XXVI. *Researches on the Foraminifera.*

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PART II.

ON THE GENERA ORBICULINA, ALVEOLINA, CYCLOCLYPEUS AND HETEROSTEGINA.

Genus ORBICULINA.

78. *History.*—THE interesting group of organisms belonging to this type seems to have early attracted notice, probably on account of the great abundance in which it presents itself on the sands of many of the West Indian shores. Three species are described and figured by FICHTEL and MOLL*, under the names of *Nautilus orbiculus, N. angulatus*, and *N. aduncus*. LAMARCK, however, in his first systematic treatise†, separated them from *Nautilus*, and raised them to the rank of an independent genus, to which he gave the name of *Orbiculina*; and he also changed two of the specific names, the three standing respectively as *O. numismalis, O. angulata*, and *O. uncinata*. By DENYS DE MONTFORT‡, these species were raised to the rank of independent genera, under the names of *Helenis, Archaias*, and *Ilotes*; but these genera have not been adopted by any other systematist. M. D'ORBIGNY§, in his first classification of the Foraminifera, not merely adopted LAMARCK's generic designation, but affirmed that the three reputed species were really nothing else than one and the same organism in different phases of growth, *O. angulata* being the youngest, *O. numismalis* the next in age, and *O. uncinata* the adult. He arrived at this result, of the truth of which I am myself well assured, by the comparison of a great number of specimens, —a process which it would have been well for science if he had more constantly adopted. The name of the adult form should of course stand as that of the species; but the organism in question is more commonly known under the designation *Orbiculina adunca*, which seems to have been conferred upon it by M. DESLONGSCHAMPS‖.

79. A considerable number of figures of this species are given by M. D'ORBIGNY in his treatise on the Foraminifera of Cuba, which forms part of the great work of M. RAMON DE LA SAGRA on the Natural History, &c. of that island¶. These figures,

* Testacea Microscopica, Vindob. 1798.

† Système des Animaux sans Vertèbres. Paris, 1801.

‡ Conchyliologie Systematique. Paris, 1808.

§ Tableau Méthodique de la Classe des Cephalopodes. Paris, 1825.

‖ Encyclopédie Méthodique, Zoophytes. Paris, 1824.

¶ Histoire Physique, Politique, et Naturelle de l'Ile de Cuba. Paris, 1840.

however, serve only to give a general idea of the diversities of external conformation which had presented themselves to him; and notwithstanding their number and variety, they do not include some of the most important among the protean shapes of these bodies, nor do they throw any light upon their internal structure.

80. The memoir of Professor EHRENBERG*, in which his group of Bryozoa was originally constituted, contains the first recognition of the relationship between *Orbitolites* (¶ 4) and *Orbiculina*; of which the first had previously been ranked among the Zoophytes; while the second (until the Rhizopodous nature of the whole group of Foraminifera was made known by M. DUJARDIN in 1835) had been associated with the Cephalopods. Professor EHRENBERG's description and figures of *Orbiculina*, however, being just as inaccurate as I have shown those of *Orbitolites* to be (partly, it seems likely, through his unacquaintance with the mode of making thin sections), there is no occasion for me to make further reference to them.

81. The excellent memoir of Professor WILLIAMSON† "On the minute structure of the Calcareous Shells of some recent species of Foraminifera," contains the first approach to a correct description of the internal conformation of *Orbiculina*; and the fact was fully recognized by him, that in advanced age, when the spiral type of growth has given place to the cyclical, there is no other difference between the structure of *Orbitolites* and that of *Orbiculina*, than that which arises from the dissimilarity of their earlier mode of development. Although I am satisfied that, as to one or two points of minute structure, Professor WILLIAMSON has fallen into error, I am disposed to attribute this to the want of a sufficient number of well-preserved specimens for examination; and for having it in my power to correct and extend his description, I am chiefly indebted to Mr. HUGH CUMING, the specimens of this type included in his Philippine collection being remarkable both for their high development, and for their very beautiful state of preservation.

82. The investigations of Professor WILLIAMSON are entirely unnoticed by M. D'ORBIGNY in his latest classification of the Foraminifera‡; *Orbiculina* being ranked in the order *Helicostègues*, and being defined as follows,—"Coquille nautiloide, comprimée, formée de loges divisées intérieurement en compartiments réguliers, percées de nombreuses ouvertures en lignes longitudinales à l'enroulement spécial;"—whilst *Orbitolites* (his definition of which has been already cited, ¶ 5) is placed in the order *Cyclostègues*. The separation of the two genera by so wide an interval, is grounded, therefore, on the assumption that the type of growth in *Orbiculina* is spiral, whilst that of *Orbitolites* is cyclical. I have already shown that this assumption is incorrect as regards *Orbitolites*, the early plan of whose growth is frequently spiral (¶ 54); and I shall presently show that it is equally incorrect as regards *Orbiculina*, whose later plan of growth is typically cyclical. And after having closely compared these and

* Transactions of the Royal Academy of Berlin, 1839.

† Transactions of the Microscopical Society, 1st series, vol. iii. p. 120.

‡ Cours Élémentaire de Paléontologie, tom. ii. Paris, 1852.

other types, we shall be in a position to inquire what value is really to be attached to such a character as a basis for classification.

83. *Organization.*—Among the diversified forms that are presented by the species before us, it is of course necessary to select some particular type as that with which others may be compared; and this I consider to be the form delineated in Plate XXVIII. fig. 5; since by far the larger proportion of the very numerous specimens I have examined show such a degree of approximation to it, that their differences may fairly be set-down to the account of incomplete development. The general aspect of a typical *Orbiculina*, then, differs but little from that of *Orbitolites*, except in the prominence of its nucleus, and in the peculiar spiral disposition of the bands by which the surface of the nucleus is marked. The species never attains, so far as I am aware, the dimensions of *Orbitolites*; the diameter of the largest recent disk in my possession (one of Mr. Cuming's Philippine specimens) being ·20 of an inch; whilst of the specimens which I have seen from the West Indian and Ægean seas, none exceed ·12 of an inch. Mr. Carter*, however, describes under the name of *Orbitolites Malabaricus* a fossil *Orbiculina* (¶ 90), whose specific identity with the type before us I see no reason to doubt, as attaining a diameter of from 7 to 8 lines. The thickness of the disk is usually less in proportion to its diameter, than it is in *Orbitolites*; but this is by no means a constant difference, depending as it does merely on the relative increase of the columns of sarcode in the vertical direction, as compared with the extension of the surface by the addition of new annular bands.

84. On more closely comparing the marginal portion of such a disk with the corresponding portion of one of those forms of *Orbitolites*, in which the concentric annulation is strongly marked externally whilst the transverse divisions of each annulus are scarcely indicated (¶ 49), no essential difference is perceptible between them; and although these transverse divisions are usually but very faintly indicated in *Orbiculina* (Plate XXVIII. figs. 13, 14), yet they are sometimes very obvious, as is seen in figs. 15, 16. In the fossil *Orbiculina* just adverted to, the surface-markings (figs. 21, 22) are entirely conformable to the ordinary type of *Orbitolites*. The margin itself exhibits one or more ranges of pores (figs. 6, 7, 18, 19) arranged after precisely the same fashion as those of *Orbitolites*: these ranges are more numerous in the fossil than in the recent forms of this type.

85. The internal structure of *Orbiculina* presents such a general conformity to that of *Orbitolites*, that it will not be requisite here to do more than specify the points of agreement and of difference. The general aspect of the horizontal section of such a typical specimen as is shown in Plate XXVIII. fig. 11, does not differ from that of a corresponding section of *Orbitolites* in any other essential particular than the disposition of the central portion, in which the successive additions to the first-formed chambers are so made as to produce a spiral, instead of a concentric disk. When we examine this central portion more closely, we see that its plan of growth is exactly the

* Annals of Natural History, New Series, vol. xi. p. 425.

same as that which is presented by those aberrant forms of *Orbitolites*, in which the central cell buds-out only on one side, instead of all around (see ¶ 54, and Plate IX. fig. 4). The spiral mode of increase is usually carried-on much further in *Orbiculina*, than it ever is in *Orbitolites*; several turns being made before it gives place to the cyclical plan. But as this is a mere question of degree, such a difference would scarcely alone afford a valid distinction between these two types. There is, however, this very definite positive distinction,—that in *Orbiculina* each turn of the spire not only surrounds the preceding, but completely invests it above and beneath, every band of new chambers being continued to the very centre; so that, whilst the spiral mode of growth continues, the thickness of the shell increases with each turn; and after this has given place to the cyclical, the central nucleus, thus augmented in thickness, projects above the plane of the disk. This peculiarity in *Orbiculina*, which I have never found to be wanting, and to which there is never the least approach in *Orbitolites*, is best seen in vertical sections. Thus in Plate XXIX. fig. 3 is shown that part of a vertical section of a large disk, which has passed through its nucleus; the innermost and therefore first-formed portion of which is seen to be invested above and below by three layers, formed by three turns of the spiral. The same peculiarity is shown in Plate XXVIII. fig. 17, which represents a portion of a fossil disk near the nucleus.

86. The transition from the spiral to the cyclical mode of growth is effected in *Orbiculina*, exactly as in the aberrant forms of *Orbitolites* just referred-to, by the opening-out (so to speak) of the mouth of the spire; the successive rows extending themselves more and more on either side, until they meet around the previously-formed portion; after which each new row forms a complete zone or annulus. The commencement of this change is seen in Plate XXVIII. fig. 1; and its subsequent stages are shown in figs. 2–5, a comparison of which will show that the specimens which they represent are in different phases of this transitional state.

