XXV. *Researches on Foraminifera.—Fourth and concluding Series.*

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172. I have now to bring to a close my account of the structure of those typical forms of Foraminifera which it has been my object to elucidate, by a description of four remarkable generic types; of which the first, *Polystomella*, has long been known, but has been hitherto very imperfectly comprehended; the second, *Calcarina*, has never been carefully studied; the third, *Tinoporus*, has only been very imperfectly known in one of its forms; and the fourth, *Carpenteria*, is altogether new. Each of these will be found to present features of interest peculiarly its own;—*Polystomella* being remarkable for the very symmetrical distribution of its canal-system, whose existence and whose relation to the multiple fossæ upon its surface have hitherto been altogether overlooked;—*Calcarina* being distinguished by the extraordinary development of its "intermediate" or rather "supplemental skeleton," and by the amplification of the canal-system for its nutrition;—*Tinoporus* presenting us with a type of structure that is intermediate between the *Rotaline* group (to which it is allied in the character of its individual chambers) and the *Orbitoline* (to which it approximates in its mode of growth), and that helps us greatly in the interpretation of the structure of the fossil *Orbitoides*;—and, lastly, *Carpenteria* furnishing us with a connecting link of the most striking significance between Foraminifera and Sponges.

Genus Polystomella.

173. *History.*—Of the minute shells to which the generic name *Polystomella* is now assigned, one species, now known as *P. crispa*, seems to have early attracted the attention of conchological observers and collectors, on account both of its beauty and of the frequency of its occurrence; having been described and figured more than a century ago by Plancus and Gualtieri, and adopted by Linnæus under the designation *Nautilus* into his 'Systema Naturæ.' By this designation it continued to be known from the time of Linnæus to that of Lamarck; having been described and figured by Walker, Soldani, Fichtel and Moll, Montague, Dillwyn, and many other writers of the latter part of the last and the early part of the present century. Its dissimilarity to *Nautilus* was first clearly pointed out in 1822 by Lamarck; who conferred upon it the generic distinction *Polystomella*, apparently under the impression that the numerous pits on its surface are really multiple mouths of passages leading directly to its chambered cavity. His definition of the genus, contained in the First Edition of his 'Animaux sans Vertèbres' (tom. vii. p. 625), is as follows:—"Coquille discoïde, multiloculaire, à tours

contigus, non apparens au-dehors, et rayonnée a l'extérieur par des sillons ou des côtes qui traversent la direction des tours. Ouverture composée de plusieurs trous diversement disposés." The genus was soon afterwards adopted by M. D'ORBIGNY in his first systematic classification of Foraminifera*; and he seems also to have adopted LAMARCK'S idea of the structure of this type, which he defines as follows†:—" Les Polystomelles se distinguent de tous les genres de Nautiloidées par ce caractère singulier, que les ouvertures du bord de la dernière loge reparaissent en fossettes, plus ou moins allongées, sur toutes les autres; les dernières seulement ouvertes, les autres fermées. Il en résulte qu'extérieurement ce genre se distingue de suite par ce grand nombre de petits excavations transversales, qu'on remarque sur toutes les espèces." He elsewhere adds to this description: " L'animal fait sortir des filamens non seulement par des ouvertures du dessus de la dernière loge, mais encore par des pores des côtés des dernières"‡. The same definition is more concisely repeated by M. D'ORBIGNY in his latest publication on the subject, notwithstanding that the true structure of *Polystomella crispa* had in the mean time been elucidated by Professor WILLIAMSON in his admirable memoir on that species; the genus *Polystomella* being still defined (in the 'Cours Élémentaire de Paléontologie et de Géologie Stratigraphiques,' tom. ii. p. 197) " Coquille nautiloïde, pourvue de nombreuses ouvertures sur la dernière loge et sur les côtés de la coquille; une cavité simple au loges."

174. I have already referred, in my General Introduction, to the elaborate inquiry of Professor WILLIAMSON into the organization of *Polystomella crispa*§, as having not only established several important facts in regard to its minute structure, but as having furnished the starting-point for all future investigations of the same kind: it now becomes necessary that I should somewhat fully recapitulate the most important features of his description, in order that it may be seen in what points my own inquiries upon a more developed form of the same group have evolved results supplementary to his. To the accuracy of his descriptions I can bear the fullest testimony; having not only had the opportunity, through the kindness of Professor WILLIAMSON, of examining the preparations still in his possession both of the shell and of the animal of *Polystomella crispa*, but having carried out an independent investigation upon specimens collected by myself.

175. On the exterior of each of the segmental divisions of the shell of *P. crispa*, strong transverse crenulations present themselves, which are deepest near the convex margin of the preceding septal band, where they terminate somewhat abruptly, and usually disappear before reaching the concave margin of the subsequently-formed chamber. The depressions between the elevated ridges, which are the "fossettes" of M. D'ORBIGNY, often present the appearance of orifices; but this appearance is fallacious, since at no

* "Tableau Méthodique de la Classe des Céphalopodes," in Annales des Sciences Naturelles, 1826.

† Voyage dans l'Amérique Méridionale, tom. v. p. 29.

‡ Foraminifères Fossiles de Vienna, p. 121.

§ Transactions of the Microscopical Society, First Series, vol. ii. p. 159.

period in the growth of the shell is there any passage through these "fossettes" to the cavity of the chamber,—the only communication possessed by any chamber either with contiguous chambers or (in the case of the outermost chamber alone) with the exterior, being afforded by a variable number of minute orifices (corresponding with the septal pores of *Peneroplis*) which are to be found near the inner margin of each septal plane, close to its junction with the preceding convolution. Corresponding to the elevated ridges of the crenulations, we find a series of grooves on the internal surface, which shallow towards the anterior or concave margin of each segment, and deepen towards the posterior or convex margin; and for a short distance from the posterior septum each groove is converted into a tube by a narrow lamella given off internally from the septum. These tubes, however, establish no communication between the contiguous chambers; for they are *culs de sac*, closed-in by the lamella of the septum which formed the boundary of the previously-formed chamber. In the living state they are occupied (as can be shown by examination of the decalcified body) by a set of processes of sarcode, which extend backwards for a short distance from both the outer or lateral margins of each segment of the sarcode-body, and then terminate abruptly. From the neighbourhood of the inner arch of each segment, on the other hand, there proceeds a series of threads of sarcode much slenderer than the "retral processes" just described, which unite each segment to the two contiguous segments before and behind, passing through the row of pores already mentioned as visible along the inner margin of the septum. The shell is described by Professor WILLIAMSON as "crowded with myriads of minute foramina," and as also covered over with small pointed tubercles, which, from the rounded forms of their bases, and their great transparency, may be easily mistaken for apertures in the shell, especially in the "fossettes," where these tubercles are often very large. He further pointed out that the umbilical region is occupied by a solid mass of shelly substance, into which the decalcified animal does not appear to extend, and the surface of which is often marked with small depressed pits, the orifices of vertical internal passages, through which pseudopodia are probably protruded.

