made; incomplete, as I was unable to secure any data on the embryology of the species. At the outset my microscope proved altogether inadequate to the work before me, though the minute size of the objects examined, coupled with the complicated texture of the shell through which the soft parts had to be observed, rendered the work, at the best, laborious and difficult. In every case, however, the figures given in the accompanying plates are correct transcripts of the drawings made from the animal: in no instance is there given any combination of several unfinished sketches to make a more intelligible, or perfect whole. This will explain the absence of detail and completeness in many of the figures presented; at the same time it is believed that the outlines will be more valuable from the fact that they are not schematic or composite.

For a clear exposition of the organization of the Brachiopoda, I would refer to the exhaustive memoir of Albany Hancock above referred to, a memoir which justly merited the honor conferred upon him in the award of the Royal medal.

*On the early stages of Terebratulina septentrionalis Couthouy.*³ The specimens upon which the following examinations were made, were dredged in fifteen fathoms of water in the harbor of Eastport, Maine, in the first week of June, 1869. The species occur in great numbers, at various depths, and have also been collected at low tide mark, by Dr. Stimpson and Prof. Verrill. The specimens were found attached to stones brought up in the dredge, and also adhering to the lower valve of adult individuals, generally near the peduncle. An examination of adult individuals showed that while the ovaries in some specimens were empty, in others they were fully charged; in some the ovaries would be partially empty, in others the ovaries of one side would be nearly empty, while those of the other side would be quite full. Specimens collected by Prof. Verrill in August, were found with eggs; and eggs were also noticed in specimens less than three sixteenths of an inch in length. The eggs, fig. 1, were generally kidney-shaped, though very irregular as to form and size; they were spermaceti white in color, and opaque, though having a central area, translucent, and apparently depressed. In general outline they suggest the kidney-shaped eggs of *Fredericella*. No intermediate stage was observed between the ovarian egg and the stage represented in fig. 2. This form recalled the general proportions of *Argiope* and *Megerlia*, in being transversely oval, in having the hinge margin wide and straight, and in the presence of a proportionately wide foramen. This stage was exceedingly minute, and only two individuals were discovered; they were attached to the rock, resting on the broad hinge area; nothing could be traced of the structure, except an appearance of granular contents, as indicated in the figure; the shell showed nothing of

¹Proceedings Boston Society Natural History, vol. ix. 1862.

²Proceedings Essex Institute, Salem, vol. ix, part 6 1865. Also reprinted in American Journal Science and Arts, vol. XLII, no. 124. 1866.

³A brief resumé of this paper was published in the Amer-

ican Naturalist, Sept. no., vol. III, 1869. Since reprinted in American Journal of Science and Arts for Jan., 1870.

The general results were communicated at the 18th Annual Meeting of the American Association for the Advancement of Science, Aug., 1869.

the scale-like structure so characteristic in later stages. Between this stage and the next, fig. 3, the shell rapidly elongates, while the hinge margin remains nearly the same in width; this is also shown in the concentric lines of growth seen faintly on the surface, indicating a rapid increase in the length of the shell, while no corresponding increase takes place in the widening of the hinge margin. The peduncle is longer than the shell, having distinct walls apparently enclosing a clear interspace, the end slightly dilating and forming a pear-shaped adhering disk. The structure of the shell, of which more will be said in subsequent pages, showed clearly the scale-like structure, with the cæcal tubules of the pallial lobes perforating it. The anterior margin of the pallial lobes gave rise to seven setæ of variable lengths, all of them projecting forward. These setæ, in nearly all instances, were clothed with desmids, and were probably available in attracting sustenance to the animal; they resembled in structure the setæ of the adult, as figured by Hancock, and the longest of them was as long as the shell. The future position of the calcareous loop was indicated by a strongly arched process midway the length of the shell, from which sprang six short and stout cirri, all of them curving towards the mouth, which occupied the centre of the base from which the cirri sprang. The digestive sac hung from the mouth, and was twice as long as broad, having a strong constriction in the centre, forming two chambers, the lowermost one being globular in shape, and having its walls colored a light reddish-brown, this colored portion evidently indicating hepatic cells. The cavity next the mouth indicates the stomach, while the lowermost cavity indicates the future intestine, or cul de sac. The cirri moved frequently, and in various directions, though generally performing a grasping motion, as if securing some bit of food, imitating precisely the movement of the cirri in Polyzoa, and this resemblance was more complete from the fact that the tentacles were densely clothed with cilia (fig. 4), and their movements caused visible currents in the water. The two cavities of the digestive sac were also ciliated, and little pellets of food were seen rapidly circulating back and forth from one cavity to the other. The cavities were alternately dilating and contracting, and assumed the forms represented in figs. 5, 6 and 7. At this stage the lower cavity of the digestive sac was diverted to the larger valve, as represented in fig. 4.

In this stage, and several succeeding stages, the outline of the shell is remarkably like that of *Lingula*, and this resemblance is more striking from the proportionately long peduncle.

In another stage, numerous irregular shaped calcareous spiculæ lined the outer margin of the cirri, while the future position of the calcareous loop, or crura, was indicated by a row of irregular shaped spiculæ, the correct forms of which are given in fig. 15.

Fig. 16 represents portions of two cirri more highly magnified, in which correct outlines are given of the spiculæ. It is to the presence of these calcareous particles that we must account for a certain rigidity noticed in the texture of the cirri. In these slightly advanced stages, the peduncle becomes much shorter in proportion to the length of the shell, though the shell presents the same lingula-like form, differing, however, from *Lingula* in the much greater length of the neural valve, which is always perforated and rostrated from the outset.

In all these stages the peduncle has very slight adhesion to the rock, or whatever substance it may be attached to, in this respect differing greatly from the adult, which often requires great force to detach it, frequently leaving the peduncle separated from the body, and adhering to the rock.

In figs. 8 and 9 are given side views of the shell at this period. The flatness of the valves will be observed, again resembling *Lingula* in this respect; the under valve is much flatter than the upper one. I was fortunate in observing an individual at this age in motion. The animal whirled quickly on its peduncle; when at rest the shells were always closed, and rested on the rock; from this position it turned slowly more than half way round, raising the body at the same time almost erect; this movement being completed, the valves would very slowly open, and the cirri expand as if to perform a grasping motion; in no case, however, were they projected beyond the margin of the valves. The cilia lining the cirri produced gentle currents in the water. In this position, with the valves widely open and cirri expanded, the animal would remain motionless for twenty or thirty seconds, and then, with an abrupt closing of the valves, suddenly assume its first position. These two positions are represented in fig. 10, where the animal is seen from the side, and in fig. 11, where it is seen from above. The outline marked A represents the shells closed and at rest, while B represents the shells open; the line of arrows indicates the direction of the rotatory movement.

In watching these motions for a long time, one could not help being impressed with the fact that caution was evidently indicated in the slow and careful movements made in elevating and opening the shell, while the prompt closing of the valves, and the alert manner in which the animal regained its first position seemed to show that food had been secured, and further caution was unnecessary.

In another stage, fig. 12, the tentacles were seen of various lengths, some of them just budding from the lophophore. A fold upon each side of the stomach was first noticed; these folds are the first appearance of the liver. At this time the hepatic folds expand and contract independently of each other (fig. 14).

In fig. 13 another view of the same individual is given, where the upper portion of the digestive sac, or that portion which answers to the œsophagus and stomach, is in a contracted state, while the lower portion is widely expanded. A peculiar constriction appears at times between the two chambers of the digestive sac, which recalls the cardiac or œsophageal valve, as seen in the *Phylactolæmatous* Polyzoa; it has no coniform projection into the stomach, and really appears more distinctly as an annular dilatation. All traces of it disappeared during certain expansions and contractions of the gastric walls. All portions of the sac and the lateral folds were strongly ciliated, and the food, now gathered into round pellets, and again scattered in granules, was violently impelled back and forth.

In fig. 4, the cirri are shown, clothed with cilia; in fig. 12 the cirri are shown plain, while the cilia are shown lining the digestive sac. In fig. 15 only the calcareous spiculæ are shown; but in all these cases each possesses the characters of the others, which for clearness are shown singly.

Fig. 17 exhibits the only example where the soft parts are drawn from an alcoholic specimen. In this example is first seen a set of muscles, rendered visible by their contraction in alcohol, and consequent greater density. They are probably the divaricator muscles, though somewhat in advance of what their position would be in the adult state.

Owing to the contraction of the digestive sac, its diverticular cavities are sharply defined, and the globular appearance of the lower cavity is marked. In another alcoholic specimen of the same age, a band, evidently one of the lateral gastro-parietal bands, was

made out. As this could not be verified in other specimens of the same age, the figure is not given.

A still more advanced stage is shown in fig. 21. The shell is now becoming proportionately broader, and the cirri increase in number, though still forming a simple circle around the mouth. The crura have also begun to form.

In fig. 22 a considerably more advanced state is shown. The valves have been forcibly separated, and the smaller one is thrown back. The cirri are more numerous, numbering thirty-one; two of them are seen encroaching upon the circular lophophore, and at this stage the lophophore has begun to assume its hippocrepiian character.

The crura (*cr*) are plainly seen supporting the crown of cirri, and the liver already shows the first indications of its differentiations into the peculiar caecal ramifications which become so numerous in the adult; and at this stage is seen the division of each lateral portion of the liver into a dorsal and ventral lobe; a lateral lobe is shown in fig. 23. It will be seen that the liver is divided into a series of caeca, though these are united.

The divaricators (*d*) are completely formed, and between these two muscles is seen the lengthened intestine (*i*), the blind extremity of which is held firmly to the shell by a membrane, called by Hancock the ventral mesentery.