87. But this transition by no means constantly occurs; for the original spiral plan of growth is not unfrequently maintained, apparently through the whole of life; so that specimens are often met-with, which are not inferior in size or in number of rows to the larger disks, but which retain the *aduncal* form. Such a series of specimens is shown in figs. 8–10; the first of which represents a very young *Orbiculina*, in that stage which is common to both types of growth; whilst it is obvious from a comparison of this with the two following, that *their* increase has continued to take place upon the same plan, each row that is put-forth from its predecessor terminating abruptly like it at its free extremity, without any such disposition to extend itself as would carry it round the nucleus so as to form a complete annulus. A horizontal section of such a specimen as is represented in fig. 10, is shown in fig. 12.—It may, of course, be urged that such a difference ought to be accounted sufficient to separate the *spiral* and the *discoidal* types of Orbiculina, as two distinct species; but the following reasons appear to me quite sufficient to negative such a mode of viewing

them :—First, they so closely resemble one another, as to be undistinguishable, in their early condition. Second, they correspond in every particular, so far as regards the structure of their minute parts. Third, the assumption of the cyclical plan of growth does not take-place at any one fixed epoch of development, but may occur at various periods. Fourth, the persistence of the original plan of growth throughout life, cannot be fairly regarded as anything else than an arrest of development, such as we shall presently see to be a common occurrence in *Orbiculina*, as in *Orbitolites*, in regard to other particulars (¶ 90).

88. Turning now from the general plan of growth to the minute structure of the individual parts of *Orbiculina*, we continue to find a very close conformity to the type of *Orbitolites*. The texture of the shell is precisely the same; and it exhibits no other peculiarity than a minute punctation of the superficial layers (Plate XXVIII. fig. 13), which at first suggests the idea of apertures*, but which is found on careful examination of transparent sections (Plate XXIX. fig. 2) to be due to a mere thinning of the shell at certain points, so as to give an appearance of cellular areolation closely resembling what is seen in *Orbitolites* (Plate VI. fig. 5).

89. Not having had the good fortune to obtain specimens in which the animal body has been preserved, I cannot speak as confidently on the subject of its conformation, as I could in regard to that of *Orbitolites*; but a comparison of the features which present themselves in the structure of the calcareous skeleton of the two types, can leave no reasonable doubt that the general arrangement of its segments of sarcode must have been precisely the same. For the conformation of the chambers and passages, as displayed by a horizontal section (Plate XXIX. fig. 1), shows that the soft body must consist of a succession of bands of sarcode, each band swelling at intervals into larger segments; that the segments of each band usually alternate with those of the bands internal and external to it, so as to be opposite to the intervals between them; and that the stolons which connect one band with another pass-forth from pores in the intervals between the segments of one, into the segments of the next, those of the outermost band emerging from the margin as pseudopodia. By the coalescence of these a new band would originate, which would become thickened into segments opposite the pores of the preceding, and would give-off its own pseudopodia from the intervals between the segments.

90. Again, by an examination of the natural margins of *Orbiculinæ* (Plate XXVIII. figs. 6, 7, 18, 19), and by a comparison of these with vertical sections (Plate XXIX. fig. 3), it becomes evident that the same variety exists as in *Orbitolites*, in regard to the increase of the disk in thickness by the vertical elongation of the segments of sarcode. For some specimens are altogether conformable to the 'simple type' of *Orbitolites*, in having but a single floor of chambers (so to speak), with a single row of marginal pores; whilst others correspond with the complex type of *Orbitolites*, in

* Professor WILLIAMSON (*loc. cit.*) has described these punctations as *perforations* for the passage of pseudopodia; but I am quite certain that such is not the case.

having many such floors, with numerous rows of marginal pores. In the former, the segments of sarcode, with their single annular stolon, would resemble rounded beads strung at short distances on a cord. In the latter the segments would be columnar, with constrictions at intervals, and would communicate with each other by two or more annular stolons.—It is true that we seldom find any such complete differentiation of the superficial cells, as the fully-developed type of *Orbitolites* presents; but we have seen that such differentiation is by no means a constant character in that genus (¶ 58); and the structure of the most developed specimens I have examined among the recent *Orbiculinæ* closely corresponds in this respect with that of the fossil *Orbitolites* of the Paris basin, as will be seen on comparing the left-hand portion of Plate XXIX. fig. 3 with Plate VI. fig. 11 of my former memoir. But it is not a little remarkable, that while the fossil *Orbitolites* of the Paris tertiaries are *less* developed in this respect than their existing representatives in the South Seas, the fossil *Orbiculinæ* of the Malabar tertiaries should be *more* developed than existing specimens of the same type; for in them we find the superficial cells differentiated from the intermediate layers (Plate XXVIII. fig. 20), precisely as in *Orbitolites**. Looking to the far larger dimensions, as well as to the higher development, which these fossils present (¶ 83), as compared with the existing specimens of *Orbiculina*, I am disposed to believe that this type attained its highest evolution in a period long since passed, and that we now have, so to speak, only the degenerate descendants of an ancestry of higher rank; whilst in the case of *Orbitolites*, I am inclined to think that the type is most fully evolved at the present time.

91. *General conclusion.*—From the foregoing details it is obvious that the relationship between *Orbitolites* and *Orbiculina* is extremely close; the only essential point of difference between them being that which is furnished by the structure of the nucleus. Whether or not they ought to rank as types of *distinct genera*, or whether they ought (as Professor WILLIAMSON maintains) to rank as *cognate species* of the same genus, is a point as to which it is impossible to arrive at a satisfactory conclusion, until the characters which should serve for the distinction of genera and species in this class shall have been determined on a physiological basis. This much I think myself entitled to assert with confidence,—that even if they are to be regarded as distinct genera, they must be ranked in the *same family*, and in immediate proximity to each other; and that no classification can have any claim to be considered as *natural*, in which they shall be widely separated.

Genus ALVEOLINA.

92. *History.*—Although the form and aspect of the Foraminifera which are referable to this genus, would seem to remove them altogether from proximity to the pre-

* Although Mr. CARTER has described this fossil as a species of *Orbitolites*, yet it is really an *Orbiculina*, as is shown by the spiral conformation of its central portion (Plate XXVIII. fig. 17), and by the investment afforded by each turn of the spire to its predecessor, as shown in fig. 18.

ceding, yet the two really bear a very close relationship in all essential points of minute structure, as will appear from the particulars I shall presently have to detail. The following outline of what has been previously ascertained respecting it (for which I am indebted to M. D'ORBIGNY*), will show how little the nature of its organization has hitherto been understood.—Most of the species at present known are fossils, occurring in association with *Nummulites, Orbitolites,* &c. in the Nummulitic limestone, or in other formations which represent it; and the examples first described (by FORTIS) were confounded with Nummulites and Orbitolites under the term *Discolites.* By FICHTEL and MOLL, they were ranked as a sub-type of their comprehensive genus *Nautilus.* The designation *Alveolites* was first given to this type by BOSC†; but it was not generally adopted; and MONTFORT, according to his wont, raised three of Bosc's species to the rank of genera, under the names of *Borelia, Clausalia,* and *Meliolites.* LAMARCK did not adopt either Bosc's or MONTFORT'S generic designations, but substituted a new one, *Melonia*; and this was adopted by CUVIER and FERUSSAC. DEFRANCE proposed yet another name, *Orizaria.* And finally M. D'ORBIGNY, in 1825, adopted Bosc's name, with a slight alteration in its termination, which served at the same time to mark the continued existence of the type, and to distinguish it from a genus of Corals which also had received the name of *Alveolites.* The name *Alveolina* was soon afterwards adopted by M. DESHAYES; and it may now be considered as the established designation of the genus. The following is the latest definition given of this type by M. D'ORBIGNY:—"Coquille allongée dans le sens de l'axe d'enroulement, formée de loges divisées par des canaux capillaires, ronds, percées de nombreuses ouvertures placées en lignes transversales à l'enroulement spiral." Not the least idea seems to me to be conveyed by this definition of the real structure of these bodies, such as is brought into view by thin sections; and no one, so far as I am aware, has previously attempted thus to elucidate it.

93. *Organization.*—My investigations have been made upon specimens which were tolerably abundant both in Mr. JUKES'S Australian dredgings, and in Mr. CUMING'S Philippine Collection. These were obviously identical specifically, but the latter considerably exceeded the former in average size. The length of the longest complete specimen in my possession is ·35 of an inch; but I have a specimen whose shape is somewhat abnormal—indicating that it has increased with unusual rapidity in length, as proportioned to its diameter,—which, though incomplete at one end, measures ·50 of an inch. The ordinary form, from which any considerable departure is very rare, is that which is exhibited in Plate XXVIII. fig. 23; and it is obviously produced, as correctly stated by M. D'ORBIGNY, by the involution of a spiral around an elongated axis. The surface is marked-out by longitudinal furrows into a succession of bands of tolerably uniform breadth; and each of these is crossed by secondary furrows,

* Foram. Foss. de Vienne, p. 140.

† Bulletin des Séances de la Société Philomathique, No. 61.

which lie so closely together as to mark-out each band into a series of very elongated cells, which remind us of the oblong superficial cells of the complex type of *Orbitolites*, but are much narrower in proportion to their length. The mouth of the spire is closed by a solid wall, the surface of which is nearly flat, and which is perforated by three, four, or five rows of rounded pores, bearing a very close resemblance to those at the margin of *Orbitolites* and *Orbiculina*.