176. It is obvious from the foregoing account that if *Polystomella crispa* is to be taken as the type of the genus, the generic definition given by M. D'ORBIGNY is based on an entire misapprehension of its true structure; the only considerable departure from the general type of *Hélicostègue* structure being the substitution of a series of isolated pores for the ordinary single orifice of communication between the successive chambers (a difference which in the case of *Peneroplis* and *Dendritina* we have seen to have not even a specific value), and the supposed lateral orifices having no real existence.

177. Subsequently to Professor WILLIAMSON'S memoir, an elaborate account of the characters of the genus *Polystomella*, and especially of a species designated *P. strigilata* (which seems to me only one of the multiform varieties of *P. crispa*), has been given by Professor MAX SCHULTZE, in the excellent treatise 'Über den Organismus der Polythalamien,' to which I have already referred. He had the advantage of being able to study this species in the living state; and he has thus been enabled to give a beautiful

figure, not merely of the shell, but also of the pseudopodia protruded from various parts of its surface; as well as to make preparations of the sarcode-body of the animal, by dissolving away the shell in dilute acid. He does not seem, however, to have had the advantage of a full knowledge of Professor WILLIAMSON'S memoir; his acquaintance with it being apparently limited to the abstract of it contained in 'L'Institut' (No. 787); and I find in his description of the shell a confirmation of the belief I have already had occasion to express, that he has not availed himself as fully as is desirable of the mode of examining the intimate structure of these minute objects by the preparation of very thin sections. In every point, in fact, in which he differs from Professor WILLIAMSON, I am satisfied that the truth lies with the latter; and this not merely on account of the entire coincidence between the results of my own inquiries into the structure of *Polystomella crispa* and those of my accomplished predecessor, but also because our views are in every respect borne out by the structure of the much larger and more highly developed form of *Polystomella* which I am presently to describe. One point in Professor SCHULTZE'S description, however, requires special notice. He states that each of the crenulated prominences which are seen on the surface of the lateral walls of the chambers is traversed longitudinally by a wedge-shaped fissure, that is narrowest as it approaches the septal band, near which it penetrates the cavity of the chamber, whilst it becomes shallower as it widens out at the part where the crenulation merges in the smooth wall of the shell. I expect to be able to show that the supposed "fissures" of Professor SCHULTZE no more communicate with the cavity of the chambers, than do the "fossettes" of M. D'ORBIGNY; but that they are really the outlets of the canal-system, whose existence in *Polystomella* has not been discovered either by Prof. SCHULTZE or by Prof. WILLIAMSON, but which attains an extraordinary development in the type which has specially fallen under my observation.

178. The specimens of *Polystomella*, of which I have now to give an account, were chiefly collected by Mr. JUKES in his Australian dredgings; I have met with the same form, however, in Mr. CUMING'S Philippine collection; and I have reason to believe it to be generally diffused through the Indian and Polynesian seas. It seems to be the *P. craticulata* of FICHTEL and MOLL. The empty shells are occasionally the subjects of that very curious infiltration of silicate of iron, to which attention was first directed by Professor EHRENBERG as a peculiar mode of fossilization of Foraminifera,—causing internal "casts" of their chambers to be preserved long after their shells have been destroyed,—in his memoir 'Über den Gruensand und seine Erläuterung des organischen Lebens"*, and which was soon afterwards shown by Professor BAILEY† to be taking place at the present time over certain parts of the ocean-bottom. I have recently been enabled, through the kindness of Mr. W. K. PARKER, to examine a number of most perfect and beautiful "casts" which he has obtained, not merely of fragments, but of the entire animal of this type of *Polystomella*, by treating with dilute acid shells which

* Abhandlungen der Königl. Akad. der Wissenschaften, Berlin, 1855.

† Quarterly Journal of Microscopical Science, vol. v. p. 83.

have been thus infiltrated. These casts represent not merely the segments of the sarcode-body with their connecting stolons, but also those prolongations of the body which occupied the canal-system; and as they preserve with the greatest exactitude the natural forms and relative positions of these parts, they really afford more precise and satisfactory information than that which could have been derived from an examination of the sarcode-body of the animal itself, since its softness and friability are such as greatly to interfere with the due appreciation of its characters, when it is deprived of the support afforded by the shell.

179. *External Characters.*—This type of *Polystomella* (Plate XVII. fig. 1, *a*, *b*) is distinguished from the others already noticed, not only by its comparatively large dimensions,—the diameter of some of the specimens in my possession exceeding one-sixth of an inch,—but by the considerable proportion of its two lateral surfaces occupied by that solid calcareous nucleus which is confined in other species to the umbilical region. The diameter of this nucleus is usually about three-fifths of the whole diameter of the specimen; so that it covers and conceals all the earlier convolutions, meeting at its outer margin the chambers of the last formed whorl (as is made evident by vertical sections, Plate XVII. fig. 2), which are consequently the only chambers that show themselves externally, although the last formed whorl does not itself extend far over the preceding. I have not unfrequently found this central nucleus, however, to be sufficiently transparent (after its surface has been cleaned by a short immersion in dilute acid) to allow of the inner convolutions being discerned through it, when the microscope is focused down to their surface, and a strong light is directed upon this; and it then becomes obvious that, if the solid nucleus were removed, the form of the shell would be bi-concave instead of bi-convex, the thickness of each whorl (*i. e.* the distance between its two lateral surfaces) being greater than that of the preceding, and the later whorls not extending themselves over those previously formed. The septa are marked externally (as in most other Foraminifera of the nautiloid type) by bands which indicate their junction with the outer walls of the chambers: these bands are meridional (so to speak) in their direction, extending from the margin of the nucleus on one side to that of the nucleus on the other side; they are not usually (in adult specimens at least) either elevated above or depressed below the surface of the walls of the chambers on either side of them; but they are distinguished by their difference of texture, their substance being much more transparent and glistening than that of which those walls are composed.