The appearance of the shell at this stage is represented in fig. 26. Radiating ribs, to the number of fifteen, ornament the shell. It will be seen by this figure, that the setae correspond in growth and position to the radiating furrows, and this observation is also made by Hancock in his examination of the adult. A well defined concentric line seems to indicate the earlier lingula-shaped shell, and though no ribs appear in the earlier stages, they are defined upon this area afterward, and it would appear from this that the ribs are formed on the inner surface, and that the setae direct and induce the furrow. The lobes of the liver (*l*), and the peduncle (*p*) and peduncular capsule, are shown in this figure.

In fig. 24 a stage still more advanced is given; the valves are thrown back, disclosing the stomach and intestine suspended from the calcareous loop. The crura (*cr*) are well defined, and the ventral mesentery (*vm*) is more distinctly seen in this figure. Two lateral bands are seen holding the stomach in position; and these appear to be attached to the crura, though they probably pass by them, and become attached to the hæmal valve. These are the lateral gastro-parietal bands first described by Huxley.

The walls of the blind intestine are yet light brownish in color, as in the *Phylactolæmata*, and, as before remarked, are hepatic. A kidney-shaped area is faintly defined on the neural valve. A portion of this outline indicates the point of attachment of the perivisceral wall.

In fig. 24a an enlarged view of the digestive sac and adjacent parts of fig. 24 is shown. The liver in this stage communicates with the stomach by large openings on each side, and fine granules were seen rapidly circulating to and fro, from the liver to the stomach. The faeces, rolled into a spiral and pyriform shape, were constantly in motion by the action of the cilia lining the stomach. This mass was frequently urged toward the mouth before it was finally discharged. The passage of the faeces through the mouth was repeatedly witnessed; though after the careful investigations of Huxley, Hancock, Lacaze-Duthiers and Gratiolet, no further proof is needed of the absence of an anal outlet to the intestine of this, and allied species.

The experiments of Mr. Hancock, such as bursting the intestines under a compressor,

were performed on many living adult specimens, yet in no case was the slightest evidence of an anal outlet observed.

Fig. 25 represents a stage but slightly advanced from fig. 24. The cirri are more numerous, but still spring from a circular lophophore.

Fig. 27, plate II, represents a considerably advanced stage, in which the lophophore, before circular, has rapidly assumed its hippocrepian character; rapidly, — since forms nearly of the same size show no marked indications of change, for in one example we may have a circular lophophore, or one showing but slight indentation, while in another example, hardly differing in size, we have the lateral processes well advanced in development. It is possible that we may have here a feature observed by Fritz Müller in the young *Discina* described by him; he mentions the remarkable fact of having repeatedly captured free swimming young which had evidently advanced further in their development than the oldest of those which had already fixed themselves. It will be noticed that in this stage (fig. 27) the cirri stand erect upon the arms, that is pointing towards the anterior margin of the shell, and that the arms are not deflected. This stage of the lophophore vividly recalls the hippocrepian forms among the Polyzoa, such as *Plumatella*, *Cristatella*, *Lophopus* and others.

The liver now shows its adult characters in having its ramified cæca separated, and not adhering by their walls in one mass. In this early condition it resembles the liver of *Thecidium*, as described and figured by Lacaze-Duthiers.

Fig. 28 represents a stage where the arms become deflected; as yet no central process of the lophophore is developed; the mouth is very large, and that margin of it not bearing cirri is very pliant in its movements.

In the next stage (fig. 29) the arms are more deflected and make a sharper curve in their approach together, and the central process of the lophophore is indicated by that portion forming the base of the inner curve, developing into two prominences. The free lip is seen in irregular curves, and these changed with every movement of the parts.

Fig. 30 represents a slightly more advanced stage, where the central processes of the lophophore are more developed. The free lip is here seen thrown broadly back, disclosing a capacious mouth, within which are seen two blunt projections, though in another view of the mouth (fig. 31) only one projection was observed. The free lip seemed to perform all the functions pertaining to the epistome in the higher Polyzoa, and we find it on the inner bend of the arms, as in the Polyzoa, though not occupying the same homological position in regard to the flexure of the intestine. It will be noticed that in all these stages the cirri are comparatively thick.

In the stage represented by fig. 32, the cirri become more attenuated and increase rapidly in number; the central process is more advanced, though not yet thrown into a vertical spiral, as in the adult, and the mouth has lost the broad reflected character of the lip, which it possessed in the earlier stages, though the free lip has yet considerable pliancy, as seen in figs. 33 and 34, where other views of the same mouth are presented. For the first time now appears another adult character, in the apparent decrease in the length of those cirri in the median line of the mouth.

In figs. 35, 36 and 37, different aspects of the mouth of an adult individual are shown; figs. 35 and 36 representing the outline of the mouth alone, while in fig. 37 the cirri are shown. In these three views the oral tubercle (*ot*), as it may be called, is strongly

marked. The same projection is represented in the mouth of *Thecidium Mediterraneum*, as figured by Lacaze-Duthiers. A singular lunate groove, running parallel with the free lip, is indicated in the figures, which may be called the oral groove (*og*). It seems more like a wrinkle caused by the expansion of the free lip, though its limits are well defined and the furrow is quite deep.

The independent movements of the cirri are shown in fig. 37; these are just as pliant in their movements as in those of the extreme young, and at all times recall the motions of the cirri in the Polyzoa.

Structure of the Shell. In the younger stages of the shell the peculiar scale-like structure may be studied to the best advantage. The scales are few in number, but slightly overlapping, and form a layer quite distinct from the outer layer, which appears to be homogeneous, save the concentric lines of growth appearing like rows of oblong and flattened nodules. The terminal portions of the pallial cæca within or upon this outer layer, are brown in color and distinctly granulated. I failed to make out anything satisfactory regarding the character of these peculiar parts. In a few doubtful cases I thought I saw one or two tubules radiating from the terminal ends of the cæca, and in fig. 38, A, one observation is represented. It will be seen by this that the tubules radiate from the largest diameter of the cæca, and not from the periphery of the granulated disk, and this is in accordance with the admirable observations made by King.¹ The scales do not appear to encroach upon the walls of the cæca.

Fig. 38 shows a small fragment of the shell at an early stage; portions of five scales are here seen forming the inner layer of the shell. In the earlier stages, when they are large and few in number, the scales are flat; now and then showing a raised line caused by the encroachment of two superincumbent scales, between which the under scale is closely adjusted. This may be seen in fig. 39, and better in fig. 40, where the ends of the scales are broken, and show in section; also in fig. 41, where, in a later stage, they become more numerous; here the terminal ends of five scales are shown in juxtaposition.

In fig. 42 a portion of the anterior margin of one valve is shown. The newly formed scales are just indicated near the border, beyond which the outer layer projects.

Fig. 43 represents two scales from a stage still more advanced; here the numerous lines upon the scales indicate their closer aggregation. As the shell increases in age, the scales become more attenuated, and now the scale is diverted wherever it encounters a cæcal process, and forms a yoke or loop around it.

In fig. 15, plate 1, a few spiculæ at the base of the cirri mark the commencement of the calcareous loop. At a later stage the spiculæ increase rapidly in number, and finally anastomose, appearing as in fig. 44. The scales composing the base of the crura are acicular in shape, and run parallel with the crural axis. In adult specimens the scales of the crural supports resemble acicular crystals, and when boiled in a solution of caustic potash, glisten and separate, resembling the fibres of asbestos (fig. 47).

Fig. 46 represents the crural process of one side, taken from a specimen less than an eighth of an inch in length. It exhibits the first stages of the loop. The acicular scales are shown at the base, while the remaining portion is made up of scales similar to those

¹ Prof. W. King, on the Histology of the Test of the Academy, vol. xxiv, pt. xi, 1869.
Class Palliobranchiata. Transactions of the Royal Irish

composing the shell. From an extremely young specimen I observed these same peculiar acicular scales (fig. 45), and they probably indicate the presence of the crura.

Nothing of a satisfactory nature was made out regarding the structure of the shell in the earliest stage (fig. 2, plate I), though had the shell possessed the peculiar scale-like structure and cæcal perforations, they would have been visible.

Growth of the Shell. Figs. 18, 19 and 20, plate I, severally show portions of the hæmal valve, neural valve, and the valves connected, from an early lingula-form stage. In fig. 18, the hinge plate (*hp*) and the dental socket (*ds*) are well marked; in the earlier stages of their development the crura appear as slight projections. In fig. 19 the prominence of the so-called teeth of the shell (*te*) is given.

Fig. 20 represents the valves joined; the cæca are seen perforating the entire margin of the shell about the foramen, which is very wide and rudimentary.

On plate II a series of stages are given to show the gradual development of the crura, and parts surrounding the foramen. The upper line of figures in this series, marked N, represents the neural or ventral valve, and the lower line of figures, marked H, represents the hæmal or dorsal valve. In the youngest of these stages, figs. 48 and 49, a broad gap in the neural valve indicates the peduncular foramen. It will be seen that the shell is folded upon each side of the peduncular passage. These folds never meet in this species.

Figs. 50 and 51 show a slightly more advanced stage, the difference being mainly in the greater prominence of the crura.

In the next stage, figs. 52 and 53, the calcareous loop is well advanced, though not yet connected by a continuous shelly layer, though at all stages these portions are connected by a membrane charged with spiculæ. Figs. 54 and 55 represent similar portions of an adult shell for comparison. It will be seen that the neural process of the loop becomes connected, while the hæmal process does not become so connected, though in some specimens it closely approximates. The peduncular opening becomes more circular, and the cardinal process (*cp*), which does not appear in the earlier stages, is now present.

Figs. 56, 57 and 58 are added, to exhibit the relative outlines of the more prominent stages in the growth of the shell. Compare, also, fig. 2, plate I, where the shell is as long as it is broad, and the hinge margin represents the greatest transverse diameter of the animal. In fig. 56 the shell elongates, with the sides nearly parallel, and the peduncular opening wide and gaping. (The line accompanying the figures represents the natural size of the shell.) Fig. 57 represents a stage intermediate between the lingula form and the adult; the peduncular opening is more contracted, the sides of the shell are no longer parallel, though the hinge margin has nearly the same outline as in the first stage. Fig. 58 represents the adult shell. Here the outline assumes entirely different proportions, being nearly oval, while the hinge margin forms a sharp angle, and the foramen is quite circular.