94. The resemblance suggested by external configuration is fully borne-out by the examination of the internal structure of this genus, as brought into view by longitudinal and transverse sections. For it is shown in Plate XXVIII. fig. 24, that the whole organism has originated from a single large nearly-globular cell, around which are successive layers of chambers freely communicating with each other, each layer completely enveloping the preceding, and adding much more to its length than to its diameter. A portion of such a section, more highly magnified, is shown in Plate XXIX. fig. 9. The formation of the successive layers by spiral involution, is well displayed by a series of transverse sections taken at different points, such as are delineated in Plate XXIX. figs. 4 to 7; the first (fig. 4) having crossed near the narrow termination of the fusiform shell, and having consequently traversed only the two last-formed turns; the last having crossed near the middle of its length, and having traversed all the six turns by which it was formed. Each whorl seems to be, as to all essential particulars, a repetition of the rest; and hence it will be sufficient to make a detailed examination of only a small part of a section, such as is shown on a larger scale in fig. 8. It is there observed that the spaces occupied by the sarcode-body and bounded by the shell, though far from regular, conform to a certain general plan. Each lamina is made-up (as the surface-furrowing and the marginal pores indicate) of a succession of bands of superimposed cells, of elongated form; each band answering to one of the annuli of *Orbitolites*. At each point corresponding with the external furrow, the superficial layer of shell sends a prolongation inwards (*a*, *a*, *a*), which thus marks-off the superficial cells more completely from each other than is the case with the subjacent cells; just below this projection is a rounded perforation (*b*, *b*, *b*), which marks the passage of a longitudinal channel; and at a little distance beneath this is another (*c*, *c*, *c*), which is of very considerable dimensions. Sometimes there are more than two such channels; but this is comparatively rare. These channels must have given passage to longitudinal bands of sarcode, running from one end of the lamina to the other, and freely connecting together all the segments occupying the piles of elongated cells of which it is composed. The marginal pores are the orifices of the chambers of the last-formed band; and it will be observed in Plate XXVIII. fig. 23, that one row of them is contiguous with the preceding whorl of the spire, along which, as is shown in Plate XXIX. fig. 8, there is always a free passage. Thus we may consider the sarcode-body, as in the case of Orbitolite, to be composed of a mass of closely-connected segments, between which a calcareous skeleton grows-up according to a certain tolerably-regular type. It seems to me

probable from the conformation of the shell, that the segments forming successive bands do not communicate directly with each other so much as with the great longitudinal stolons; just as the successive annuli of superficial cells in Orbitolites communicate with each other, not immediately, but through the annular stolons (¶ 28). The pseudopodial prolongations issuing from the marginal orifices, probably first coalesce into a longitudinal cord of sarcode, when a new band of cells is to be formed; and from this another series of segments is then budded-off.—In the texture of the shell, in the relations of the different chambers, in their mode of communication with the exterior, in all (to speak concisely) which marks the physiological condition of this organism, its conformity to the types previously described is so close, that, notwithstanding the marked difference in their mode of increase (on which depends their form), they must rank, in any natural classification, in very close proximity with these*.

Genus Cycloclypeus.

95. The organisms which I have now to describe, and to which I shall give the generic designation *Cycloclypeus* (suggested to me by Dr. J. E. Gray), are amongst the most interesting of all the Foraminifera at present existing; on account both of the large dimensions which they sometimes attain, and also of the complexity of their structure. The only specimens of them yet known, were dredged by Sir Edward Belcher from a considerable depth of water off the Coast of Borneo. Two of these, which are now in the British Museum†, are complete disks measuring no less than $2\frac{1}{4}$ inches in diameter; and by the kindness of Dr. J. E. Gray, I have had the opportunity of making microscopic sections of a fragment of a disk, which, when entire, must have nearly equalled these in size. Smaller disks of various dimensions presented themselves in the same dredgings.

96. *Organization.*—The external aspect of these disks is sufficiently like that of *Orbitolites*, to prevent the two genera from being readily distinguished by a superficial examination, especially when young specimens of *Cycloclypeus* are compared with *Orbitolites* of the complex type; since, on the two snrfaces of the former (Plate XXX. fig. 1), there can be distinguished concentric rings of oblong chambers, which are not at all unlike the similarly-disposed superficial cells of the latter. The peculiarly-compact texture of the shell of *Cycloclypeus*, however, gives to its surface a smooth and glistening appearance, which is very different from that of *Orbitolites*. And further, the forms of the two disks ordinarily differ in this,—that whilst the centre of *Orbitolite* is usually rather depressed than elevated, and the thickness

* I have confined myself to an account of the existing species, as I have not had the opportunity of making a similar examination of any large number of fossil forms of this type. It is well, however, for me to mention, that the existing species seems to me to be certainly identical with the *A. Boscii* of the Paris tertiaries.

† These are the disks referred-to by Professor Williamson in his Memoir on Orbitolites, &c., Trans. of Microsc. Soc. ser. 1. vol. iii. p. 127. He appears to have considered them as gigantic Orbitolites, not being acquainted with their peculiarities of internal structure.

of the disk generally increases towards the periphery, the central portion of *Cycloclypeus* always presents a knobby elevation, on the surface of which the oblong boundaries of the chambers are superseded by rounded 'punctations,' whilst the thickness of its disk gradually diminishes towards its margin, where it is so reduced as to come to a sharp edge. In older specimens of *Cycloclypeus*, the boundary-markings of the chambers are scarcely distinguishable, save near the margin; their concentric annuli are marked-out, however, by rows of 'punctations,' similar in appearance to those of the central eminence. In either case, it is usually observable that the breadth of the annuli is far from constant; and that the annuli are not unfrequently incomplete, extending round only a portion of the disk. This irregularity has been noticed in *Orbitolites* (¶ 20) as of rare occurrence; in *Cycloclypeus* it is so common that I have not yet met with specimens which are entirely free from it.

97. Whilst agreeing with *Orbitolites* in those external features which result from the *cyclical* mode of growth that is common to both forms, *Cycloclypeus* presents as wide a contrast to it in every other feature of its organization, as is anywhere known to exist within the limits of the Foraminiferous group. For whilst, as we have seen, the general plan of structure of *Orbitolites* removes it but little from the grade of Sponges—the several segments of its aggregate body being but very imperfectly separated one from the other, and the shell which grows-up in the midst of them having no discoverable organization,—that of *Cycloclypeus* closely approximates to the Nummulitic type, in which the successive segments are as completely isolated as they can be without entire disconnection, and in which, by the peculiarly-elaborate construction of the shelly covering, a special provision is made for their independent nutrition.

98. On making horizontal and vertical sections of the *Cycloclypeus*-disk, its central plane is found to be occupied by chambers, disposed (ordinarily in a single layer) in concentric annuli; these being covered-in above and beneath by compact plates of shell, which are thicker towards the centre, thinner towards the circumference (Plate XXX. fig. 1). The typical form of these chambers seems to be a parallelogram with its angles rounded off, whose sides are to each other as $1\frac{1}{2}$ to 1, or as 2 or even 3 to 1, the longest side lying in the direction of the radius of the disk; but owing to the variation in the *length* of the chambers which results from the before-mentioned irregularity in the breadth of the annuli (¶ 96), the *breadth* of the chambers remaining more constant, their proportions vary greatly in different parts of the same annulus, or in adjacent parts of different annuli, as shown in Plate XXIX. fig. 12. I have occasionally met with chambers whose length was to their breadth as 4 to 1 (Plate XXXI. fig. 3). The vertical thickness or depth of the chambers, seems usually to be pretty constant in different parts of the disk, except near its centre; the thinning-away towards its margin being due, not so much to a diminution in the vertical height of the chambers, as to the reduction of the thickness of the shelly plates that enclose them above and below.

99. But although the existence of only a single layer of chambers is obviously the rule in this species, yet exceptions to it are not unfrequent; a subdivision of the entire stratum into two or three presenting itself when its thickness is above the average, as is shown in Plate XXXI. fig. 8, *a*. Occasionally one or two chambers only are thus subdivided, as shown in figs. 4, 5. The cavity of each chamber is surrounded by a proper wall of its own, quite distinct from that of the chambers which it adjoins; and hence the septum by which each chamber is divided from the adjacent one on either side, is formed of at least two lamellæ (Plate XXIX. fig. 12). These come into close contact with each other at the junction of the vertical septum with the horizontal roof and floor of the chamber, as shown in Plate XXXI. figs. 2, 4, 5; but elsewhere they diverge from one another, leaving an interseptal space, which is partly filled-up by an interposed lamina of shell-substance, but is partly occupied by the *interseptal canals* to be presently described. A thicker space of the same kind is in like manner left between the proper walls of the chambers forming one annulus, and those of the chambers forming the annuli internal and external to it: this space is almost entirely filled-up by a shelly deposit, the interseptal canals which pass between the successive annuli being less numerous than those which run between the chambers of the same annulus (¶ 105).

100. As in *Orbitolites*, the chambers of each annulus usually alternate in position with those of the annuli internal and external to it. But this is by no means constantly the case; since additional chambers are 'interpolated' here and there, so as to increase the number according to the augmented diameter of the annulus; and such an interpolation disturbs the regular arrangement of the neighbouring chambers.