180. The surface of the central nucleus is marked at pretty regular intervals with minute punctations (fig. 1, *b*), each of which occupies the centre of a little dimple or depression; and rows of similar punctations are very commonly seen to extend from the nucleus on either side, in a direction corresponding to that of the septal bands (fig. 1, *a*), two such rows usually intervening between each septal band and that which precedes or follows it (Plate XVIII. fig. 1, *hh*, *h'h'*). In the older portion of the last formed whorl, it is sometimes to be observed that these punctations with their surrounding dimples

constitute the only interruption to the general uniformity of the surface, the septal bands not being clearly distinguishable; and this disposition is commonly found to prevail on the surface of the inner whorls, when it is exposed by the removal of the outer (*ii'*, *ii'*). In the newer portion of the last formed whorl, on the other hand, we may observe that instead of each punctation having a separate dimple of its own, the corresponding punctations of the two rows lie in a succession of furrows that pass transversely between the septa (*gg'*, *gg'*). In the most recently formed portions of specimens that have not attained their full growth, we find these furrows to be deeper towards the posterior than towards the anterior margin of each interseptal space; and in the deepest portion of each of these furrows, which obviously correspond with the "fossettes" of *P. crispa* (although much less pronounced), a minute punctation may be brought into view by careful examination,—a corresponding row of punctations being also traceable on the other side of the septum*. These varieties of superficial aspect may present themselves on different parts of one and the same specimen; and it will appear from the explanations which I shall presently have to furnish, that they are occasioned by differences in the degree in which the proper external wall of the chambers is thickened by an exogenous deposit upon its surface, continuous with that of which the central nucleus is composed (¶ 185).

181. *Internal Structure.*—By the fortunate contingency already adverted to, I have been enabled to study the internal structure of this remarkable type, not merely by examining thin sections of the shell taken in various directions, and by comparing the appearances they present with those obtained by laying open its interior by fracture; but also by submitting to microscopic examination siliceous "casts" of its cavities and channels, which appear to represent with the utmost fidelity the forms and connexions of the various parts of the sarcode-body which occupied those cavities and channels in the living state of this organism. Between the results of these two modes of study I have found the conformity to be so exact, that the account of the structure of the animal which I should have given from examination of the shell alone, has not needed to be modified in the slightest particular by the information more recently furnished by these "casts;" and, in point of fact, the ideal representation in Plate XVIII. fig. 1, which was entirely based on the former source of information, has not needed the least alteration to bring it into accordance with the exact delineations of the latter class of objects which are given in figs. 12, 13†.

182. In the general shape and proportions of its segments, this type of *Polystomella*

* In order to distinguish the orifices of these punctations, it is advantageous to remove from the surface of the shell that opacity which it derives from abrasion, and to get rid of the fine particles of calcareous matter which often choke up and obscure its pores. This is readily effected by immersing it for a short time in water so slightly acidulated with nitric or hydrochloric acid as only to exert a very feeble degree of solvent power.

† I think it well to state this circumstance, as it may increase the confidence accorded to my descriptions of other types, of which the shells alone have been submitted to examination.

differs remarkably from most of the other nautiloid Foraminifera; the breadth of each of the later whorls being many times exceeded by what may be termed its thickness, that is, by the distance between its two lateral surfaces. Thus the segments come to have somewhat of the form and arrangement which the carpels of an orange would exhibit, if, instead of lying in a single circle round a central axis, they were disposed in a succession of whorls, with a progressive increase in their dimensions. This comparison may be conveniently carried a little further. For as each carpel of the orange has its own investing membrane, so that the partitions between the adjacent carpels are double, so each segment of *Polystomella* has its own proper shelly investment, causing the septa which separate the adjacent segments to be double,—as was originally pointed out by Professor WILLIAMSON, and as I have shown to be the case also in the higher types of Foraminifera generally. But further, as the separate carpels of the orange are collectively invested by a general integument, which also to a certain degree dips down between them, and which fills up what would otherwise be void spaces about the two poles of the spheroid, so shall we find that the proper walls of the spirally arranged segments of *Polystomella* are strengthened and consolidated by a secondary calcareous deposit upon their external surface, corresponding to that "intermediate skeleton," of which less developed examples have already been furnished by *Cycloclypeus*, *Heterostegina*, *Operculina*, and *Amphistegina*,—its most distinctive peculiarity in *Polystomella* being its extraordinary thickness on the two lateral surfaces of all but the last formed whorl.

183. The spire of *Polystomella*, like that of other nautiloid Foraminifera, commences in a central cell, the dimensions of which are extremely variable; the difference between the extremes of its size being, in fact, not less remarkable than that which I have shown to present itself in *Orbitolites* (First Series, ¶ 44). Thus in Plate XVII. fig. 3, which represents a section of the five inner whorls of a full-grown specimen, taken through the equatorial plane, we trace a progressive diminution in the size of the chambers as we approach the central cell, which is itself no larger than the chambers in nearest proximity to it. In fig. 4, on the other hand, which represents a corresponding section of the inner portion of another specimen, drawn under the same magnifying power, we see that not only is the size of the earlier whorls and of their component chambers considerably greater, but that the central cell alone occupies about the same space as the first 2½ whorls of the specimen represented in fig. 3. The average seems to be intermediate between these two extremes. The breadth of the successive whorls increases much more gradually than in most other nautiloid Foraminifera, in this respect resembling *Nummulites* rather than the recent forms described in former memoirs; and there is no tendency whatever, even in the oldest and most developed specimens, to that rapid opening-out of the spire, which we have seen to be so marked a feature of the older specimens of *Heterostegina*, *Peneroplis*, *Operculina*, and *Amphistegina*. The largest number of whorls I have met with in any individual (that, namely, to be counted in the specimen whose inner portion is represented in fig. 3) is *eleven*:

the earlier four or five of these completely invest the preceding, their chambers extending on either side to the centre of the spire, as is partly shown in the vertical section (Plate XVII. fig. 2); but as new whorls are added around these, the chambers cease to be thus prolonged over the preceding whorls, which would consequently be apparent externally if not concealed by the nucleus. The distance between the successive septa remains nearly the same after the spire has made two or three turns; and thus the size of the segments, as seen in an equatorial section, remains pretty much the same throughout all the later growth of the shell, while the number of chambers in the successive convolutions increases nearly in proportion to the length of those convolutions.