Relations with the Polyzoa. The general affinities of the Brachiopoda with the Polyzoa, as indicated by Milne Edwards, Huxley, Hancock, Agassiz, Hyatt and others, are admitted by most zoologists.

In the preceding examinations of the early stages of *Terebratulina*, we have additional evidence of their relationship. In the evolution of the lophophore, from its circular character, surmounted by a few cirri, to that of the hippocrepian stage, we have suggested, first, the circular lophophore in the inferior, or Gymnolæmatous Polyzoa, and finally, the

bilateral lophophore of the superior, or Phylactolæmatous Polyzoa. The brachial fold, a delicate membrane bordering the lophophore, immediately within which the cirri spring, as seen in *Lingula* and *Discina*, may properly be compared to the calyx in the higher Polyzoa. Still later the presence of a distinct fold bordering the mouth, very pliant and active, may be compared as to function and position, with the epistome of the Polyzoa, though not occupying an homological position in regard to flexure of intestine. It would appear that the membranes suspending the stomach and intestine in the perivisceral cavity, have some relation to the funiculus in the Polyzoa. In *Paludicella* there are two flexible cords connecting the stomach and the endocyst, called by Allman the anterior and posterior funiculus, to which are attached respectively the ovary and testis. In *Lingula* and *Discina* we find the reproductive organs attached to bands, that connect the stomach and intestine to the perivisceral wall. In *Aleyonella* the ovary arises from the endocyst, and likewise in *Terebratulina* and allied genera we find the mantle, or endocyst, holding the reproductive organs.

The early appearance of the divaricator muscles in *Terebratulina* would justify Mr. Hyatt in his views, that these muscles represent the retractors of the Polyzoa.¹

The combination of the stomach and intestine in their early stages, with the presence of hepatic cells lining their inner walls, and the presence also of a cardiac valve or constriction, all recall similar parts in the higher Polyzoa.

That these relations may be carried farther, there is no reason to doubt. Fritz Müller has noted in an early stage of some species of *Discina* (though from observations I have made in *Lingula pyramidata*, the embryos examined by him are as likely to belong to this genus, as to *Discina*) several sets of setæ, which project from the body and are capable of locomotion. F. A. Smitt² has noticed in the development of *Lepralia Peachii*, a cluster of six bristles bent at their points, that from time to time were drawn in and again thrust out.

With propriety may also be suggested a certain parallelism between the leading groups of the Polyzoa and the Brachiopods. We have forms, like *Lepralia*, attached by one region of their shell, this shell being calcareous and exhibiting minute punctures, which have been compared to similar markings in certain Brachiopods. So among the latter group do we find forms attached, as in *Thecidium*, and some species of *Productus*; and generally the articulate Brachiopods might be compared to such forms as *Lepralia*, while on the other hand such genera as *Pedicellina*, with its long, pliant and muscular stalk, or *Loxosoma*, with a stalk highly retractile, may be compared to *Lingula*. The limits or intentions of this paper will not allow any considerations regarding the relations of the Brachiopods with the other groups of the animal kingdom. I have elsewhere³ expressed my belief that they are true articulates, having nearer affinities with the Vermes; and in view of the above relations of the Brachiopods with the Polyzoa, it is interesting to remark

¹ A. Hyatt. Observations on Polyzoa, suborder Phylactolæmata. Proceedings Essex Institute, vols. iv, v. Salem, Mass.

² Om Hafs-Bryozoernas utveckling och fettkroppar. Öfversigt af Kongl. Vetenskaps-Akademiens Förhandlingar. Stockholm, 1865.

³ The Brachiopoda, a revision of Annelida, American Journal Science, July, 1870. Reprinted in Annals and Magazine of Natural History, London, no. 33, vol. vi, 4th series.

that Leuckart has for a long time placed the Polyzoa with the Vermes, and in a new edition of the "Outlines of Comparative Anatomy,"¹ Prof. Carl Gegenbaur removes the Polyzoa from the Mollusca, and associates them with the Vermes.

EXPLANATION OF PLATES.

PLATE I.

- Fig. 1. A few eggs in their natural position, from pallial membrane of an adult individual.
 Fig. 2. Earliest stage noticed. This was attached to rock, resting upon broad hinge margin.
 Fig. 3. Another stage in which the body has rapidly lengthened, and the peduncle is equal in length to the remaining portion of the animal.
 Fig. 4. Stage in which a few cirri are developed with the œsophagus and stomach hanging below.
 Figs. 5, 6, 7. Œsophagus and stomach of last individual, showing different conditions of expansion and contraction of the parts.
 Figs. 8, 9. Partial lateral views of the shell of fig. 3.
 Fig. 10. Represents the animal at rest, and in action.
 Fig. 11. The same from above; the arrows indicating the direction of rotation.
 Fig. 12. A state more advanced, with the liver as a simple hepatic fold on each side of the stomach.
 Figs. 13, 14. Different states of contraction of incipient hepatic folds of fig. 12; and showing cardiac contraction in fig. 14, c.
 Fig. 15. Crown of cirri to show calcareous spiculæ. [For distinctness and to simplify the drawings, the cilia clothing the cirri are only shown in fig. 4, the simple outline of cirri in fig. 12 and the calcareous spiculæ in fig. 15. It will be understood, however, that each figure possesses all the characters of the others.]
 Fig. 16. Portions of two cirri highly magnified to show more plainly the form of spiculæ.
 Fig. 17. Alcoholic specimen in which divaricator muscles were visible owing to contraction of the parts in alcohol. This is the only figure drawn from a preserved specimen. All the others are from life.
 Fig. 18. A portion of hæmal valve.
 Fig. 19. A portion of neural valve.
 Fig. 20. The same portions before separation.
 Fig. 21. A slightly more advanced stage, showing crown of cirri.
 Fig. 22. A still more advanced stage, with hæmal valve forcibly thrown open, showing divaricator muscles with stomach between. The crown of cirri shows first indications of its bilobed character.
 Fig. 23. An hepatic mass from one side; at this stage showing the first forming of cæcal folds.
 Fig. 24. A stage more advanced; valves forcibly separated in which all the parts are plainly seen.
 Fig. 24, A. A highly magnified view of the stomach, hepatic folds, lateral bands, etc., of fig. 24. This figure shows a fæcal mass rolled in a spiral form, in the act of being discharged through the mouth. The line bordering the upper portion of the figure indicates the inferior margin of the crural process.
 Fig. 25. The hæmal valve with crown of cirri, etc.
 Fig. 26. A view of fig. 22 with the valves closed.

PLATE II.

- Fig. 27. A stage considerably more advanced than preceding ones, showing lophophore already bilobed, the cirri, however, not deflected. The cæcal lobules of liver few in number but separated. In fig. 23, plate I, the lobules are just indicated.
 Fig. 28. Showing lophophore, with cirri deflected. The stomach and blind intestine hanging below.
 Fig. 29. The arms of the lophophore more sharply bent; the central processes first indicated. The highly flexible lip is here seen in folds.

¹ Grundzüge der Vergleichenden Anatomie. Zweite ungearbeitete Auflage. Leipzig, 1870.

Fig. 30. A stage slightly more advanced than the preceding. The lip is seen thrown back, disclosing the capacious mouth.

Fig. 31. Another view of the same opening.

Fig. 32. A stage more advanced, in which the lophophore begins to assume the characters of the adult. The cirri are now more numerous and more attenuated, and the lip is not so widely reflected.

Figs. 33, 34. Showing the mouth of fig. 32 in different states of contraction.

Figs. 35, 36, 37. Views of the mouth of an adult individual, showing oral tubercle, and oral groove.

Fig. 38. Fragment of shell highly magnified, showing scales, tubules and outer layer, with lines of accretion indicated by rows of flattened, bead-like nodules.

Fig. 38, A. Exterior portion of tubule, showing radiating pores.

Fig. 39. Single scale.

Fig. 40. Single scale, broken across, and showing ridge in section.

Fig. 41. Five scales in position.

Fig. 42. Fragment of anterior portion of hæmal valve.

Fig. 43. Two scales from an adult specimen.

Fig. 44. Portion of crural process from early stage.

Fig. 45. Acicular scales from early stage.

Fig. 46. Right crural process, from early stage.

Fig. 47. Acicular scales from base of crural process of adult.

Figs. 48, 49, 50, 51, 52, 53. Portions of hæmal and neural valves of early stages showing development of crura.

Figs. 54, 55. Corresponding parts of adult, natural size.

Figs. 56, 57, 58. Outlines representing different stages from extreme young to adult, fig. 58 being natural size.

NOTE.—No means of measurement were at hand when the original studies were made. A line enclosed by a circle indicates the entire length of the shell from which the parts were drawn. Where the size is not indicated, it will be understood that the parts are from equally young stages, unless otherwise described in the explanation of plates.

EXPLANATION OF LETTERS ACCOMPANYING THE FIGURES.

<i>m</i> , mouth.	<i>t</i> , cirri.
<i>e</i> , epistome.	<i>g</i> , granules passing to and fro from liver to intestine.
<i>œ</i> , œsophagus.	<i>cr</i> , crura.
<i>s</i> , stomach.	<i>cl</i> , calcareous loop.
<i>c</i> , cardia.	<i>ex</i> , external shell layer, of a chitinous nature.
<i>i</i> , intestine.	<i>in</i> , internal shell layer, of calcareous scales.
<i>f</i> , fæces.	<i>œ</i> , pallial cæca.
<i>vm</i> , ventral mesentery.	<i>hp</i> , hinge plate.
<i>l</i> , liver.	<i>cp</i> , cardinal process.
<i>h</i> , hepatic cells.	<i>ds</i> , dental sockets.
<i>og</i> , oral groove.	<i>fo</i> , foramen.
<i>ot</i> , oral tubercle.	<i>te</i> , teeth of shell.
<i>d</i> , divaricator muscles.	<i>cs</i> , calcareous spiculæ.
<i>lb</i> , lateral gastro-parietal bands.	<i>cn</i> , notch for pallial cæca.
<i>p</i> , peduncle.	<i>h</i> , hæmal valve.
<i>pa</i> , point of attachment of peduncle.	<i>n</i> , neural valve.
<i>se</i> , setæ.	
<i>cm</i> , pallial cæcum.