101. The adjacent chambers of the same annulus have not, so far as I have been able to ascertain, any direct communication with each other; an indirect communication, however, is perhaps established through the system of interseptal canals. But each chamber normally communicates with two chambers of the annulus within it, and also with two of that which surrounds it, by large passages (shown in horizontal section in Plate XXIX. fig. 12, and in vertical section in Plate XXXI. fig. 2, *c*, *c*, and represented in perspective view in Plate XXX. fig. 4, *ff* and *g g*), which traverse the annular septa; of these passages there seems to be normally but a single one for each pair of chambers thus to be brought into communication; but I have frequently met with two, and occasionally three, one placed directly or obliquely above the other. Thus at each extremity of the oblong chamber, there are normally two passages leading to two chambers of the annulus next internal or external to it; but since to each of these chambers there may be two or even three passages, the total number at each end may be three, four, five, or six. The variations as to this point of structure which are presented in adjacent chambers, are shown in Plate XXXI. fig. 2. But since, on the other hand, each of the 'interpolated' chambers communicates with only one chamber in the annulus next internal to it, there may be but a single passage, in place of two or more.

102. The shelly plates which bound the chambered plane above and below, are formed of a succession of superimposed lamellæ (Plate XXXI. fig. 10). These lamellæ, which are of tolerably uniform thickness, are most numerous in the older or more central portions of the disk, and diminish in number towards the marginal or last-formed portions; so that it seems pretty certain that new lamellæ must be added from time to time, as the disk is augmented by the formation of new annuli. I have often met with appearances, which might seem to indicate that the formation of a new lamella over the entire surface of the disk, and the addition of a new annulus at its margin, were parts of one and the same act of growth, the new lamella being continued into the annular septum; but if this were constantly the case, the number of lamellæ which form the ceiling or floor of any chamber, would always correspond with the number of annuli external to it, which I do not find to hold-good.

103. Each of these lamellæ is perforated by an assemblage of parallel tubuli very closely set-together, which pass from its inner towards its outer surface (Plate XXXI. figs. 9, 10); and there is such a continuity between the tubuli of successive lamellæ, that a communication is thus established between the cavity of the thickest-walled chamber, and the external surface of the disk. These tubuli, however, are very minute, their diameter being not above $\frac{1}{10,000}$th of an inch. They are wanting in certain parts of the shell, which then presents a transparence that contrasts strikingly with the semi-opacity produced by the tubular perforations. By the comparison of vertical with horizontal sections taken in different planes, it appears that these transparent portions of the shell have a conical form, the base of each being on the surface of the shell, and its apex pointing to one of the angles at the outer margin of a chamber (Plate XXX. fig. 4, *c c*, *d d*). Their gradual widening towards the surface causes the diameter of their bases to increase with every addition to the thickness of the shell; and thus it is on the older portion of the shell, and especially on its central protuberance, that they become most conspicuous as rounded 'punctations' (§ 96). In horizontal sections of the superficial lamellæ, they form a large proportion of the area (Plate XXXI. fig. 6); whilst in similar sections near the chambered plane (fig. 9), they become blended with angular projections of the annular partitions, that fill-up the spaces left between the proper walls of the chambers by the rounding-off of their angles.

104. The lamellated structure is seen in these conical pillars (Plate XXXI. fig. 10, *b*), the lamellæ being continuous with those of the tubular part of the shell; so that at each increase in thickness, a tubular and a non-tubular portion must be superimposed upon the corresponding parts of the preceding lamella. Both in the tubular structure of the shell, and in the presence of these non-tubular columns, there is an exact conformity to the structure of *Nummulite* and its congeners*.

* I avail myself of this opportunity of correcting a mistake into which I fell in my original description of the structure of *Nummulite* (Quart. Journ. of Geol. Soc., 1850, p. 26), in regarding the non-tubular *columns* of the shell as having been *passages* which had become filled-up by the infiltration of carbonate of lime

105. I have now to speak of another feature in the structure of this organism, which most strikingly differentiates it from *Orbitolites* and its congeners, and at the same time furnishes an additional proof of its close approximation to *Nummulites*, notwithstanding the difference in its plan of increase. I allude to the system of *interseptal canals*, which establish a direct communication between the external surface, and the parts of the interior most removed from it. Such *radial* canals are seen both in horizontal and vertical sections (Plate XXIX. fig. 10, Plate XXXI. fig. 4, *c*) excavated in that shelly substance, which occupies part of the space that intervenes in the radiating partitions between the proper walls of adjacent chambers of the same annulus. When the canal reaches the end of the radial septum, it usually subdivides into two, which diverge at a considerable angle from each other, so as, by traversing the annular septum, to reach the two alternating radial partitions of the next annulus; and as each branch, before entering the partition towards which it runs, unites with another branch that inclines towards it from the radial canal next adjacent, it follows that just as every chamber communicates (normally) with the two alternating chambers in the annuli internal and external to it, so do the interseptal canals of every radiating partition communicate with those of the partitions alternating with it in the internal and external annuli. This arrangement, which cannot be described verbally without some complexity, will be readily comprehended by an inspection of Plate XXIX. fig. 11. In each radial partition there are at least two, and very commonly three tiers of such canals, as is best seen in vertical sections that cross the radial partitions transversely (Plate XXXI. figs. 4, 5). Short transverse branches, apparently communicating with the cavity of the chambers (Plate XXIX. fig. 11), are sometimes seen to proceed from the longitudinal canals; in regard to these communications I would not speak with confidence from what I have seen in *Cycloclypeus*; but that they exist in other organisms, hereafter to be described, is unquestionable. There can be no doubt, moreover, that the horizontal radiating canals communicate with *vertical* canals which pass directly towards the two surfaces of the disk, whereon they open (Plate XXXI. fig. 5, *c*); these canals are best seen in horizontal sections taken near the upper or under surfaces of the chambers (Plate XXXI. figs. 3, 9), in which they present themselves in regular rows, *d, d*, corresponding to the radial partitions; whilst in similar sections taken nearer the surface, they are seen to be less regularly disposed, in consequence of their following a somewhat oblique

in the process of fossilization. I was led to this by the very marked contrast which exists in *Nummulite* between the tubular, and non-tubular portions of the shell, and the peculiarly inorganic semi-crystalline appearance of the latter, closely resembling that of the calcareous infiltration which usually occupies the interior of the chambers. Subsequent examination, however, of *Nonionina* and other recent forms most closely allied to *Nummulite*, has satisfied me that these columns were part of the original shell, as my friend Professor WILLIAMSON maintained from the first. It is not a little curious, however, that in certain other species of *Nummulite* described by MM. D'ARCHIAC and HAIME, a system of passages should exist, very analogous to those which I thought I had discovered in *N. lævigata*.

direction. Still their continuity is maintained through all the successive layers of which even the thickest part of the shelly disk may be composed.

106. Besides the radial and vertical systems of canals, there is an *annular* system, which traverses the thick band of shell-substance that usually intervenes between the successive annuli, and which is continually brought into view in horizontal sections (Plate XXIX. figs. 10, 12). It appears from vertical sections traversing the annular septa, that several tiers of these annular canals may exist. I have frequently traced them running continuously for a considerable distance, without appearing either to give off any branches, or to communicate with the radial canals; but I have occasionally seen appearances which indicate that such a communication is established by means of canals passing vertically downwards at the angles of the chambers, so as to unite the three sets of canals into one continuous system, furnished with a multitude of orifices upon the surface of the disk. A representation of the whole canal-system, as I believe it to exist in this organism, is given in Plate XXX. fig. 4.

107. The uses of this canal-system can only be a matter of speculation. Not having had the opportunity of examining specimens in which the soft animal substance had been preserved, I am unable to affirm whether the interseptal canals of *Cycloclypeus* are occupied in the living state by a portion of the sarcode-body, or whether they are empty; but as I have unquestionable evidence that the former is the case in *Polystomella,* I should think there can be little doubt that it is also true of this genus. Now if we come to examine the purpose of this canal-system, we are at once struck with the fact, that it can scarcely be requisite for the nutrition of the segments of the sarcode-body enclosed within the chambers; since the mutual communication which these segments have with each other, seems fully as adequate for the purpose in *Cycloclypeus,* as it is in *Orbitolites, Orbiculina,* or *Alveolina.* If we examine wherein this organism so differs from the foregoing as to require such an additional system, we may find a not improbable answer in the possession of that additional skeleton which intervenes between the proper walls of the chambers; for the canal-system, excavated in the very substance of this, would seem to furnish the appropriate channel for its nutrition. And that such is its object, will be shown in a future memoir to be almost certainly proved, by the comparison of facts then to be adduced from the structure of other genera.

108. *Monstrosities.*—Although the number of specimens of this type which I have had the opportunity of examining is but small, yet two among them exhibited the same kind of monstrosity as that which is common in *Orbitolites*; namely, the superposition of a vertical plate upon the horizontal disk (Plate XXX. fig. 3). And in each it is sufficiently apparent that this plate has originated from the central cell, and that its increase has taken place *pari passu* with that of the horizontal disk.