184. In these particulars, therefore, *Polystomella* corresponds rather with the *Cyclostègue* than with the ordinary *Hélicostègue* Foraminifera; and this correspondence is further borne out by the existence of an obvious relation in the position of the chambers of successive whorls, which exists in the former, but which cannot be traced in those forms of the latter to which our attention has hitherto been directed. It has been shown that, in *Orbitolites* and *Cycloclypeus*, the chambers of each concentric zone normally alternate in position with those of the zones which adjoin it internally and externally (¶¶ 17, 18, 100); and that this relation arises out of the mode of their communication with each other. In *Peneroplis*, *Operculina*, and *Amphistegina*, on the other hand, the position of the chambers of each successive whorl appears to be perfectly independent of that of the chambers in the whorl which preceded it. Now in the *Polystomella* whose structure we are considering, such an alternating arrangement appears to be the normal one, as is shown in the relation of the chambers *b*, *b*, Plate XVII. fig. 8, to *a*, *a*, and *c*, *c*; so that lines drawn from the centre of the spire through the septa of one convolution would pass through the middle of the chambers of the next, and would again meet the septa of the convolution beyond. This arrangement is shown in Plate XVII. fig. 7, as it presents itself in an actual section, and more diagrammatically in Plate XVIII. fig. 1; in both the vertical plane of section lays open the chambers a, a^1, a^2, whilst it traverses the septa b, b^1, b^2, b^3 of the alternating whorls. It is, however, by no means constant; being very liable to be disturbed by that *interpolation* of additional chambers, which is required for the augmentation of their number in successive whorls. We shall presently see (¶ 189) that although this relation does not depend, as in *Orbitolites* and *Cycloclypeus*, upon direct communications between the chambers of successive rows, it is manifestly connected with the peculiar disposition of the canal-system, which here acquires a remarkable development and importance.

185. Although, however, there is but little progressive increase in the dimensions of the successive chambers, and of the segments of the sarcode-body which occupy them, as seen in sections taken through the equatorial plane, it is made obvious by sections made at right angles to this (Plate XVII. fig. 2), that a rapid augmentation takes place in what may be termed the meridional direction; the distance between the two lateral surfaces of each whorl being considerably greater than between those of the preceding, so that the chambered portion of the shell progressively increases in thickness from the centre

towards the circumference. The conical hollow thus left on each side in the central portion of the shell, is entirely filled up by the solid nucleus already adverted to: the calcareous deposit, however, of which the nucleus is composed is by no means limited to it, but extends over the whole outer surface of each whorl, except where (in well-preserved specimens) the portion last formed is as yet unconsolidated by it. For a careful examination of sections taken in different directions, makes it clear that whilst the internal portion of the spiral lamina that forms the outer wall of each chamber is continuous with the nearest lamella of the adjacent septum on either side (Plate XVII. fig. 10), the substance of the external portion is no less continuous with that of the calcareous nucleus. The additional deposit is obviously homologous with that which forms the "intermediate skeleton" in *Cycloclypeus* (¶ 99), though less differentiated from the proper walls of the chambers than we have seen it to be in that type, or than we shall find it to be in *Calcarina* (¶ 202). The whole thickness of the spiral lamina is generally traversed by minute tubuli, passing in a radial direction from one surface towards the other; but these have by no means either the closeness or the regularity which distinguishes the tubular structure in *Cycloclypeus* and *Operculina*, and the shell-substance is in many parts so destitute of tubuli as to be of almost glassy transparence. The furrowing of the external surface (¶ 180) is seen in vertical sections (Plate XVII. fig. 2) not to be produced by mere superficial excavations, but to proceed from a plicated arrangement of the spiral lamina; and this is related to the prolongation of the posterior margin of each segment into a series of "retral processes" (Plate XVIII. fig. 12, *a*), corresponding to those described by Professor WILLIAMSON in *Polystomella crispa* (¶ 175). They are, however, much less elongated in this type, simply giving a crenulated margin to that angle of the segment, which contrasts remarkably with the smooth unbroken aspect of its anterior border *b*, *b*′. The spiral lamina which forms the outer wall of the chamber, being modelled (so to speak) upon the surface of these retral processes, presents internally a corresponding series of grooves, which are deepest towards the posterior margin, and become rapidly shallower in passing towards the anterior margin, of each chamber, as is shown at a, a^1, a^2, figs. 1 and 11, Plate XVIII.: these grooves are not, however, as in *P. crispa*, completed into tubes for part of their length by an additional lamella of shell given off from the septum (¶ 175); but they are sometimes shown, in sections which happen to traverse them (Plate XVII. fig. 10), to be extended into cæcal prolongations (*a*, *a*) by backward inflexions of the septa at their junction with the spiral lamina.

186. The communication between the successive segments of the same whorl is established by a number of minute processes or *stolons* of sarcode (*c*, figs. 12, 13, Plate XVIII.), which pass at regular intervals between their internal margins through a series of pores which can be distinguished along the inner border of each septum (fig. 1, c, c', c'') close to its junction with the preceding convolution. I have not detected in any instance, either in sections of the shell, or in the siliceous casts which so exactly represent the sarcode-body, any other communications between the chambers or their contained seg-

ments; and I am therefore strongly disposed to believe that Professor MAX. SCHULTZE must have been misled by appearances when he stated (*op. cit.* p. 65) that various other parts of the septal plane are marked by similar pores,—more particularly as his figures of the decalcified body do not show that any other threads or stolons of sarcode pass from one of its segments to another, than those just described.

187. So far, then, the structure of this comparatively gigantic type of *Polystomella* accords very closely with that of the more delicate species so well described by Professor WILLIAMSON. I have now, however, to give an account of a remarkable feature in its organization, namely, its highly developed *canal-system*; which, though not entirely wanting in *P. crispa*, is so imperfectly presented there, that Professor WILLIAMSON may well be excused for having overlooked it, especially when it is borne in mind that at that period the existence of such a system in Foraminifera was altogether unknown. The general arrangement of this canal-system may be most readily apprehended from an examination of the delineations of the internal casts given in Plate XVIII. figs. 12, 13; for the infiltrating substance which has penetrated the chambers has also found its way not only into the main trunks, but also into the minute ramifications of this system, and has thus given just that representation of their distribution and relations, which is afforded in regard to the blood-vessels of the higher animals by a well-injected and clearly dissected anatomical preparation. We observe, in the first place, that in each of what may be termed the two polar regions of the spheroidal body, there is a continuous spiral canal (fig. 12, d, d^1, d^2), which overlies the extremities of the segments. These two spiral canals (which, although so widely removed from each other, are obviously homologous with the two spiral canals of *Operculina*, ¶ 159) communicate with each other by a very regularly disposed series of canals which pass in a meridional direction between the adjacent external margins of the segments (e, e^1, e^2). And each of these meridional canals gives off, in its course from one polar region to the other, a uniform succession of pairs of short passages (f, f^1, f^2) that diverge from each other widely, one series inclining backwards over the uniform anterior margin of the segment next behind it, whilst the other series passes forwards in the intervals between the "retral processes" of the segment next in front of it. The passages which thus diverge from the meridional canals of the outer whorl speedily debouch at its surface; but if we examine into the termination of those appertaining to the inner whorls (which is best seen in such fragments as the one represented in fig. 13), we find that they become continuous with the stolons of the whorl which surrounds them, as is shown at c, c', fig. 12. Further, it may be perceived that each of the meridional canals receives branches from the canal-system of the segment internal to it; this point, however, can be more clearly made out in sections of the shell.