EDW. S. MORSE ON THE EARLY STAGES OF TEREBRATULINA.

EMBRYOLOGY OF TEREBRATULINA.

BY EDWARD S. MORSE, Ph.D.,

PROFESSOR OF COMPARATIVE ANATOMY AND ZOOLOGY IN BOWDOIN COLLEGE.

From the Memoirs of the Boston Society of Natural History, Vol. II.

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VIII. EMBRYOLOGY OF TEREBRATULINA. BY EDWARD S. MORSE.

WITH the great impulse given to the study of Zoölogy through the labors of Charles Darwin, renewed effort has been made to work up the embryology of those forms which have rendered so little satisfaction from the study of their mature characters, and thus through the labors of European naturalists new light has been thrown upon the developmental history of Sagitta, Amphioxus, the Tunicates, and many other aberrant groups. And now while the embryology of nearly every prominent group has been more or less studied, and important relations revealed that would have otherwise been obscured, little or nothing has been done to throw any light on the embryology of the Brachiopods, a class represented by thousands of species in past times, and one of which we have the earliest records in the rocks.

This dark portion in the history of the Brachiopods seems all the more strange when we recall the many beautiful monographs of various genera of Brachiopods published since Cuvier's famous memoir, in the year 1802, on *Lingula*, and when it is remembered that a hundred and more species still exist in the seas at present. What little has been accomplished in this field, however, has shed great light on the natural affinities of the class, and it may be well briefly to recall what has already been done in order to make this portion of their history more complete.

To Oscar Schmidt is due the credit of giving the first figure of a larval Brachiopod. In the "*Zeitschrift für ges. Naturwissenschaften*," 1854, p. 325, he gives a description of the embryo of some species of *Terebratula* collected in the North Sea. Accompanying this description a simple figure was given. In this the embryo shows a deep constriction in the centre, the free or cephalic portion being wider than the posterior half, which is abruptly truncate at the end, and he infers, and rightly too, that at this end the embryo becomes attached. I add a brief translation of his description.

The embryos of the Norwegian *Terebratula* observed by me differ remarkably from the embryo *Lingula* as described by Owen. They resemble a *Euastrum* composed of unequal halves; the round end seems to be the anterior. The somewhat narrower hinder portion extends into two projections. In none of the ovaries examined by me — for in these were the embryos found — had the development gone farther. In the perfect ignorance in which we now are with regard to the development of *Terebratula*, every small contribution towards clearing up this question is acceptable.¹

¹ The allusion to the embryo *Lingula* of Owen has reference to Prof. Owen's memoir on the Anatomy of *Terebratulina*, forming the introduction to Davidson's *British Fossil Brachiopoda*, published by the Palæontological Society, London. On Plate 1. of the Introduction, Owen figures five eggs of *Lingula anatina*, which he supposes are impregnated

ova. In one egg he suggests the rudiments of a peduncle. The egg, as it escapes from the ovary by dehiscence, often presents the appearance figured by him, from the thin membrane still adhering to the egg after its rupture, and consequent separation, from the cluster.

To Lacaze-Duthiers, however, is due the credit of first presenting several stages in the embryology of a Brachiopod. In a memoir¹ upon the curious form *Thecidium*, from the Mediterranean, he figures the egg, as well as several subsequent stages in the early history of the embryo. These were found in a pouch attached to the cirri and contained within the pallial cavity. The embryo is first divided into two transverse segments, then into three, and finally into four segments. In one embryo he found two red ocular points upon the cephalic ring, in another four red eye spots occurred.

In one figure he represents the rings contracted upon each other, as will be seen to be the case with the embryo of *Terebratulina*. As before, I shall give the reader a condensed translation of the paper.

The youngest egg studied had already a somewhat pyriform and elongated shape. The most striking fact was the size of the cells composing it, and which themselves enclosed a great quantity of granules of relatively very large size. The cells no doubt were the result of segmentation, and the granules must have appeared during the first movements of embryonic activity, for the vitellus had only very minute granules.

In the next stage frequently seen after the preceding, and which I have observed in the same lot of young, the embryo divided into two lobes, the larger being always attached to the *suspensory filament*. In the embryo so divided by a circular furrow, perpendicular to the longer axis, the mass has a yellow tint, and is no longer composed of large cells, but is filled with yellow granulations much finer, and enclosed in smaller cells. In the smaller lobe a clearer space is seen, where the cells are filled with nearly colorless granules. On each side of the larger lobe also, and very near the transverse furrow, are two transparent spaces smaller than the preceding, but similar in other respects.

The larger lobe, attached, as stated, to the *suspensory filament*, is the anterior; the faces cannot yet be distinguished; but later it is possible to recognize the superior or inferior aspect.

The development, therefore, commences by the appearance of the two lobes, one the anterior, with two white spots, and the other with a single clear spot; later other spots with less coloring matter appear. Thus there appears near the point of attachment, on each side of the peduncle, a clear white spot, then the two lateral spots above referred to, grow longer and obliquely extend towards the centre of the lobe.

Between these two last spots, on the line of separation between the lobes, the colored granules accumulate and form these lobules, the median later extending toward the posterior lobe.

The posterior lobe itself does not increase in proportion to the rest of the embryonic mass, but the transparent spot begins to show what it will later become. It extends towards the place where the lobules commence, then it becomes depressed in the middle, and will form, in fact, a real depression. There is still a gap between this and the succeeding stage to be described. The two white lateral bands, near the separation of the lobes, are traces of the formation of a new lobe, for the anterior lobe divides into two by a transverse furrow, and these two anterior lobes always remain relatively very large, the posterior changing but little.

At the time when this division takes place, toward the point of attachment where two other little clear spots have been seen, a lobule rises, which forms the counterpart of the little primitive posterior lobe. Thus the embryo is composed of four portions, two large in the middle and two smaller at the ends.

If the embryo is examined on all sides, it is soon seen that the two poles of the ovoid embryo are bent towards each other on one side, as if the two anterior lobes were curved over towards the two posterior. The concave face may be considered as the inferior, and the convex, the dorsal aspect.

The insertion of the suspensory peduncle is on the dorsal side of the anterior extremity, on the back of the little anterior lobule, not far from the edge of the second lobe. This peduncle is cellular, and composed of very distinct elements, and easy to recognize. The embryo is, therefore, suspended by the back of the head.

The inferior side of the anterior lobule is flat and somewhat quadrilateral in the most developed embryo seen; near the middle is a sort of oval longitudinal slit, which appears to be the mouth, although I have never seen particles of coloring matter, which I have put into the surrounding liquid, penetrate this opening, but indeed the embryos are still too young to feed.

¹ Annales des Sci. Nat., 4^e Serie, Vol. xv., p. 317.

On the inferior side also of the lobule, somewhat deeply seated in the tissues, appear some red dots symmetrically placed on each side. These spots I believe to be eye spots; they are sometimes four in number, and sometimes only two. The presence of these spots and of the slit, lead me to consider this extremity as anterior.

The second, or large, anterior lobe is swollen behind, and nearly flat beneath. Its posterior edges run obliquely backward to form a very obtuse angle, hardly closed on the ventral side of the large posterior lobe, extending towards the angle made by the posterior lobule, which seems to be hollowed out with a wide depression.

The embryos, when the peduncle is broken, swim and whirl round by means of the cilia clothing the lobes. The anterior extremity moves forward always. The embryos are very contractile, so that, often on meeting an obstacle the longitudinal diameter becomes shorter than the transverse, the two extremities contracting towards each other. The cilia then stop and seem to disappear.

It has not been possible to carry the observations farther.

To sum up, then, on the inferior aspect one of the most advanced embryos shows four eye dots, as well as a distribution of the yellow material in the midst of the large anterior lobe, which reminds one much of the origin of the liver in the *Acephala* or *Gasteropoda*, and it is probable that the alimentary tract is hollowed out in the middle of these yellow granules, so that the secretory lobules of the liver of the adult *Thecidium* are foreshadowed in these series of little packets.

In the early summer of 1872 I was fortunate in tracing the embryology of *Terebratulina* so far as to carry the embryo to a form with three well marked and deeply constricted segments, and saw enough at that time to convince me that the embryo became attached by its caudal segment. These meagre results were published in *Silliman's Journal*.¹

Some interesting features, however, had been brought to light in studying the early stages of certain *Brachiopoda*, the most important of which were presented by Fritz Müller in a note published in *Reichert und Du Bois-Reymond's Archiv*, 1860, p. 72, and a subsequent note in *Wiegmann's Archiv*, 1861, p. 53. These notes referred to the early stages of a form supposed to be *Discina*, collected at Santa Catharina, Brazil. I subjoin the notices which were published in the *Annals and Magazine of Natural History*, 3d series, Vol. VI., p. 310.

"Dr. F. Müller has sent from Brazil the description of a larva belonging undoubtedly to a *Brachiopod*, which is the more interesting, as the *Brachiopoda* are the only *Mollusca* regarding the development of which we have no information.