109. *General Summary.*—If, now, we review the principal facts relating to the structure of *Cycloclypeus,* and compare them with those furnished by *Orbitolites* on the one hand and by *Nummulites* on the other, we shall see that, notwithstanding

its resemblance to the former in external aspect and plan of growth, it is far more closely allied to the latter in those features of its organization which indicate its physiological condition. It has been shown that in *Orbitolites* the communication between the different portions of the sarcode-body is so free, that the whole may be regarded as a continuous mass in which the segmental division is but imperfectly indicated (¶ 67); and this view is in complete harmony with the fact, that every addition made to the shelly disk forms (save in a few rare cases) an entire annulus. In *Cycloclypeus*, on the other hand, the chambers are so completely separated from each other laterally, that no other communication exists between them than such as may be established by the interseptal canals; and the communications between the chambers forming successive annuli, are only large enough to allow the passage of narrow bands of sarcode. Hence we see that there is here as much segmental independence as is consistent with the existence of these animals, which involves the maintenance of a communication between the innermost and outermost chambers, for the transmission of nutriment to the segments of the sarcode-body contained within the former. And this independence is strikingly manifested, by the frequency with which incomplete annuli are added to the previous margin of the disk, extending (it may be) along not more than a third, a half, or two-thirds of the entire circumference. The want of constancy in the number and position of the communications between the chambers (¶ 101), even in this high type of Foraminiferous structure, is a point of fundamental importance in the determination of the value of the shape of the aperture, as a character of discrimination between genera and species in this group of organisms. I have elsewhere shown that a like want of constancy exists in *Nummulites* (*op. cit.* p. 24), the different septa of one and the same specimen having apertures of very varied forms. We are not in a condition to assign a positive function to the minute tubuli that traverse the shelly layers intervening between the chambers and the two surfaces of the disk. But it is quite possible that these tubuli may give passage to pseudopodial prolongations of extreme minuteness, which may spread themselves forth from the whole surface of the disk, as we know that they do from the larger pores of *Rotalia*, and may coalesce so as to form upon it a continuous layer of sarcode, by whose instrumentality a lamina of shell is added from time to time to those previously existing. That either by giving passage to threads of sarcode, or by conveying organizable fluid, they furnish the means for progressive increase of the shell in thickness, would seem a very probable account of their use. Whether this hypothesis, however, be correct or not, there can be no reasonable doubt that the minute organization of these shelly layers in *Cycloclypeus* and *Nummulites*,—an organization as high as that of dentine,—is a feature of high elevation, as compared with the simple concretionary condition of the calcareous skeleton in the three genera previously examined.

110. Thus, then, in the almost complete isolation of the segments, in the enclosure of each of them in its own proper wall, in the interposition of an intermediate skele-

ton and of a canal-system between the contiguous walls of adjacent chambers, and in the minutely-tubular structure of the shell,—all of them points of high physiological importance,—*Cycloclypeus* differs entirely from *Orbitolites*, and agrees with *Nummulites*; whilst it agrees with *Orbitolites*, and differs from *Nummulites*, in the single circumstance that its mode of increase is cyclical instead of helical,—a difference which we have seen to present itself at two different periods of life of the very same specimens of *Orbitolites* and *Orbiculina*, and which must, therefore, be a character of quite subordinate importance.

Genus Heterostegina.

111. The correctness of the views just advanced is fully borne-out by the occurrence of a type, which bears precisely the same relation to *Cycloclypeus*, that *Orbiculina* bears to *Orbitolites*; one, namely, in which—the form and connexions of the individual chambers, the minute structure of the shell, and the distribution of the canal-system, being essentially the same—the plan of growth is *helical*, at least during the earlier period of life. This is the case with the genus *Heterostegina*, which was established by M. d'Orbigny in his memoir of 1825, but the essential structure of which he has altogether misapprehended. In his latest classification of the Foraminifera*, he ranks this genus in his order *Entomostègues*, which is composed of Foraminifera, whose segments are disposed in a spiral, but in two different planes alternating with each other, so as to render the entire shell inequilateral. Of the genus *Heterostegina*, which he ranks in close approximation to *Amphistegina*, he gives this definition:—"Coquille à spire embrassante, dont les loges sont séparées intérieurement par des cloisons transversales." Now in the first place, I am quite satisfied that the chambers of *Heterostegina* do not alternate one with another, but are arranged in one plane about the same axis, as is shown in figs. 1, 7, Plate XXXI.; and secondly, it gives by no means a correct idea of its structure, to liken its chambers to those of *Amphistegina* save for their division by transverse partitions.

112. I have had the opportunity of examining, by the kindness of Mr. Cuming, a very extensive series of specimens of this genus (belonging, apparently, to the species *H. costata*, D'Orb.†), from the Philippine islands; many of these are of large size, attaining as much as half an inch in diameter; and the appearance of the adult specimens scarcely differs less from that of the young (which latter are alone figured by M. d'Orbigny), than it does in the case of *Orbiculina*. The dredgings of Mr. Jukes have furnished me with numerous specimens of *Heterostegina* from the Australian coast; these closely correspond with the figures of M. d'Orbigny, being of comparatively small size, and not exhibiting that peculiar mode of development which is characteristic of the adult. As the Australian forms correspond precisely with the young of the Philippine, there can be no doubt of their specific identity. I recognise the shells of the same species as almost the sole components of a fossilized deposit,

* Cours élémentaire de Paléontologie, tom. ii. p. 201.

† Foram. Foss. de Vienne, p. 212.

which I understand to be very commonly met-with in Malta in fissures of the rocks, but of which the age is uncertain.

113. *Organization.*—The older specimens of *Heterostegina* (Plate XXX. fig. 2) present a form which, when regular, may be characterized as discoidal. There is, however, a knobby elevation or nucleus, which is usually somewhat excentric; and from this the turns of a spire are seen to commence, the last of which usually becomes continuous with one part of the margin of the disk (*a b c*), which there possesses a thick and defined border. As this spire opens-out, however, it becomes thinner and flatter; and this thinning is especially noticeable at that part of the margin of the disk (*a d c*) which corresponds with the opening of the spire. An examination of this portion of the disk shows that it precisely corresponds in structure with *Cycloclypeus*; the form and disposition of the chambers, their mode of communication, the structure of their shelly walls, and the interposition of the intermediate skeleton and of its canal-system, being all points of such close resemblance, that, as there is positively no other point of difference than a somewhat inferior thickness of the intermediate skeleton between the successive rows of chambers in *Heterostegina*, a fragment of this marginal portion of the spirally-formed disk of *Heterostegina* might be taken for a fragment of the cyclical disk of *Cycloclypeus*, without the possibility of certainly distinguishing them, and *vice versâ*. It is interesting to observe, moreover, how close is the conformity of these two types, even as regards their irregularities; for it will be seen, on an inspection of the figure, how little uniformity there is in the breadth of the successive rows of chambers, and how frequently it happens that a row is incomplete, just as in *Cycloclypeus* (¶ 96).

114. If, now, we examine the structure and arrangement of that spirally-coiled portion of the disk, which constitutes its nucleus, and which is best shown in younger specimens, we see that, as in the other cases, the first chamber (Plate XXXI. fig. 1, *a*) is globular, that the second (*b*) buds-forth from one side of this, and each successive chamber from the outer side of the preceding, just as in *Nummulite* or any other simple helical form. But before one turn of the spire is completed, each newly-formed chamber is seen to be double (*c c*) instead of single, a small portion being divided-off (as it were) near the marginal part of the whorl; and just about the part where the second turn is completed, the gradual opening-out of the spire gives room for the interposition of a third chamber in each row (*d*); and the number is soon further augmented, in accordance with the progressive increase in the breadth of the spire, the dimensions of the individual chambers retaining a pretty close conformity to a constant average. An examination of this figure will further show, that the increase in the number of chambers in successive rows always takes-place at the inner margin of the spire; some of those nearest the outer margin dying-out, as it were, without giving origin to new chambers in the next row. This may, I think, be connected with the fact, that there is always a large free opening (*e, e*) between one row of chambers and the next, at the inner margin of each spire (the situation of the open-

ing in *Nummulite*), and that the chamber of the row abutting on the preceding whorl is nearly always much larger than the rest, and gives origin to two or even three chambers in the next row. Further, it is shown by vertical sections (Plate XXXI. fig. 7), that the innermost chambers of the whorl are not only broader but thicker, their upper and under walls diverging from each other where they are to be continued over the spire they invest. Hence it is pretty obvious, that this portion of the whorl is that wherein the most active nutrition takes place; and it is here that the marked accession to the number of chambers occurs, which tends to carry the later rows around the whole circumference of the disk.

115. Each of the early turns of the spire not only surrounds, but completely invests its predecessor; as is best shown by a vertical section, such as that represented in fig. 7. The investing whorl does not, in the younger part of the spire, come into immediate contact with the two surfaces of that which it includes, but is separated from it by the prolongation of the chambers and of their septa, very much as in ordinary *Nummulites.* But between the later whorls, there are no such interspaces. The successive layers come into absolute continuity with one another; both the tubuli and the cones of non-tubular substance being continued from each into the one external to it. From the time that the rapid thinning-away and opening-out of the spire commences, the investment of the previously-formed whorls seems to discontinue. It is at the margin of each whorl, that we find the intermediate or additional skeleton most remarkably developed; and the canal-system sometimes forms quite a network in its substance (fig. 11).

116. *General Summary.*—It is obvious, from the foregoing details, that the physiological condition of each individual segment of the animal of *Heterostegina* must be essentially the same as that of each segment of *Cycloclypeus*; and that the only difference in the condition of the two organisms arises out of the mode in which these segments are increased in number. In *Cycloclypeus,* in which each row of segments is (normally at least) a complete annulus, a new annulus is formed around its predecessor by gemmation from its several segments along the entire circumference; and this mode of increase may be traced-back to the central cell, which buds-out equally on all sides. But in *Heterostegina*, each row is limited by the breadth of the spire; and while most of its chambers are formed by the like kind of gemmation from their predecessors, there is a special provision for an augmentation in the number of chambers at the end of the row nearest the previous whorl. Tracing-back the spire to its origin, we find that it commences in the one-sided gemmation of the central cell, just as we found it to do in *Orbiculina* (¶ 85) and in those forms of *Orbitolites* which have a spiral commencement (¶ 54). Hence there is nothing but the plan of increase, which separates *Heterostegina* from *Cycloclypeus*; and their relation is exactly the same as that of *Orbiculina* and *Orbitolites.* For in *Heterostegina,* as in *Orbiculina,* the first-formed portion is a spire, of which each turn invests its predecessors; but after three or four turns have been made, the spire spreads-out,

tends to surround the whole disk with its mouth or growing margin, and thenceforward the growth is cyclical, as in *Cycloclypeus* and *Orbitolites*.