188. The spiral canals are frequently brought into view for part of their course, by sections of the shell that pass through it in a direction parallel to the equatorial plane, but at no great distance from one of the lateral surfaces. Such a section, passing over the chambers of the inner whorls, is shown in Plate XVII. fig. 5; where we see the

spiral canal giving off the meridional canals, and these again sending off their diverging branches. Towards its centre, the spiral canal communicates with an irregular set of *lacunæ*, which are excavated in the solid nucleus. In Plate XVII. fig. 6, are shown portions of two whorls (*a*, *a*, and *b*, *b*) of the spiral canal, as shown in a section passing near the lateral surface of the outer convolution; proceeding from the outer side of these, in like manner, we see the meridional canals (*c*, *c*, c', c', c') with their first pairs of diverging branches (see also fig. 12); whilst another set of canals (*d*, *d*, *d*) is seen to proceed from the inner side of the spiral canals, tending more or less obliquely towards the lateral surface; and the portion of the section which passes through the solid calcareous nucleus is seen to be perforated by numerous apertures (*e*, *e*) of corresponding diameter, disposed at pretty regular intervals. The relation of these to the canal-system is clearly evidenced by vertical sections, such as those represented in figs. 2 and 11; in which we see at *a*, *a*, the orifices of the spiral canals transversely or obliquely divided, and their connexion with the meridional canals *b*, *b*; and which further show that the solid calcareous nucleus is itself traversed by straight canals, *c*, *c*, *c*, which spring from the successive convolutions of the spiral canal, and pass directly, without branching or inosculation, to the external surface. That this remarkable portion of the canal-system does not fully show itself in the "casts" represented in Plate XVIII. fig. 12, is easily understood, when it is remembered that the whole substance traversed by the straight canals having been removed, their long and slender casts would be left entirely without support; and the points at which these have been broken off from the cast of the spiral canal are in fact to be seen on a careful examination, as there represented.

189. It is shown by the comparison of vertical and horizontal sections of the shell with fragments obtained by fracture (Plate XVII. figs. 2, 7, 10, Plate XVIII. fig. 11), that the meridional canals are in reality spaces left by the divergence of the two layers of which each septum is composed, in the immediate neighbourhood of its junction with the spiral lamina which constitutes the external wall of the chamber (Plate XVII. fig. 7, *c*, and fig. 10, *b*; Plate XVIII. fig. 11, *b*, *b*); and that they are thus homologous with the arches of the interseptal system of canals that connect together the spiral canals of *Operculina* (¶ 157),—presenting, however, a much greater uniformity and constancy in their disposition. The diverging branches given off from these (Plate XVII. fig. 8, *d*, d^1, d^2) consequently pass at once into the spiral lamina, through which they run obliquely towards the external surface of the convolution, usually increasing in diameter as they proceed. The divergence of the branches of each meridional canal causes those proceeding from adjacent canals to approach one another; and when the spiral lamina has attained its full development, they not unfrequently open at its surface into the same depression, this being midway between the septa from which they respectively sprang; and it appears to be from the correspondence of these junctions with the intervals between the segments of the succeeding whorls (as seen at *e*, e'), that the alternating arrangement of the chambers of consecutive whorls arises, of which

mention has already been made (¶ 184), the prolongations of sarcode which occupy the diverging branches there passing into the stolons which connect the adjacent segments. It will be easily understood, however, that the position of the external orifices of these diverging branches will depend upon the thickness of the spiral lamina which they have to traverse before gaining its surface. In the newest portion of a shell which has not yet attained its full growth, we find that lamina comparatively thin; its surface is distinctly marked by the septal bands (Plate XVIII. fig. 1, *gg'*, *gg'*); and the external walls of the chambers present an alternation of ridges and furrows, passing directly across from one septal band to another,—the ridges corresponding to the grooves of the internal surface that receive the "retral processes" (¶ 185), and the furrows with the internal ridges that separate these grooves. Into these furrows, which represent the deeper "fossettes" of *P. crispa*, the diverging pairs of branches from each meridional canal open by minute pores on either side of the septal band, as is shown in fig. 1, and as will be readily understood from the relation of the parts as displayed in fig. 12. The subsequent formation of a calcareous deposit, continuous with that which solidifies the umbilical portion of the shell, upon the external surface of the spiral lamina (¶ 185), renders the septal bands less distinct, and obliterates the ridges and furrows of the intervening surface, as shown in the portion *h h'* of fig. 1; and at the same time it carries the orifices of the diverging branches from the neighbourhood of the septa into closer proximity with those of the branches proceeding from the adjacent meridional canals. As the diverging branches enlarge greatly in diameter with their augmentation in length, their superficial orifices become more and more conspicuous; each is surrounded by a little pit or depression of its own (fig. 1, *ii'*, *ii'*); and the rows of these depressions, when the spiral lamina has acquired its full thickness, constitute the only markings which it presents, the septal bands being completely obliterated,—as is best seen on the surface of one of the interior whorls, exposed by the removal of that which covered it. It is obvious, therefore, that these depressions, which are related only to the distribution of the canal-system, are essentially different in character and position from the "fossettes" of *P. crispa*, which intervene between the ridges that cover-in the retral processes; but they have this in common, that the orifices of the diverging branches are to be found in both of them; and the removal of the superficial portion of the spiral lamina, even when thickest (which may easily be accomplished by the assistance of dilute acid), brings back these orifices, in *P. craticulata*, to the immediate neighbourhood of the septal bands, which then again become apparent*.