"The larva in question is a small, perfectly orbicular, bivalve *Mollusk*. The two valves are similar, but unequal in size, the dorsal valve being the largest. At the place of the hinge a small oval plate is placed transversely between the two valves of the shell. The mantle is gaping all round. Five pairs of very stiff setæ, of which one is much stronger than the others, and curved backwards, project at the periphery. They originate in the mantle of the ventral half; at least this is the case with four of them. A series of finer setæ spring from the circumference of the mantle of the dorsal valve, and curve down upon the outside of the ventral valve. The animal, as well as the shell, would be divided into two symmetrical halves by a plane drawn vertically through the middle of the hinge. The body, which is furnished with an alimentary canal, two auditory capsules, and two eyes, fills the posterior half of the space between the valves. The anterior half is occupied by four pair of cylindrical arms, between which a rounded knob is situated. Behind the knob the mouth is perceptible.

"These four pair of arms are supported upon a common peduncle, at the extremity of which, therefore, the mouth is placed. The arms are covered with a very well developed ciliary coat, by the agency of which the little animal swims. The reproductive and circulatory organs are wanting.

"During natation the mouth is always directed forwards, which is in favor of the generally received opinion

¹ *Am. Jour. Science and Arts*, IV., 1872, 262.

as to the anterior and posterior regions in the Brachiopoda. It is, in fact, now evident that the Brachiopods are *depressed* animals, having an anterior or ventral, and a posterior or dorsal valve. MM. Agassiz and Vogt are therefore wrong in regarding them as *compressed* animals like the Lamellibranchiate Mollusks; that is to say, as animals having a right and left valve.

"The larva, moreover, can not only swim, but also creep. This latter mode of progression is effected by a sort of rotation of the ventral valve alternating to the right and left. In this movement the animal pushes by supporting itself principally upon the strongest of the bristles above mentioned."

In Wiegmann's Archiv, Dr. Müller communicates additional observations on the larval Discina, a notice of which follows from the Annals and Magazine of Natural History, 3d Series, Vol. VIII., p. 505.

"In the Annals for October, 1860, p. 310, we gave a short abstract of a description of the larva of a Brachiopod observed by Dr. F. Müller at Santa Catharina, on the coast of Brazil; he now adds some further details from repeated observations in the summers of 1859 and 1860. The larva appears to occur late in the summer, from February to April.

"When the little animals are placed in good-sized vessels with pure sea-water, they soon ascend slowly; the slightly gaping shells stand perpendicularly, the hinge-margin downward; close to the anterior margin the eight arms spread out horizontally like rays, with their tips slightly bent downwards; and the roundish knob situated between the uppermost pair projects beyond the plane of the arms. In this posture they move slowly about near the surface. When strongly shaken, or sometimes without any perceptible reason, they retract the arms and close the shells, which then slowly turn over and sink to the bottom with the free margin downwards. If the arms be again protruded, the hinge-margin also again turns downwards.

"The duration of this state never exceeded five to six days, and in general the larvæ adhered to the bottom or sides of the vessel in a still shorter time. When they adhered to the sides, the mouth was always directed downwards; the ventral shell was strongly drawn forward until its anterior margin reached or passed that of the dorsal shell; the transversely oval plate, previously concealed within the shells (the peduncle), was protruded, apparently twisting around the notched hinder margin of the ventral shell, so that its anterior margin became posterior. For a day or more the animal remains contracted and quiet; then, the shells being slightly opened, the arms are half extended, and strike inwards, one or more at a time, just as in the marine Bryozoa. In a few days new bristles appear at the anterior margin, in the space left between the more delicate setæ of the dorsal shell. In a week the author counted twenty of these, mostly belonging to the dorsal shell. The longest were 0.8 mill. in length, straight, colorless, 0.006 mill. in thickness at the base, terminating in a fine point, unjointed and distantly feathered with fine lateral setæ 0.02 mill. in length. The principal change in the soft parts consisted in the retrogression of the organs of sense. The eyes had become broken up into groups of about ten black points; the previously spherical auditory vesicles were shrunken into longish sacs, closely surrounding the otoliths. In somewhat older animals there was no trace of the organs of sense, although they had not lost their sensibility to light.

"One of the larvæ lived for a month after its adhesion; but from the lapse of a day before its death was noticed, the soft parts had become greatly decomposed. The older bristles of the free larvæ appeared to be still present, as also the plumose bristles of the anterior margin. Besides these, there were on each side, about in the middle between the median line and the origin of the great bristles of the fourth pair, straight, smooth bristles, 0.2 mill. in length, projecting obliquely backward, little thicker than the strong posterior setæ, but with a much stronger outline.

"It is remarkable that in two years the author has repeatedly captured free-swimming larvæ which had evidently advanced further in their development than the oldest of those which had already fixed themselves. They were all destitute of the transversely oval plate, and of every trace of organs of sense; the plumose setæ of the anterior margin were also wanting, as were, more or less entirely, the older bristles. Of the more delicate bent bristles, some were usually still present, and these appeared to be unabbreviated, so that the missing ones had probably been lost by shedding. The stronger bristles, on the contrary, are gradually absorbed at the base; at least this is the case with the fourth pair; these were repeatedly met with of about half their proper length; the stalk, with its fusiform dilatations, had disappeared, while the apex remained readily recognizable by its peculiar curvature and denticulation. In a still older animal about a fifth of the length was still present, so that it no longer extended beyond the margin of the shell. This animal (the oldest examined by the author) had lost all the older setæ, except the small residue. On the other hand, the two straight, smooth bristles, which in the oldest attached animals scarcely began to protrude from the shell,

had attained a length of double the diameter of the shell, and being inserted into thick muscular sheaths were strongly and rapidly moved by the animal, sometimes spread out horizontally, sometimes again crossed backwards.

"During this complete change of the setæ the soft parts had undergone no essential alterations. The roundish stomach, reaching from the front to the middle of the longitudinal diameter, still showed the two dark spots of the young larvæ, which remind one of the similar spots in the larvæ of some Bryozoa. From the back of the stomach sprang the intestine, which bends under the margin of the stomach to the right, and then forwards, terminating about the middle of its right side. The œsophagus goes from the front of the stomach straight forward half way to the front of the shell, and then bends downward, so that the mouth lies close to the stomach. The arms, especially the two middle pair, had become longer and slenderer, and the knob between the anterior pair had diminished in size. No vessels or pulsating heart were recognized. — Wiegmann's Archiv, p. 53, 1861."

In the year 1869 I communicated to the American Association for the Advancement of Science the results of a study of the early stages of *Terebratulina septentrionalis*, made at Eastport, Me., in the early part of that year. This was afterward published in the Memoirs of the Boston Society of Natural History, accompanied by two plates.

In this memoir I showed the incipient cirri, seven or eight in number, and the gradual development of the complicated arms, the unfolding of the hepatic cœca from two folds upon the walls of the digestive cavity, the character of the shell structure, etc. And these two papers comprised all that has yet been done as to the early stages of the class.

A wide gap, however, has existed between the free swimming Annelidan larva clothed with cilia and the attached form revealing its Brachiopodan character in the presence of a dorsal and ventral plate, and the presence of cirri. After repeated visits to Eastport, almost solely for this purpose, I have at last succeeded in closing this gap, and in this paper I hope to make plain the history of the development of the dorsal and ventral areas, the peduncular attachment, and the relations the different parts of the mature animal bear to the embryonic segments, as well as to present some new features in the early stages of the species.

For two seasons I have found *Terebratulina* spawning at Eastport during the last of May and the early part of June. It is probable that they spawn through the season, since I have found them depositing eggs in April. At my request Mr. Rathbun made several observations during the summer, to ascertain how long the species continues to ovulate, and he informs me that on the only dates he collected them, namely, June 26, July 12 and Aug. 29, they were freely discharging their eggs. It is best, however, to study them as early in the season as possible, as the water in which the eggs develop must be kept at a low temperature, and this essential condition can be most easily accomplished at Eastport in May, where the temperature at that time ranges from forty to sixty degrees Fahrenheit.

The manner in which I secured the eggs for study was simple enough. Several shallow glass dishes were prepared by painting the bottoms black. Having dredged a lot of specimens, I arranged them in a circle around the edges of the dish, with their anterior ends pointing toward the centre of the dish. By arranging the specimens in this manner the difference in the sexes becomes at once apparent.

The eggs are discharged from the anterior margin and drop just beyond the pallial membrane, hanging in clusters from the setæ, and covering the bottom of the dish in the immediate vicinity of the animal, presenting the appearance of a white powder, though with a simple lens the individual eggs are plainly seen. They are opaque and spermaceti white in

color. In the course of a few hours they become clothed with cilia, and while many of them slowly move away, some remain and perish, or, at least, show no sign of development. These are probably not fertilized.

The sexes are separate, and the spermatozoa are discharged by the males in the same way that the eggs are discharged by the female, but whether the eggs are fertilized after they have left the parent, or before, I was not able to determine, as different lots of eggs behaved differently after their escape. In some cases the eggs did not appear to be locomotive until two or three days after their discharge, while in other cases they became active on the day of their discharge.

Great care must be taken to change the water every day, since the water soon becomes vitiated, and *Paramæcia* rapidly develop and appear to feed upon the embryos. The temperature of the water must be kept as near as possible to that from which they were taken. In drawing and replacing the water a glass syphon was found the best, as in this way the embryos were not disturbed, though some skill was required during the active natatory condition of the embryos, to prevent them from leaving the dish also.