Concluding Remarks.

117. Looking now to the general organization of the five genera which I have described, and to the peculiarities by which I have shown that each is characterized, I think that we are in a position to inquire into the value of the system of classification which has been erected by M. D'ORBIGNY on the exclusive basis of plan of growth; on which inquiry, the facts which I have now brought together have an obvious and direct bearing.

I. The very close physiological relationship which has been shown to exist between *Orbitolites* and *Orbiculina*, requires that they should be associated in the same Family, if not in the same Genus. In the classification of M. D'ORBIGNY they are ranked under different Orders (*Cyclostègues* and *Helicostègues*).

II. In like manner, the close physiological relationship which has been shown to exist between *Cycloclypeus* and *Heterostegina* requires that they should be associated in the same Family, if not in the same Genus. In the classification of M. D'ORBIGNY they would be ranked under different Orders (*Cyclostègues* and *Entomostègues*).

III. Again, the strongly-marked physiological difference which has been shown to exist between *Orbitolites* and *Cycloclypeus*, would seem to require that they should be separated by the widest possible interval; yet the system of classification adopted by M. D'ORBIGNY would have forced him to associate them (if he had been acquainted with the last-named type) side by side in the same Order (*Cyclostègues*).

IV. In like manner, the corresponding difference which has been shown to exist between *Orbiculina* and *Heterostegina*, would seem to require that they should be separated by the widest possible interval; yet the system of classification adopted by M. D'ORBIGNY would have forced him to associate them (if he had been acquainted with the real plan of structure of the last-named type) side by side in the same Order (*Helicostègues*).

V. The doctrine which I base on the foregoing facts,—that physiological conformity in the condition of each individual segment, as indicated by the structure of its shelly investment, is a character of primary importance, whilst the plan of growth, that is, the mode of increase in the number of chambers, is a character of subordinate importance,—is further borne-out by the following considerations:

1. In *Orbitolites*, the general plan being cyclical, the early plan of growth is frequently spiral.
2. In *Orbiculina*, while the early plan of growth is uniformly spiral, and this is sometimes continued throughout life, it is very commonly exchanged in adult age for the cyclical.
3. In *Alveolina*, whose physiological approximation to *Orbitolites* and *Orbiculina* is unquestionable, a plan of growth is followed, which differs more from

that of either of them, than the plans of the two latter differ from each other.

4. In *Heterostegina*, as in *Orbiculina*, the early plan of growth being uniformly spiral, there is a tendency in adult age to the assumption of the cyclical.

118. I think myself justified, therefore, by the foregoing comparisons, in asserting that the system of classification proposed by M. D'ORBIGNY is founded on an estimation of the value of characters, which is entirely erroneous; and that any classification which shall be really *natural*, must be based on an order of facts relating to the economy of the animal, of which his imperfect methods of observation have left him in entire ignorance*. It is not my intention, in this stage of the inquiry, to propose the erection of any new system; my sole aim, at present, being to establish the fundamental principles upon which alone can a natural arrangement be securely built-up.

EXPLANATION OF THE PLATES.

PLATE XXVIII.

Figs. 1–5. Successive stages of growth of the ordinary type of *Orbiculina adunca*, showing the change from the *spiral* to the *cyclical* plan of development:—16 diam.

Fig. 6. Edge of a disk of *Orbiculina adunca*, showing but a single row of apertures, as in the simple type of *Orbitolites*:—50 diam.

Fig. 7. Edge of a disk of *Orbiculina adunca*, showing three rows of apertures, as in the complex type of *Orbitolites*:—50 diam.

Figs. 8–10. Successive stages of growth of the less common type of *Orbiculina adunca*, in which the spiral plan of development is retained throughout life:—16 diam.

Fig. 11. Horizontal section of a disk resembling fig. 5:—16 diam.

Fig. 12. Horizontal section of a spiral resembling fig. 10:—16 diam.

Figs. 13–16. Portions of the superficies of *Orbiculina adunca*, showing varieties in the surface-markings:—50 diam.

Fig. 17. Central portion of a disk of a fossil *Orbiculina* (*Orbitolites Malabaricus*, CARTER), showing its spiral commencement on the plan of fig. 8:—16 diam.

Fig. 18. Marginal portion of a similar disk, showing the investment of the early whorl by the later, with the characters of the surfaces and edge:—50 diam.

Fig. 19. Marginal portion from a similar fossil disk, which had extended itself like fig. 5:—50 diam.

* I am constrained to make a similar remark respecting the classification proposed by Professor SCHULTZE (Über den Organismus der Polythalamien); which, although in many respects an improvement upon that of M. D'ORBIGNY, is almost equally far from representing the natural affinities of these organisms, as revealed by minute investigation of the structure of their *testæ*.

Fig. 20. Inner surface of one of the annuli of a similar fossil disk, showing the differentiation of the superficial from the intermediate layers of cells :—50 diam.

Figs. 21, 22. Portions of the superficies from similar fossil disks, showing varieties in the surface-markings :—50 diam.

Fig. 23. External aspect of *Alveolina Boscii* (recent); *a, a,* growing margin, showing multiple apertures resembling those at the margins of *Orbitolites* and *Orbiculina* :—40 diam.

Fig. 24. Longitudinal section of *Alveolina Boscii,* showing its internal structure and the successive stages of its growth :—40 diam.

PLATE XXIX.

Fig. 1. Section of disk of *Orbiculina adunca* parallel to the surface, showing the cells and their communications :—100 diam.

Fig. 2. Surface-layer of disk of *Orbiculina adunca,* showing its punctuated appearance :—100 diam.

Fig. 3. Vertical section of disk of *Orbiculina adunca,* passing through its central nucleus, and showing columnar arrangement of its cells, and the manner in which the earlier whorls of the spire are invested by the later :—100 diam.

Figs. 4–7. Transverse sections of *Alveolina Boscii,* showing the increase in the number of turns of the spire from its terminal to its central portion :—40 diam.

Fig. 8. Portion of a similar transverse section enlarged; showing—*a, a, a,* internal prolongations of the surface-layer; *b, b, b,* outer longitudinal canals; *c, c, c,* inner longitudinal canals :—80 diam.

Fig. 9. Portion of a longitudinal section (Plate XXVIII. fig. 24) similarly enlarged; showing 1, 2, 3, 4 successive layers formed by the involution of the spire; and in each the passages *a a, b b,* and *c c,* between one band and the next. (N.B. The variation in the appearances presented by the other layers, depends upon the difference of relative direction in which the section traverses each of them respectively) :—80 diam.

Fig. 10. Thin section of *Cycloclypeus,* taken parallel to the surface, and close to the covering of the chambers; showing part of the system of interseptal canals :—50 diam.

Fig. 11. Diagram of a single chamber of *Cycloclypeus,* showing its relations to other chambers, and to the interseptal system of canals: *a,* cavity of chamber; *b, b′,* adjacent chambers of the same annulus, each separated from *a* by a double septum; *c c′* and *d d′,* chambers of internal and external annuli, separated from *a* by the annular partitions *e e, e′ e′,* but communicating with it by the passages *f, f, f, f*; in the septa between *a* and *b, b′* are seen the interseptal canals, each of which sends two oblique branches across the annular septa, to communicate with corresponding canals in the septa

dividing *c c′* and *d d′*; these interseptal canals seem to communicate by short lateral twigs with the cavities of the adjacent chambers, whilst at *g, g, g, g* they become connected with vertical branches, which unite them with those of other planes: at *h h, h′ h′* are seen the canals proper to the annular septa.

Fig. 12. Thin section of *Cycloclypeus*, passing through its central plane, showing portions of four annuli, 1 1, 2 2, 3 3, 4 4, with the general relations and connexions of their chambers, the double septa by which they are separated, and (in parts) the interseptal system of canals:—36 diam.

PLATE XXX.

Fig. 1. General view of a disk of *Cycloclypeus*, showing the aspect of its surface, and the appearances presented by horizontal and vertical sections:—12 diam.

Fig. 2. Surface-view of a full-grown specimen of *Heterostegina*, showing its tendency to assume the discoidal form by the opening-out of the spire: *a b c*, the thickened margin of the spire; *c d a*, its growing edge or mouth:—10 diam.

Fig. 3. Monstrous specimen of *Cycloclypeus*, having a vertical plate superimposed upon the horizontal disk:—5 diam.

Fig. 4. Ideal figure of a portion of a *Cycloclypeus*-disk laid-open to show the details of its structure: *a, a, a*, upper stratum, consisting of superimposed tubular laminæ; *b, b, b*, portion of lower stratum; *c, c, c*, cones of non-tubular substance, sometimes perforated by larger canals; *d, d, d*, their bases projecting on the surface; *e, e*, plates of non-tubular substance, continuous with the septa between the chambers; *f, f*, passages of communication between the chambers, through the inter-annular partitions, as seen in section; *g, g*, the same as seen from the interior of the chambers; *h, h*, interseptal canals cut across; *i*, a chamber on the walls of which the system of interseptal canals is represented as fully displayed; *k, k*, passage of the principal canals along the line of junction between the roof of the chambers and the vertical septa:—60 diam.