190. The meridional canals are further connected with the older and more internal portions of the organism, as well as with the newer and more superficial; this connexion being established by a series of branches that pass between the two layers of the septa

* This arrangement of the orifices of the diverging branches of the meridional canals is beautifully shown (as Mr. W. K. PARKER has pointed out to me) in the *Nautilus striato-punctatus* of FICHTEL and MOLL, which Mr. PARKER considers to be the *Geoponus stella-borealis* of EHRENBERG, but to be really a Nonionine form of *Polystomella*. See Ann. of Nat. Hist. ser. 3. vol. v. p. 103.

in a radial direction (Plate XVII. fig. 2, *d*, *d'*, Plate XVIII. fig. 1, *f*, *f*), from the meridional canals of each convolution to the stolons which unite the segments of that convolution. These, which may be distinguished as the converging branches, are, however, much less regular in their distribution than those which pass outwards from the meridional canals to the stolons of the succeeding whorl.

191. Thus, then, it becomes apparent that by means of the two *spiral canals*, the number of convolutions of which equals that of the whorls of the shell,—the very numerous *meridional canals*, of which there is one for every segment of each whorl,—the vast multiplication of pairs of *diverging branches*, of which each meridional canal sends off a number equal to that of the connecting stolons between the segments,—and the very considerable aggregation of *converging branches*, which probably do not fall far short of the preceding except in being single whilst they are in pairs,—a very complete system of intercommunications is maintained between the external surface and even the innermost portions of the shell. That these passages are occupied, in the living animal, by prolongations of the sarcode-body, there can scarcely, I think, be any reasonable doubt; and when we look to the remarkable development of what has been elsewhere termed the "intermediate skeleton," but which may here be more appropriately termed the "supplemental skeleton,"—namely, the secondary calcareous deposit which not only forms the solid nucleus, but spreads itself over the entire surface, adding considerably to the thickness of the spiral lamina,—it cannot be deemed improbable that the special purpose of the canal-system is the formation and nutrition of this supplemental skeleton, which has obviously no direct relation to the segments of the animal body contained within the chambers. Through the trumpet-shaped diverging branches which open in such numbers upon the surface of those chambers, and the straight canals which arise from the nucleus, there will be abundant opportunity for the sarcode-body to extend itself over the whole exterior of the shell, and thus to form any additional deposit upon its surface.

192. Having carefully re-examined *P. crispa* with a view of ascertaining to what extent the canal-system is developed in it, I am enabled to state that I have found it to possess a canal-system distributed on the same plan with that of the organism we have been considering, but much more limited in its extent, as might be expected from the much inferior development of the "supplemental skeleton." In the vertical section represented in Plate XVII. fig. 9, we see the solid umbilical protuberances *a*, *a'*, traversed by straight canals, which terminate in the pits on their surface that were originally noticed by Professor Williamson, and supposed by him to give exit to pseudopodia. At *b*, *b*, *b'*, *b'*, we see the transverse sections of the spiral canals, from which the straight canals just mentioned may be presumed to proceed; and at *c c*, *c'c'*, we see plain indications of a system of interseptal canals, resembling those of *Operculina* in their aspect and distribution, but clearly homologous, in their relations to the spiral canals, with the meridional canals of *P. craticulata*. I have not been able to detect any indication that diverging branches are given off from them, to pass through the spiral lamina to the

external surface; and the absence of any such distribution accords with the absence in *P. crispa* of any of that supplemental calcareous deposit which so remarkably changes the aspect of the general surface in *P. craticulata.*

Genus Calcarina.

The type next to be described is one in which the supplemental skeleton and the canal-system both attain a more remarkable development than in any Foraminiferous organism that has yet fallen under my notice; and their mutual relation here becomes so obvious, that no reasonable doubt can be entertained in regard to it.

193. *History.*—The generic name by which this type is now known, and which indicates its resemblance in form to the rowel of a spur, was first conferred upon it by M. D'Orbigny in 1825; the organism itself, however, was previously well known, both in the recent and in the fossil state, having early attracted the attention of the collectors of minute Testacea through the singularity of its shape. It seems to have first received the name of *Nautilus Spengleri* from Gmelin, its specific designation having been conferred on it in compliment to Spengler, who was among the earliest to direct attention to it; and under this name it was described and well figured in several of its varieties in the 'Testacea Microscopica' of Fichtel and Moll (p. 84, plate 14. figs. *d–i*, plate 15. figs. *i–k*), who refer to the authors cited below* for previous notices of it. Spengler's specimens were from Amboyna and Coromandel; Schröter found the species in the Adriatic; Fichtel and Moll obtained their specimens from the Indian Ocean and from the Red Sea; and D'Orbigny received his from Madagascar, the Isle of France, Rawack, the Marianne group, Cayenne, and Martinique. The specimens on which my own descriptions will be founded were partly collected by Mr. Cuming in the Philippine Seas, and partly obtained by him from the Mediterranean, in the neighbourhood of Malta. This type may be said, therefore, to have a wide distribution through the seas of the warmer regions of the globe.

194. The fossil specimens of this type appear to have been first noticed in the cretaceous beds of Maestricht by Faujas†. They were described and figured by Lamarck‡ under the designation of *Siderolites calcitrapoides*; but he totally misunderstood the nature of the organism, which he grouped with the Corals, instead of among Polythalamia. The genus *Siderolina* has been adopted by M. d'Orbigny, who seems to have been entirely ignorant of the generic if not specific identity of the Maestricht fossils with his recent *Calcarina calcar*, as to which no doubt whatever is entertained either by myself or by Messrs. W. K. Parker and T. Rupert Jones§. It is stated by these observers (*loc. cit.*), that another variety of the same with shorter spines, occurring in

* Linnæus, Syst. Nat. xiii.; Gmelin, Syst. Nat. p. 3371, No. 10; Spengler, Schrift. dän. Gesellsch. Kopenh. vol. i. p. 373, pl. 2, fig. 9, *a, b, c*; Schröter, Einleit. Conch.-Kennt. vol. i. p. 756; Neue Literat. u. Beytr. z. Naturg. vol. i. p. 309, pl. 1, figs. 3–6; Schreibers, Conch.-Kennt. vol. i. p. 5, No. 10.

† Hist. Nat. de la Montagne de St. Pierre, à Maëstricht.

‡ Syst. des Anim. sans Vertèbres, 1801, p. 376; and Tableau Encycl. et Méthod. pl. 470, fig. 4, *a–k*.

§ Ann. of Nat. Hist. 3rd Series, vol. iii. p. 480.

the Eocene Tertiaries of France, has been described by D'ORBIGNY* under the name of *Rotalia armata*, and by DESHAYES† under that of *Calcarina rarispina*.