The development of the embryo presents a series of well defined stages, and I shall consider each stage in turn. In the first stage the embryo becomes widened at one end. The segments are barely indicated, the posterior end is the widest, the anterior portion is ornamented with a conspicuous tuft of long cilia, so peculiar to the embryos of many worms. The embryo is also clothed with vibratile cilia, and in this condition slowly moves along the bottom of the dish without rising from it, or remains quiet. In the second well marked stage the embryo is divided into two prominent segments, these expand and contract upon each other slightly, and the cephalic segment has the power of partially bending from side to side. In this stage the embryo is most active, swimming rapidly in every direction and turning abruptly about. The oesophagus also becomes dimly defined. In the third stage the peduncular segment is developed and projects from the posterior portion of what can now be called the thoracic segment. At this stage the embryo either remains immovable upon the bottom of the dish or slowly moves about. In two cases delicately barbed setæ to the number of thirty-five projected directly backward from the peduncular segment. In the fourth stage the embryo becomes attached by means of its peduncular segment. The embryo is still clothed with cilia, though the long pencil of cilia has disappeared. The head is closely drawn to the thoracic segment, which becomes wider in transverse diameter, so as nearly to hide the peduncle. In the fifth stage the thoracic ring commences to fold, or turn upward upon opposite surfaces of its circumference, so as to gradually enclose the head; one fold being made slightly in advance of the other represents the larger or ventral valve. In this stage appear clusters of barbed and deciduous setæ upon the anterior margin, and in a later portion of this stage the first hardened areas of the dorsal and ventral plates make their appearance, and the cirri appear as blunted papillæ about the mouth. In the sixth stage the shell becomes rounded, the peculiar scaled structure makes its appearance, and the formation of tubules perforating the shell, and permanent setæ takes place.

In another memoir I hope to present the characters of the genitalia of the Brachiopoda. I will state here, however, that the eggs not only fill the large pallial sinuses, but hang in clusters from the genital band; from these parts they escape by dehiscence, and float freely in the perivisceral cavity. The anterior perivisceral wall is sufficiently trans-

parent to allow one to watch the eggs as they are gradually drawn to the infundibuliform orifices of the oviducts, and to secure them as they escape by the external orifice of the oviduct. In parting the shells for this purpose great care must be taken not to open them too far, as the parietal wall will rupture, and from this opening the perivisceral fluid and eggs will escape. The eggs are not uniform either in shape or size, though a distinct granulated membrane, the ovishell, is formed while the egg is contained in the perivisceral cavity. Segmentation is next seen, first as a few indentations upon the periphery of the egg, until finally the whole egg presents a mass of cells, as shown in Fig. 11. The egg next assumes an oval shape, becomes ciliated, and in several eggs at this stage a dim opening extending to the centre midway between the opposite poles of the egg was seen—whether this was the micropyle or the scar from which the egg escaped from the ovisac I could not determine; gradually the egg becomes widened at one end, which is to be the base, or posterior pole of the embryo. A long pencil of cilia springs from the smaller anterior end, so characteristic of the Annelid embryo.

First Stage. From some of my drawings it would seem as if the peduncular ring consisted of the primary posterior pole of the egg, the thoracic ring widening and enclosing it. At all events the thoracic ring forms the widest portion of the embryo, directly in front of which a second fold makes its appearance. Whether this is an indication of another ring I could not make out; later, however, it merges into the base of what is to be the cephalic ring, and the deep constriction that is soon to follow occurs between this fold and the thoracic ring. An end view shows the thoracic ring slightly flattened while the cephalic ring preserves its circular outline. In this condition the embryo swims slowly about. This ends the first stage.

Second Stage. In this stage, and one that seemed of the longest duration, a matter of three or four days, the embryo is quite elongated, and is divided by a deep, transverse line into two unequal halves, the head segment being the smallest. At this stage it is the most active, no longer moving slowly along the bottom of the dish, or remaining motionless, but ceaselessly swimming in a rapid manner back and forth through the water, and abruptly turning about; the segments expanding and contracting upon each other, and the head bending from side to side, the thoracic segment often being transversely wrinkled by this bending. A peculiarity of the embryo at this stage consists in the various external outlines assumed by the embryo, presenting also different proportions, as shown in Figs. 18, 19, 20 and 21, drawn from the same embryo. The first definite trace of internal structure now occurs in the formation of the alimentary tract, appearing as a long, narrow tract running from the thoracic to the cephalic ring, closed posteriorly, but blending with the cell contents of the cephalic segment. A clear interspace is also seen at the anterior portion of the thoracic ring. What appeared to be an opening in the posterior end of the embryo was seen in some cases.

During all these stages, from the egg upward, great difficulty arises in making out any feature of internal structure, owing not only to the minute size of the objects, but to their opacity, and what little has been made out has in most cases been done by slightly compressing the embryo.

During this active swimming stage in some embryos is seen a structure that appears to be the incipient peduncular segment. In Plate VIII., Fig. 25, and Plate IX., Fig. 78, a rounded process is seen protruding from the thoracic segment, the walls of which extend as far as

the division between the two segments. The alimentary tract is seen here, its anterior portion blending with the cell contents of the cephalic ring, while posteriorly it hangs in the cavity supposed to be the incipient peduncular segment. Whether this is the proper interpretation I cannot say, and the difficulty arises from the fact that in some embryos farther advanced this structure does not appear. Thus in Fig. 83, Plate ix., an embryo is shown in which no sign of the peduncle appears, and yet it seems in advance of the one just described, in showing the widening of the thoracic ring, one side of which shows a bulging which represents the future ventral fold. An irregular cavity is thus left by the bulging of the external wall, and in this cavity at a later stage I have seen the circulation of minute granules. Within this cavity is another cavity bordered by thick walls which hang from the suture dividing the two segments. The alimentary tract is seen suspended between the two segments, and showing a faint connection with this cavity. The cephalic segment shows no change in its granular contents save the presence of the alimentary tract. The parts surrounding this tract are continually contracting in a spasmodic way, though no trace of a muscular band could be detected. The interpretation of these cavities has perplexed me exceedingly. The most reasonable supposition is that the outside cavity in the thoracic ring marked *pl.* represents the cavity from which the pallial sinuses are to arise; in this cavity I observed the circulation of minute granules, as before stated. The cavity within surrounded by thick walls is the peduncular cavity, and a faint interspace running from the upper part of this cavity to the base of the digestive tract appears to be the opening up of the peduncular cavity into the cephalic segment, a cavity in which the stomach is afterwards to be suspended, and this may be called the perivisceral cavity. In *Lingula* and *Discina* the peduncular and perivisceral cavities are in open communication. In *Discina* the large azygos opening is very apparent. Future study will undoubtedly modify the interpretation of these cavities, and possibly show it to be altogether wrong.

In the hundreds of embryos examined, a few only were of sufficient transparency to reveal any structure within, and from this stage onward, the difficulty in this respect increases, as the embryo becomes more opaque, and with the after formation of the dorsal and ventral plates, combined with their minute size, render the study of their internal structure almost hopeless. Plate ix., Fig. 86, represents the peduncular portion just ready to protrude.

Third Stage. In this stage the peduncular segment has made its appearance as a rounded knob, varying in size in different embryos. Soon after the appearance of the peduncle, granules are seen gathering about its end, apparently adhering to the mucus secreted by it. Soon afterward adhesion takes place, the embryo remaining fixed when the water is disturbed, though even before the embryo becomes attached, the bulging of the thoracic ring becomes more conspicuous, leaving a clear cavity within. The walls of this bulging portion present a number of highly refractive granules scattered evenly over its surface. This portion first loses its cilia (Plate ix., Fig. 87) just before attachment; the embryo becomes sluggish, or at least, in most cases, ceases to swim actively. In two cases a cluster of delicately barbed setæ, to the number of thirty-five, was seen to project directly backward from the posterior end (Plate ix., Fig. 79). That these were very transient is evident from the fact that they were only observed in two cases out of three hundred and fifty-two different embryos examined. The head continues to move freely, and shows a slight fold at its base. As the head contracts, the thoracic ring widens; this is shown in Plate I., Figs. 42, 43, where the same is sketched with the segments extended and

contracted. In many embryos the thoracic ring presents an indentation on one side, as if the ring were a band partially uniting at this place. The peduncle gradually widens at the end into a sucking disk, and at this time the embryo becomes permanently attached.

Fourth Stage. The embryo now settles down upon its base of attachment, the thoracic segment widening and flattening, and appearing pressed to its point of support, so as to conceal the peduncle. The head is closely pressed to the thoracic segment, the clear space within having disappeared, and the head only appearing ciliated. And now commences the most important portion of the developmental history, in which, for the first time, we become acquainted with the development of the dorsal and ventral plates.

Fifth Stage. The thoracic segment commences to fold upon both sides of the head, and these are the dorsal and ventral folds. Gradually the head is enclosed by the folds. In this portion of their history I was peculiarly fortunate in securing hundreds of examples just after they had become attached to adult Terebratulina. These I studied in their natural positions. In some cases the Terebratulina had been torn from Mytilus, to which they had been attached. The peduncular disk brought away a layer of the black epidermis of the Mytilus, and to this surface many embryos conveniently became attached, and against this black background the pure white embryo showed to the best advantage. At intervals the Terebratulina would twirl its peduncle, thus presenting the embryos in different positions, all of which I instantly sketched. I have a great many drawings at every stage of this interesting growth, some of which are given on Plate VIII., Figs. 47 to 77, inclusive.

One fold grows more rapidly than the other, and I infer that this is to be the larger or ventral plate. The head appears to be gradually engulfed, as it were, though for a long time protruding beyond the dorsal and ventral folds. The folds also present for a long time a thickened and rounded border. The inner edge of what I suppose to be the dorsal valve, shows a distinct notch in the median line in some (Plate VIII., Fig. 63). As the dorsal and ventral folds develop, the embryo becomes elevated upon the peduncular stalk, and the attachment becomes so firm that a forcible stream of water falling upon them does not detach them, indeed a point of a needle, or a stiff camel's hair pencil, was found necessary for the purpose, and in the removal, the parts were so soft as to break down in most cases. The mouth also makes its appearance at this time, the head for a long time occupying the area enclosed by the two folds. As soon as the embryo rises upon its peduncle it drops partially over to one side, the ventral or larger area being uppermost.

The hinge margin is broad and slightly rounded when looked at from above; a side view, however, presents a wide and flattened area, as is shown in some species of Spirifer, and the embryo for a long time assumes the position that the Spirifer must have assumed. The dorsal and ventral folds close up on the sides, and their edges become sharper; the future lateral openings of the shell gradually extend to the base. From above, the thorax is wider than long. Starting from a broad base it widens gradually to the anterior margin, which is nearly straight, to which it joins by a short curve. A heart-shaped corneous shell is formed even at this early stage, for in several cases I met with it where the softer portions had been removed by Paramæcia. (See Plate VIII., Fig. 68.)