PLATE XXXI.

Fig. 1. Section of a young specimen of *Heterostegina*, taken parallel to the surface, partly through the chambered plane and partly (owing to a slight inequality of the specimen) through the shelly investment of the chambers, the boundaries of which, however, are still distinguishable, owing to the difference of texture between the shell that covers the chambers and that which unites with the septa: *a*, first cell; *b*, second cell; *c c*, first subdivision; *d*, second subdivision; *e, e*, large passages connecting the chambers that abut on the pre-formed whorl:—60 diam.

Fig. 2. Vertical section of *Cycloclypeus*, taken in the direction of one of the annuli, showing the upper and under layers *a b*, *a' b'*, with the septa between the chambers, each of which is seen to be composed of two layers with an interposed lamella, pierced by two or more canals whose orifices are shown; on the left side of the figure, the chambers are seen to be closed by the inter-annular septum, which is pierced by several irregularly-disposed passages, *c, c*, that establish communications between each chamber and those of the annuli internal and external to it:—60 diam.

Fig. 3. Section of *Cycloclypeus*, taken horizontally (or parallel to the surface of the disk) through the shelly covering of the chambers, showing its minutely tubular structure, and its junction with the two interannular non-tubular septa *a b*, *a' b'*, and with the intercameral septa *c c*, *c' c'*, along the course of which last are seen the divided ends, *d*, of vertical interseptal canals: the chamber thus inclosed is remarkable for its great length in comparison with its breadth:—100 diam.

Figs. 4 & 5. Vertical sections of *Cycloclypeus*, corresponding with fig. 2, and showing irregularities in the division of the chambers: at *c c*, fig. 4, are seen the orifices of the interseptal canals laid open; and at *c*, fig. 5, is shown a part of the vertical canal-system, passing upwards and downwards towards the two surfaces of the shell, through its transparent portions:—60 diam.

Fig. 6. Section of *Cycloclypeus*, taken in the same direction as fig. 3, but nearer to the surface, showing the relation of the tubular and non-tubular portions of the shell, and the orifices of the canals:—100 diam.

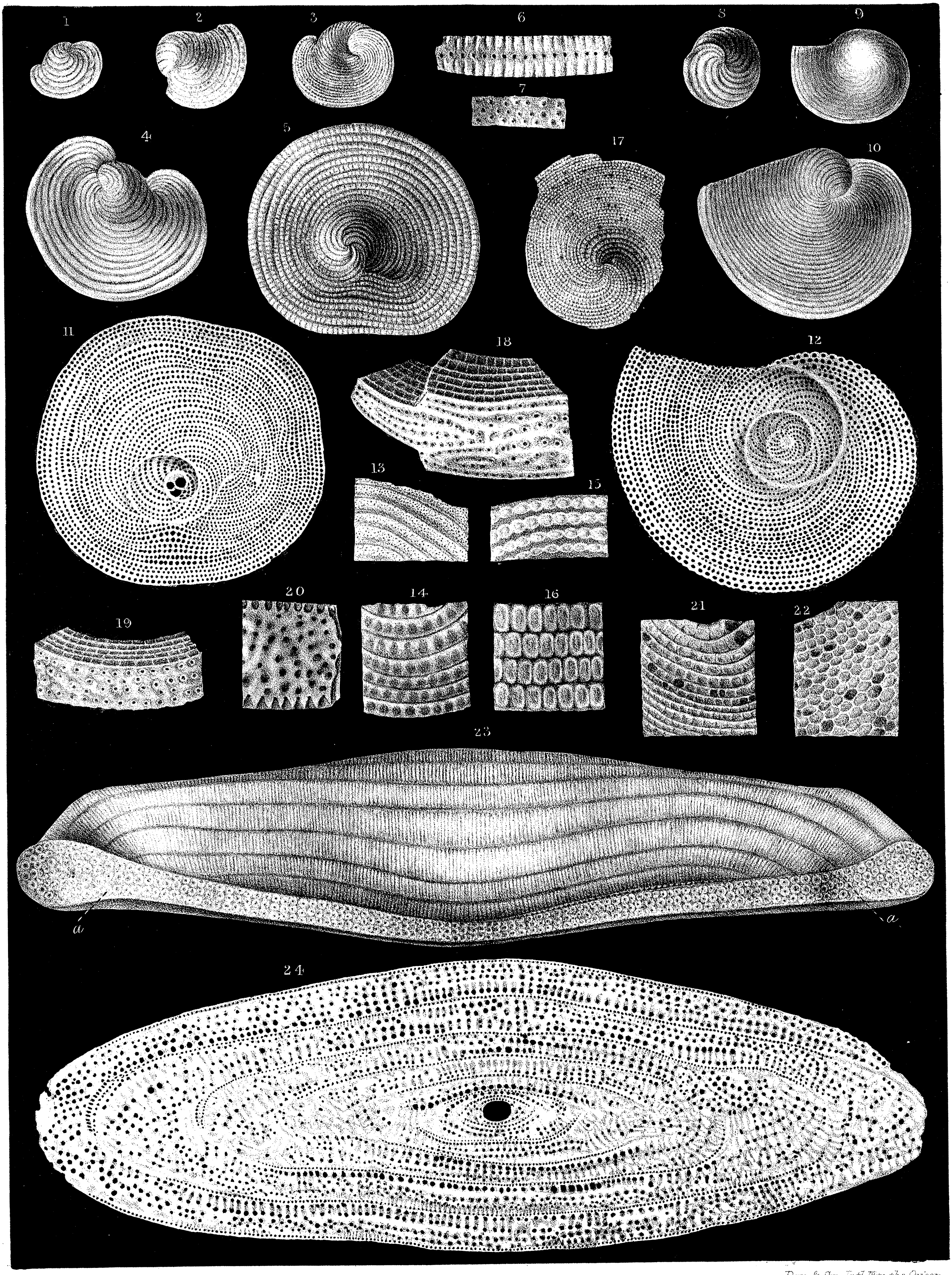
Fig. 7. Vertical section of young specimen of *Heterostegina*, showing the investment of the first-formed whorls by those which succeed them, and (on the right) the commencement of the thinning-out: *a, a, a*, passages of communication between the successive bands of which each whorl is composed:—35 diam.

Fig. 8. Vertical section of young disk of *Cycloclypeus*, showing at *a* an irregular subdivision into two or three layers of chambers:—22 diam.

Fig. 9. Horizontal section of a portion of *Cycloclypeus*, corresponding with fig. 3, but more highly magnified:—150 diam.

Fig. 10. Vertical section of the floor of one of the chambers, showing its lamellated arrangement, the minutely-tubular structure of one portion of it, *a a*, and one of the non-tubular cones, *b b*, which is continuous with the annular septum *c*:—150 diam.

Fig. 11. Horizontal section of a portion of *Heterostegina*, taken near the margin, showing the disposition of the chambers, the communications *a a* between those of successive bands, the minutely-tubular structure of their roof, the interseptal canals, and the high development of the canal-system in the thickened non-tubular margin, *b b*:—150 diam.