195. The following is the character of the genus *Calcarina* given by M. D'ORBIGNY in his 'Foraminifères Fossiles de Vienne' (p. 160). "*Coquille* libre, spirale, déprimée, très rugueuse, formée d'une *spire* enroulée sur le côté, entièrement apparente en dessus, embrassante en dessous, composée de loges prolongées en appendices marginaux, souvent très allongés, représentant, dans leur ensemble, comme la molette d'un éperon. *Ouverture* en fente longitudinale contre l'avant dernier tour de spire. Semblable aux *Rotalines* par son enroulement spiral, par ses deux côtés à peu près aussi convexes, par l'emplacement de son ouverture, ce genre s'en distingue par les très longs prolongements extérieurs de son pourtour, appendices singuliers qui font supposer, dans l'animal, un mode de sécrétion tout particulier." Of *Siderolina* he says (p. 116):—"*Coquille* libre, équilatérale, orbiculaire, encroûtée en dehors, composée d'une *spire* embrassante à tous les âges, ayant des appendices allongés au pourtour, interrompant, dans l'intérieur, la suite des loges. *Ouverture* contre le retour de la spire toujours masquée à la dernière loge. Les *Siderolina* se distinguent des *Nummulina* par les appendices du pourtour, qui, dans l'intérieur de la coquille, viennent interrompre la suite des loges obligées de passer de chaque côté." No mention is made of *Calcarina* in M. D'ORBIGNY'S most recent summary of the classification of the Foraminifera (Cours Élémentaire de Paléontologie), this genus not being regarded by him as occurring in the fossil state; but he repeats his characterization of *Siderolinæ* as Nummulites the turns of whose spire are interrupted by testaceous appendages. It will presently appear that the conception which M. D'ORBIGNY has formed of the structure of this type is erroneous in so many particulars, that without the assistance of figures and models it could not be recognized by the generic characters which he has assigned either to *Calcarina* or to *Siderolina*.

196. A very correct general description of the structure of *Calcarina* has recently been given by Messrs. W. K. PARKER and T. R. JONES, in their valuable series of papers on the "Nomenclature of the Foraminifera‡"; but their information in regard to it having been almost entirely based on external characters, and their description being altogether deficient in those minuter details which it is my special purpose to record, a full account both of its internal structure and of the principal varieties of its external configuration will not be the less valuable to those who may have occasion to study this type.

197. *External Characters.*—The comparison of the form of this organism to that of the rowel of a spur sufficiently well characterizes the general aspect which it ordinarily presents, as shown in Plate XIX. figs. 1–4. The feature which most distinguishes it from other *Hélicostègue* Foraminifera (only some *Rotaliæ* and *Polystomellæ* presenting a slight approximation to it in this particular) is the presence of a set of rays or spines, variable alike in number, length, and direction, which diverge from the central disk.

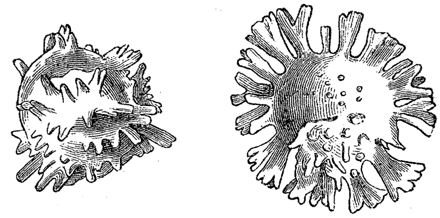
* Ann. des Sci. Nat. tom. vii. p. 273, No. 22; and Modèles, No. 70.

† Lyell's Manual of Geology, 5th ed. p. 228, fig. 236.

‡ Annals of Nat. Hist., Ser. 3. vol. v. p. 174.

These spines are usually few in young specimens, and become numerous with age; but this rule is by no means constant, since full-grown specimens are occasionally met with having no more than four or five very short spines (Fig. III. H). The spines are usually either cylindrical or somewhat club-shaped, the latter form being the more common; but we occasionally see them showing a tendency to bifurcation at their extremities; and they not unfrequently appear as if two, three, or even four spines had coalesced to form one,—this being indicated not only by its unusual size, but by the mutual divergence of its components as they extend themselves from the central disk (Fig. I. B, and Fig. II. F). A somewhat remarkable contrast in the relative development of the disk and of the spines is presented by the general aggregate of the Philippine and Mediterranean specimens placed in my hands by Mr. CUMING; as is shown in comparing Figs. II. and III. It is in the former (Fig. II.) that we meet with the greatest number as well as the greatest relative length of the spines; and that the bifurcation or trifurcation of their extremities presents itself. In full-grown specimens of the Philippine *Calcarina*, we commonly find the spines diverging from the

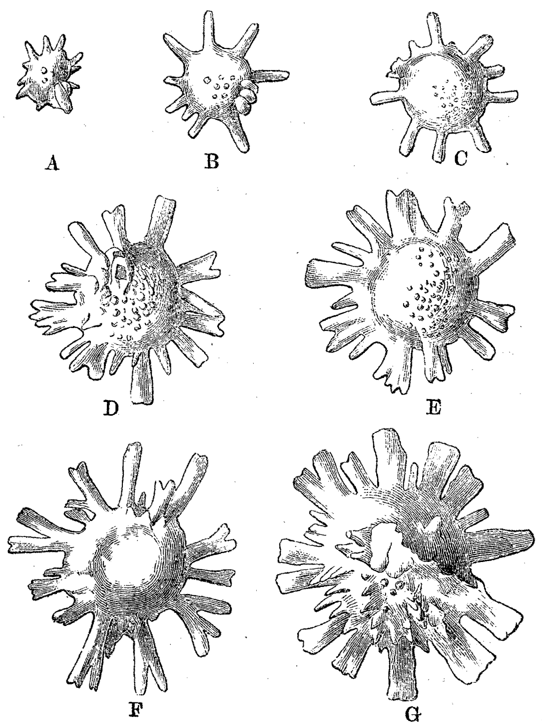
Fig. I.



A B

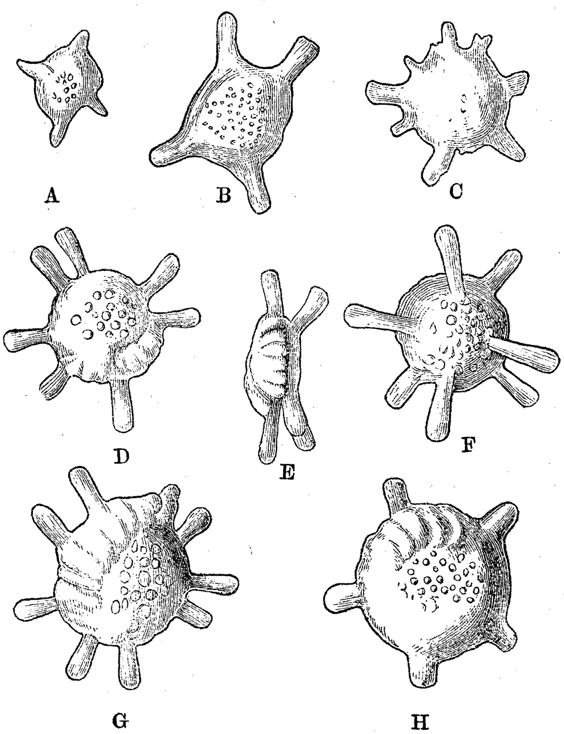
Two specimens of Philippine variety of *Calcarina*, distinguished by unusual exuberance of spinous outgrowths.