Before the folds have closed over the head, four bundles of setæ appear; one bundle containing from seven to nine setæ springing from where the folds unite laterally. These stand out at nearly right angles to the longitudinal axis. The other bundles containing from two to four setæ, spring from a point midway between the first bundles and the

median line anterior. Thus the embryo possesses from twenty to twenty-five setæ springing from the anterior margin. The larger and lateral bundles of setæ are the first to make their appearance. They are nearly as long as the entire length of the embryo, and are *delicately barbed and deciduous*. Upon pressure of the embryo they readily separate from their base of attachment. The dorsal valve is flattened, while the ventral valve is rounded, as before remarked. The first evidence of hardened plates appears in the later stages of these forms, for upon crushing the embryo in the live cage a number of angular fractures appear. (Plate II., Figs. 89 and 91.)

Fig. 85, Plate II., presents a view of an advanced stage, in which the relative position and character of the deciduous setæ are shown.

Fig. 81, just above, represents the same embryo as it appeared when slightly crushed. The manner in which the contents burst out from the shell still held by the membrane, as in a sac, the fracture of the shell and the detached setæ, are all instructive. Besides the minute granules which make up the substance of the embryo, larger cells, to the number of twenty-five or more, are seen scattered through the mass. In a slightly advanced stage, Fig. 90, Plate II., the mouth shows on each side a rounded papilla, the first appearance of the cirri. The mouth is prominent, and flush with the anterior borders of the pallial membrane; this is also shown in Fig. 82.

Fig. 91 represents the appearance of Fig. 90 crushed. Here the incipient cirri show as two prominences, one upon each side of the mouth. The shell fracture is also more apparent. As the embryo advances in growth the outline changes, having at first a transversely semicircular outline with the posterior margin straight, as in *Leptæna*. It gradually elongates, and commences to widen its anterior margin, as in Fig. 93; it becomes well rounded as in Fig. 88, and at this time is seen a difference in the length of the dorsal and ventral plate, and for the first time appear concentric lines of growth. The deciduous setæ, at this stage, separate at the slightest handling of the embryo, and as in every case the figures on the plates are exact fac-similes of my original drawings, the setæ are not shown in Fig. 88, as they dropped off in removing the specimen to the live box. A stage of the same age, or slightly later, is shown in Fig. 94, and this stage immediately precedes the formation of the scaled structure of the shell. Its outline is quite unlike any adult Brachiopod known. It is longer than broad. The posterior margin is quite broad and rounded. The anterior margin is twice the breadth of the hinder margin, semicircular, and abruptly rounded where it meets the lateral margins, which are incurved. The larger bundles of setæ project at the point where the anterior curved margin joins the lateral margin. (See Fig. 94.) A distinct triangular area is seen within, which represents the head, below which the digestive tract is faintly indicated.

Sixth Stage. The embryo has now discarded its deciduous setæ, and for the first time the permanent setæ make their appearance, as well as the peculiar scaled structure of the calcareous shell, and with these new features that of the peculiar tubules perforating the shell must be added.

Fig. 96 represents a somewhat more advanced stage than Fig. 94. The form is now bluntly oval, its posterior margin prominent and bluntly rounded. In general contour it recalls *Siphonotreta*, placed in the family Discinidæ by Davidson, a genus not occurring above the Silurian. Seven prominent setæ longer than the shell now spring and diverge from the anterior margin. These are not barbed. The shell now plainly shows its scaled

structure, and within is seen four cirri, below which the digestive cavity occurs. The tubules first formed are three in number, of large size, and are arranged in a triangular figure, the two forming the base of the triangle occurring midway between the front and hinder portions of the head, the other tubule being near the anterior margin.

The tubules, or pores first formed, present some new and interesting features. In every case examined, the first that make their appearance are three in number, and are invariably arranged so as to form a triangle as shown in Figures 95, 96 and 105. They are also much larger than those subsequently formed. They are oval in shape, and within their borders a circular, granulated plug of a reddish yellow color is seen, between which and the outer border of the tubule a clear space is visible. From twelve to fourteen hairs of various lengths, some of them three times as long as the diameter of the pore, spring from the margin of the granulated disk, and radiate in every direction. That these are veritable hairs and not minute tubules in the shell, or any internal markings, I proved in a very simple manner. First I made an exceedingly careful drawing of the tubule, showing exactly the position of each hair, and then brushing the pores slightly with a delicate camel's hair pencil I again made a careful drawing of the same pores, using the same objective, $\frac{1}{8}$ Wales. The hairs were found in every case to have changed positions, being bent in different directions. Fig. 100, *a*, represents a drawing of the tubule before brushing, though in this the hairs were bent in handling the specimen, and Fig. 100, *b*, represents the same pore after brushing. Next summer I hope to study this peculiar structure of the tubule with higher powers. The tubules subsequently formed are much smaller in size, showing, however, the same hairs in less number radiating from them.

Whether there is any relation between these veritable hairs and the radiating lines surrounding the tubules, as described by Queckett and Carpenter, and regarded by them at one time as representing cilia, I cannot say. In this connection, however, it is interesting to recall other views on the subject.¹ It is more probable that the tubules are simply organs of general sensibility. In the test of Crustacea similar tubules occur, which penetrate to the vascular layer beneath, and are regarded as endowing the test with a general sensibility.² The subsequent tubules appear to make their appearance in a certain symmetrical order as shown in Fig. 105, one occurring on each side of the peduncle. In Fig. 102 a distinct area is seen, from the anterior surface of which the cirri spring, and from the borders of which the scaled structure of the calcareous shell commences to form. This area has the same outline as the stage represented in Fig. 94. The cirri present coarse cilia as long as the diameter of the cirrus; the cavity within is large, on the outer border of which a few irregular granules are arranged in a single line. See Fig. 101, representing a cirrus from stage 102.

This brings the development of Terebratulina up to its "Early Stages," already described by me in these Memoirs.³

By comparing the early conditions of the embryo Terebratulina with that of Thecidium, described by Lacaze-Duthiers, a certain resemblance is observed, so far as the division of

¹ See an interesting paper of Prof. King on the structure of the tubules in the test of Brachiopoda, in the Memoirs of the Royal Irish Academy, Vol. xxiv, p. 439.

² See De Morgan on the Structure and Functions of the

Hairs of Crustacea, Philosophical Transactions, Vol. cXLVIII, p. 805.

³ Morse. Early Stages of Terebratulina. Mem. B. S. N. H., Vol. II., p. 29.

the body into segments, and their power of contracting upon each other is concerned, though the conditions under which they develop will be found to be entirely unlike. The egg of Terebratulina is discarded freely into the water to undergo its development, and possibly its fertilization outside the parent, while the embryo Thecidium is held attached within the pallial cavity, and separates only after it has undergone changes in advance of those found in the embryo Terebratulina after it has become permanently attached.

The presence of eye spots in the embryo Thecidium is another important difference, for though I examined hundreds of the Terebratulina embryos, yet in no instance were the traces of eye spots detected. On comparing the early stages of Terebratulina with that of Discina, we are at once struck by the marked differences between the two; Terebratulina becoming permanently attached by its peduncular segment long before a trace of the peculiar dorsal and ventral plates makes its appearance, or even before any definite structure shows within, while Discina swims freely in the water sometime after the dorsal and ventral plates, cirri, mouth, œsophagus and stomach, have made their appearance.

The long and protrusible œsophagus and head, bearing a crown of eight cirri, or tentacles, in Discina, as described by Dr. Müller, is unlike anything of the kind observed in Terebratulina. Their barbed and deciduous setæ, however, present similar features to those of the embryo Terebratulina.

The embryology of Lingula (which I hope soon to have the opportunity of studying on the coast of North Carolina) will undoubtedly afford stages similar to those observed in Discina. I have already studied, in the transparent plates of *Lingula pyramidata*, the character of the nucleus, and find it perfectly orbicular with a margin finely notched, and in certain fossil Lingulæ I have observed the same orbicular nucleus. With the other characters, in common between Lingula and Discina, we should expect to find similar features revealed in their embryology.

In considering the various degrees of persistence of embryonic features in the few forms we are thus far acquainted with, we are struck with the great difference in this respect between Discina on the one hand, and Terebratulina on the other. Thus, in Discina, attachment takes place sometime after adult characters make their appearance, the peduncle at first extending directly backward, as in Lingula. In Lingula, as I have heretofore observed, attachment never takes place, at least in *L. pyramidata*, the creature living loose in the sand; and this feature will probably be found characteristic of other Lingulæ when they shall have been carefully observed.

Thus we see in later geological forms, attachment taking place earlier in developmental history than in those of earlier geological times. Similarly in earlier geological times we find forms in which the dorsal and ventral plates are chitinous, and, as I have observed in *Lingula pyramidata*, of such transparency that the circulating fluid could be easily seen coursing through the sinuses of the pallial membranes, and in this latter species containing so little earthy matter that when dry they become twisted out of all shape, and even roll up like a leaf. With these facts it requires no hazardous supposition to conceive the primordial Brachiopods devoid of the dorsal and ventral plates, or furnished only with a semi-lunar membrane on the head, as in that curious annelid Umbellisyllis, described by Sars, and of a form that presented the annelidan characters less disguised by features that have heretofore prevented a right conception of their affinities.

As to the relations of the Brachiopods with the Polyzoa, some features of similarity are

seen between the embryo Brachiopod and the free embryo of *Pedicellina*, described by Van Beneden,¹ though the development of parts within a coenœcium, and the formation of statoblasts are features quite unlike the Brachiopod. A roundabout relation might possibly be insisted upon through the Rotifera, in their winter ova.