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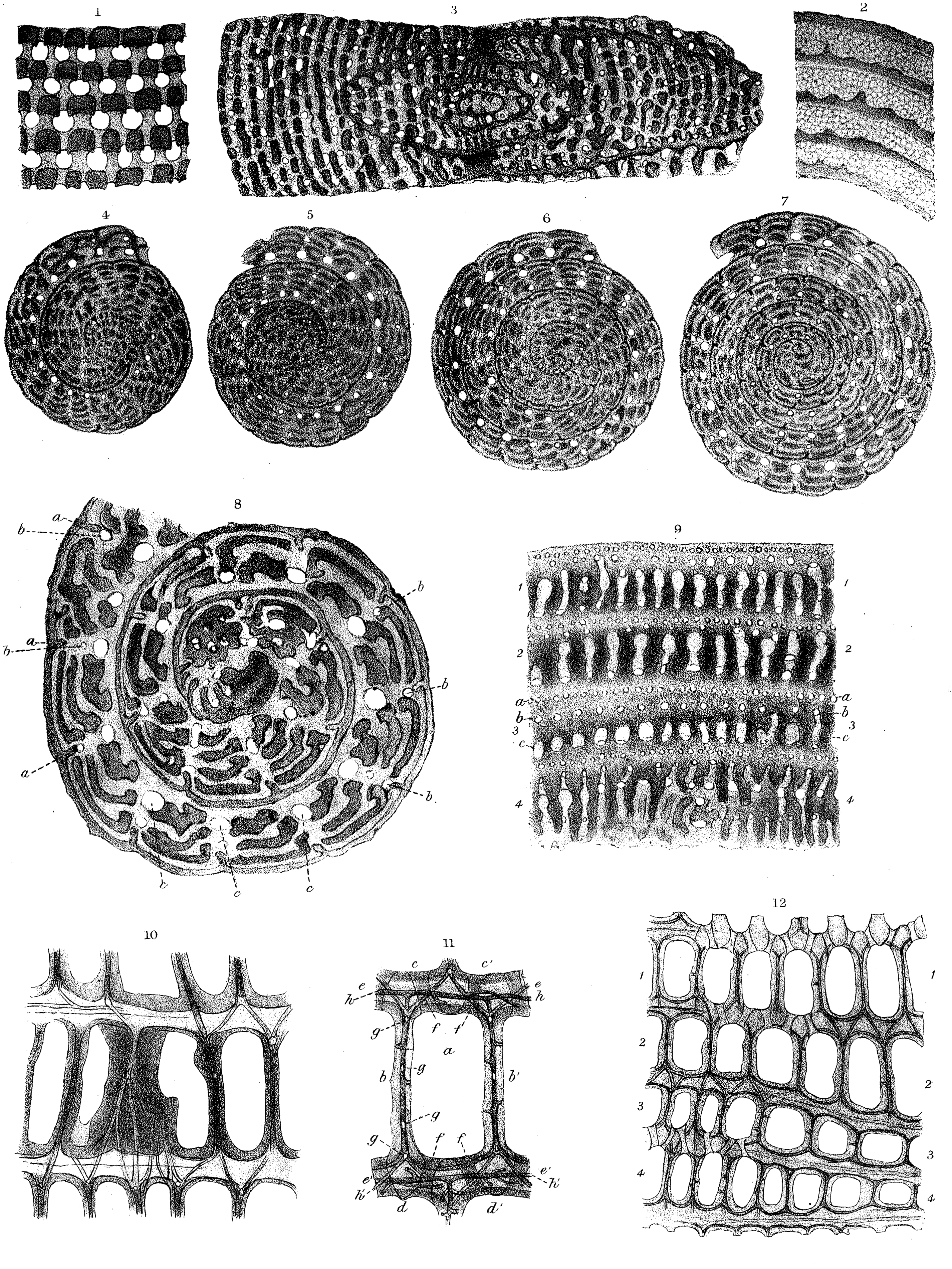
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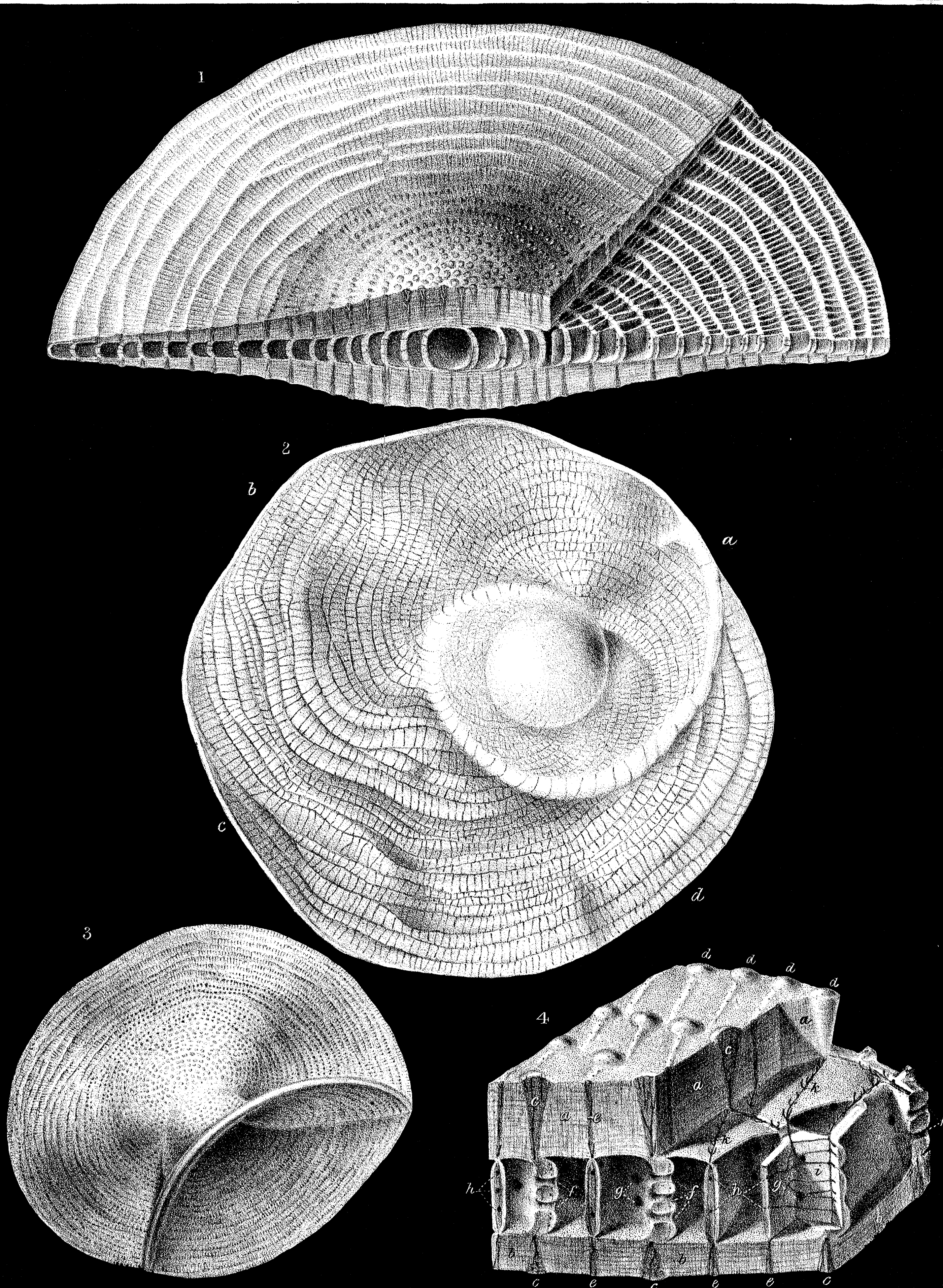

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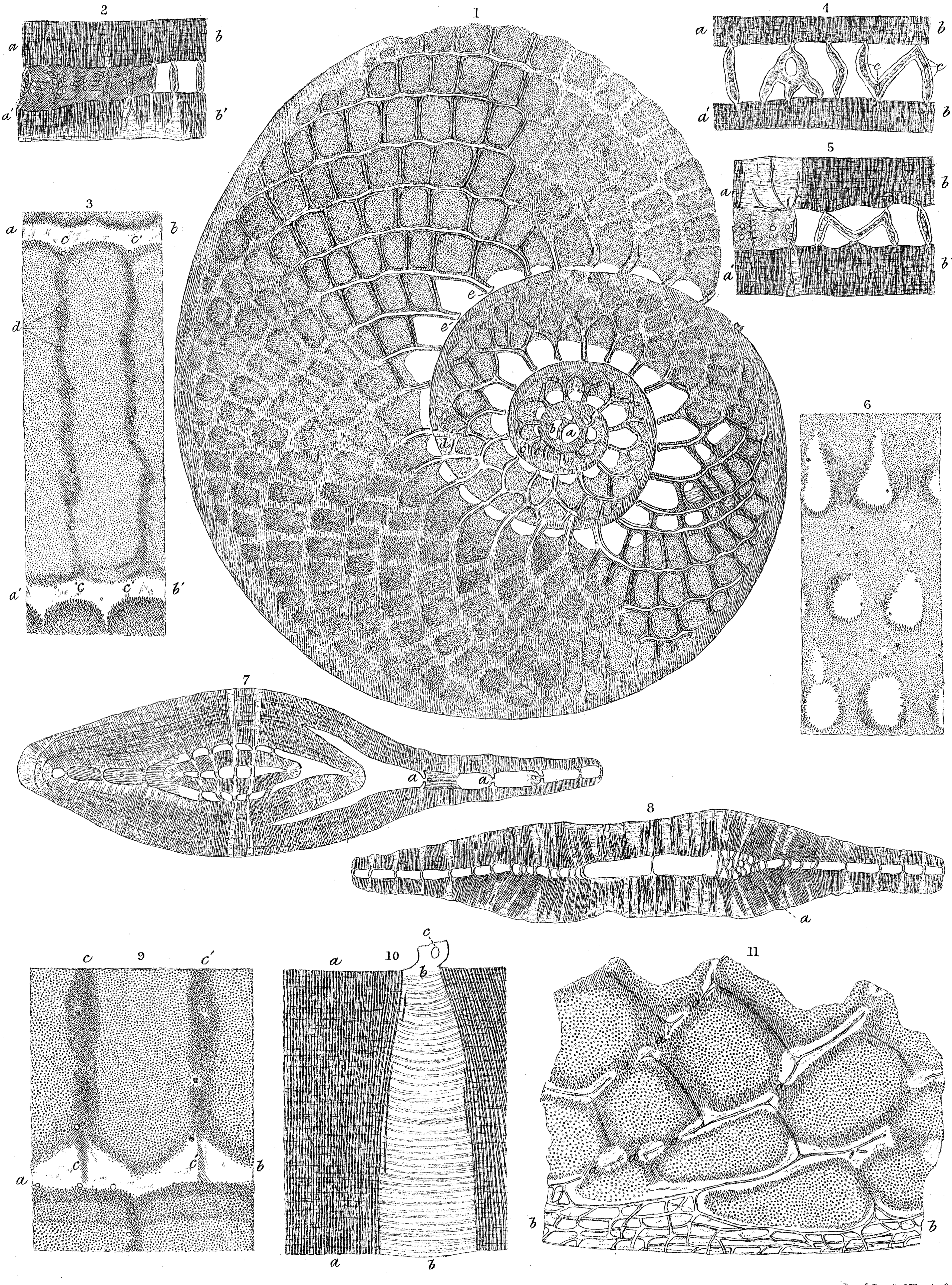

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