After this paper had been made up into pages, Mr. Alex. Agassiz called my attention to the fact that Prof. John McCrady had published in the Proceedings of the Elliott Society of Natural History of Charleston, S. C., a notice of a larval Brachiopod.

After a fruitless search among the libraries of Boston for a perfect set of the Proceedings of this Society, I learned that within a week Mr. McCrady had made his home in Cambridge, having recently become connected with the Museum of Comparative Zoölogy. From him I learned that the original description and drawing was presented before the Elliott Society, at its meeting June 15th, 1860, but, owing to the war, had never been published by the Society. In the destruction of Columbia, S. C., by Sherman's Army, Prof. McCrady not only lost his valuable library, but all of his scientific records, drawings and notes. After this irreparable loss, he drew up from memory a description of this Brachiopodan larva, and now generously allows me to make free use of this valuable manuscript, which contains the first and only observations on a larval *Lingula* ever made.

The creature in question was found by him either late in the fall of 1859, or in the spring of 1860, he cannot now remember which. It was found off Sullivan's Island in Charleston Harbor. The following is quoted from his manuscript.

"1st. The larva is a free swimming animal.

"2d. Its means of locomotion are large vibratile cilia, clothing the cirri of the arms, precisely as in Bryozoa.

"3d. It was provided with a bivalve semi-transparent horny shell, recalling the shell of *Lingula*, but with no trace of a foot stalk." (Mr. McCrady adds in pencil that the form of the shell was flattened, and more ventricose than that of adult *Lingula*.)

"4th. In motion the valves were opened just enough to allow free play to the ciliated cirri of the arms, which (*i. e.*, the cirri) was thrust out beyond the shell rim.

"5th. The arms were never extended beyond the shell rim, but just within and along their margin.

"6th. The opacity of the body was such, that added to the cloudy semi-transparency of the horny shell, it was impossible to make out other details.

"7th. When the larva ceased swimming, the arms and their cirri were retracted, the valves closed, and the animal sank to the bottom."

By comparing the above description with that of Dr. Fritz Müller's description, given in the first part of this memoir, the closest similarity will be observed between them in their general appearance, their mode of swimming, and even to the manner in which, when at rest, they close their shells and sink to the bottom of the vessel in which they are confined. Mr. McCrady assures me he has never seen Müller's description of the larval *Discina*.

It is interesting to remark that nearly at the same time, these two naturalists should make the first observations ever made on the embryology of the Brachiopods, if we except the very brief notice of Oscar Schmidt.

¹ Hist. Nat. du genre *Pedicellina*. Mém. Acad. Royal de Belgique. Tome XIX.

The expression of mine which occurs above, that the embryology of *Lingula* when known would agree with that of *Discina*, was in type long before I became aware of Mr. McCrady's discovery.

The absence of setæ in the embryo, with the opacity of the valves, is an evidence that it was considerably advanced, for Müller described some of the larva observed by him as having lost the larger bristles.

In closing this brief memoir I wish to express my thanks to Mr. Richard Rathbun, who accompanied me to Eastport, and who assisted me in securing materials for study.

To Mr. Edward Burgess I am again under many obligations during the preparation of the paper.

My thanks are also due to Mr. Chas. A. Walker, who has with great fidelity and patience reproduced accurately my drawings upon steel.

EXPLANATION OF PLATES.

PLATE VIII.

- Fig. 1. A cluster of eggs from the genital band.
 Fig. 2. A single egg encased in its capsule.
 Figs. 3, 4, 5. Eggs from the perivisceral cavity immediately after their escape from the pallial sinuses.
 Fig. 6. Highly magnified portion of the eggshell.
 Figs. 7, 8, 9, 10 11. Eggs in various stages of segmentation.
 Fig. 12. First ciliated stage.
 Figs. 13, 14, 15, 16, 17. Successive stages of transverse division of embryo, showing long tuft of cilia at cephalic extremity.
 Figs. 18, 19, 20, 21. From a single embryo, showing various outlines assumed while swimming.
 Figs. 22, 23, 24. Different views of another embryo.
 Figs. 25, 26, 27. Different embryos showing first appearance of caudal or peduncular segment.
 Figs. 28 to 36. Different embryos at the stage when the caudal segment becomes conspicuous.
 Figs. 29, 30. Representing the same embryo contracted and expanded.
 Figs. 37, 38, 39, 40, 41. Embryos just attaching themselves by their caudal segment.
 Figs. 42, 43. Drawn from the same embryo: the first showing the embryo stretched to its utmost, the second the same contracted. (These motions would often follow each other rapidly.)
 Figs. 44, 45. Embryos showing first appearance of ventral? area by the bulging of the thoracic ring.
 Figs. 46 to 53. Embryos in various stages showing widening of thoracic ring, and its gradual growth toward enclosing the cephalic ring.
 Figs. 54 to 61. Successive stages of the embryo showing formation of dorsal and ventral areas by the folding and growth of the thoracic ring. In Fig. 61 the head is still seen projecting from the dorsal and ventral folds of the thoracic ring.
 Figs. 62 to 77. Succeeding stages of embryos drawn in various positions. The deciduous setæ appear in these stages.
 Fig. 68. Dorsal and ventral plates of embryo, the contents having been removed by *Paramæcia*.

NOTE. The cilia constantly clothing the embryo have been purposely omitted except in a few cases, to save trouble in engraving. On the first appearance of the dorsal and ventral folds of the thoracic ring, the cilia disappear from that region. Figs. 18 to 77 were drawn with a $\frac{1}{16}$ objective of Smith and Beck; the embryos measure about the $\frac{1}{16}$ inch in diameter.

PLATE IX.

The figures of embryos upon this plate as follows: 78, 79, 80, 81, 82, 83, 85, 86, 87, 88, 89, 90, 91, 92, 93, and 94 were drawn with a Wales $\frac{1}{2}$ inch; a few of them are shown less magnified on Plate VIII.

Fig. 78. Free swimming embryo showing first trace of alimentary tract and peduncular segment.

Fig. 79. Free swimming embryo showing deciduous setæ projecting behind. This feature was only observed in two instances.

Fig. 80. Showing widening of thoracic segment, depression of cephalic segment, and first attachment of caudal segment.

Fig. 81. Appearance of embryo Fig. 85 after having been crushed. The embryo shell, apparently corneous, is split at the peduncular end. The membrane representing the head and cephalic wall is bulged out, with ruptures from which the cellular contents of the body are escaping, and the deciduous setæ are separated from their base of support.

Fig. 82. First stage in which the mouth makes its appearance, and dorsal and ventral plates become distinctly marked.

Fig. 83. Earliest stage in which definite internal structure was found. The peduncular segment characterized by thick walls is seen hanging in the thoracic or pallial cavity.

Fig. 84. Highly magnified drawing of deciduous setæ showing their barbed character.

Fig. 85. Showing arrangement of deciduous setæ, and contour of embryonic shell.

Fig. 86. Another stage similar to that shown in Fig. 83.

Fig. 87. Showing first bulging of thoracic ring and clear interspace within. This region is characterized by large granules marking its wall, and in first losing its ciliary lining. The bulging probably indicates the region of the larger or ventral valve.

Fig. 88. A stage slightly advanced from Fig. 85, showing change in outline, the anterior margin strongly ciliated. The deciduous setæ were easily dislodged at this stage, and were often lost in examination.

Fig. 89. A portion of shell of Fig. 88 crushed, showing by its fracture a harder consistency.

Fig. 90. Stage showing for the first time a primary cirrus or tentacle upon each side of its head.

Fig. 91. The same crushed, showing fracture of shell, and parts forced out by pressure.

Fig. 92. Stage similar to Fig. 85.

Fig. 93. A slightly advanced stage from Fig. 92, showing widening of anterior margin.

Fig. 94. A stage slightly advanced from the preceding, with a definite structure showing in the anterior portion of shell.

Fig. 95. Adult characters now assumed, permanent setæ now showing, and pallial cœca present.

Fig. 96. The youngest stage met with in which adult characters were present. The permanent setæ, seven in number, project from the anterior margin. The peculiar scaled structure of the shell is just appearing, and the primary pallial cœca are present. Within, the rounded stomach, and four tentacles are shown.

Fig. 97. Head, tentacles and stomach from an advanced stage. Figured particularly to show contour of parts about the head.

Fig. 98. A stage considerably advanced from Fig. 96, showing subsequent widening of the anterior portion of the dorsal and ventral plates.

Fig. 99. A setigerous follicle with its seta.

Fig. 100. *a. b.* One of the primary pallial cœca, showing appearance of fringing hairs. *a.* Showing the position of hairs before being disturbed by a brush, and *b.* the same after having been brushed with a delicate camel's hair pencil. These are from Fig. 105.

Fig. 101. A tentacle, or cirrus from Fig. 102, showing cavity within, and arrangement of calcareous particles, and relative size of cilia clothing it.

Fig. 102. A considerably advanced stage drawn to show relations of embryonic area, which is shaded. This portion corresponds to stage shown in Fig. 94.

Figs. 103, 104. Showing appearance of fringing hairs bordering pallial cœca.

Fig. 105. Advanced stage to show relative position and size of primary cœca and the first appearance of cœca upon that portion bordering peduncular opening.

In my Memoir on the Early Stages of Terebratulina, published by the Society, I take up the developmental history of Terebratulina from the stage represented in Fig. 105.

EXPLANATION OF LETTERS ACCOMPANYING THE FIGURES.

m, mouth.

æ, œsophagus.

s, stomach.

t, tentacles or cirri.

α, alimentary tract.

pl, pallial cavity.

pv, perivisceral cavity.

pc, peduncular cavity.

c, cephalic segment.

th, thoracic segment.

p, peduncular or caudal segment.

h, head.

ap, anterior parietal wall and head.

e, area of embryonic shell.

f, fold of larger, or ventral area.

pr, primary cœca.

ds, deciduous setæ.

es, embryonic shell.

α, foreign particles adhering to peduncle.

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