Fig. II.



Outline-representations of various specimens of Philippine variety of *Calcarina*.

Fig. III.



Outline-representations of various specimens of Maltese variety of *Calcarina*.

margin of the central disk in such abundance, that very little of that margin is left free. The length of their spines, moreover, at different ages, varies pretty constantly with the diameter of the disk, the average proportion being about two-thirds; though we occasionally meet with specimens in which the disk is unusually large and the length of the spines does not equal more than half its diameter, and others in which the disk is unusually small and the length of the spines is equal to its whole width. In the Mediterranean *Calcarinæ* (Fig. III.), on the other hand, I have seldom met with more than nine spines; and any excess beyond that number is only presented by specimens in which the disk is very large, so that wide intervals present themselves along its margin between the bases of the spines (Plate XIX. fig. 2). Their spines are nearly always simply clavate in form, any tendency to bifurcation or trifurcation at their extremities being rare; and they show but little disposition to increase in length with the enlargement of the central disk, being often not only relatively but even absolutely shorter in old specimens; as if the spines had entirely ceased to grow, and the disk had (as it were) included their basal portions within itself. In some instances, indeed, they scarcely show themselves enough to attract attention; being little more than tubercular projections from the margin of the disk (Fig. III. H). Notwithstanding, however, this strongly marked difference in general physiognomy, it becomes obvious, on the comparison of a sufficient number of individuals, that no line of specific distinction can be fairly drawn on such a basis between the Philippine and the Mediterranean forms; since among the Philippine we meet with not a few specimens, in which the spines are as few and simple as they are in the great bulk of the Mediterranean (Fig. III. B, C); and specimens not unfrequently present themselves among the Mediterranean (Plate XIX. fig. 2), in which there is not merely an addition to the ordinary number of the spines, but a manifest disposition in many of them to subdivide near their extremities, thus showing an obvious approximation to the Philippine type. Although the spines usually radiate nearly in the equatorial plane, yet it becomes obvious, when their connexion with the central disk is examined, that they originate at different levels (Fig. III. E, F); this will presently be found to depend on the fact that the form of the spire is not nautiloid but turbinoid. Besides the ordinary radiating spines, an extraordinary growth of short pointed spines is sometimes seen, either partially or completely covering one or both surfaces of the central disk (Fig. II. G); and examples occasionally present themselves (Fig. I. A), in which the development of these seems to have altogether superseded that of the ordinary radiating spines.

198. It is remarkable that among the very young specimens of this type, a yet greater variety shows itself than among those further advanced in life. In Plate XIX. figs. 5, 6, and 7, are shown what may be considered the ordinary or normal aspect of the very young *Calcarina*; whilst in figs. 8–11, and Plate XX. fig. 6, we have representations (under higher magnifying powers) of examples of what may be termed the *hispid* condition, which so frequently presents itself in small *Calcarinæ* as to give rise to a question whether they should not be made to constitute a distinct species. I have satisfied

myself, however, by the comparison of a large number of specimens, that so continuous a gradation presents itself between the smoothest and the most hispid specimens, as to render the attempt to separate them specifically altogether futile; and Mr. W. K. PARKER, who has examined a yet larger number of specimens, fully confirms this conclusion. Moreover the internal structure of these hispid specimens, as shown in horizontal section (Plate XX. fig. 8), shows no departure whatever from the ordinary type.

199. Returning, now, to the external aspect of the fully-developed *Calcarina*, we have to notice that each surface of the disk is very commonly elevated, especially in its central portion, into rounded tubercles, more or less closely set together (Plate XIX. figs. 3, 4). These are sometimes large and prominent, and present the semitransparent appearance which is common among the like tubercles of *Operculina* (¶ 146); more commonly, however, they are less conspicuous either as to size, prominence, or distinctive aspect; and sometimes they are almost or altogether wanting (figs. 1, 2). Yet it is seldom, if ever, that they are absent from both surfaces of the disk; and it is more common to find them deficient on the surface nearest to the apex of the spire, than on that on which its last-formed chambers are visible. And even when no prominent tubercles are present, a distinction may be generally made out by careful examination in the parts of the surface corresponding to their usual situation. For whilst the exterior of the disk is marked, more or less conspicuously, with minute punctations (figs. 1, 3, 4), these are not to be seen on its tuberculated prominences; and the like deficiency is generally to be noted in circular spots of the surface, even when it is not raised into tubercles. Occasionally, though rarely, not even this mark of differentiation is seen, the punctations being uniformly distributed over the surface, which is in that case always the one nearest the apex of the spire.

200. The surface of the spines is marked, more or less conspicuously, by a longitudinal furrowing (figs. 1, 3, 4), not unlike that of the "marginal cord" of *Operculina* (¶ 156). The furrows maintain a general parallelism, but there are frequent inosculations between them; and punctations marking the orifices of deeper canals are often to be noticed at the bottom of the furrows.

201. One important feature of the external aspect of the disk has yet to be mentioned; namely, the indication of a *spire*, which more or less distinctly presents itself on one of its surfaces (Fig. II. B, Fig. III. D, G, H). This indication is sometimes limited to two or three chambers; but more commonly about half a turn may be distinguished, the spire becoming absorbed (as it were) into the solid mass of the disk, as we trace it backwards. The walls of the last-formed chambers, where entirely disengaged from the disk, are extremely thin (Plate XIX. fig. 4), so that it is rare to find them perfect; and an opening formed by the fracture of the wall of the newest chamber has been mistaken by MM. FICHTEL and MOLL, and apparently by M. D'ORBIGNY also, for the true aperture of the shell, which, as will presently appear, is of an entirely different character, and not easily to be distinguished. The prominent surface of the walls of the conspicuous chambers

of the newest whorl is covered with punctations resembling those of the general surface of the disk; but they are more minute and more closely set together, and they are distributed with great uniformity, no unpunctated spaces being anywhere visible.

202. *Internal Structure.*—When the internal structure of this organism is examined by means of thin sections taken in different directions, the apparent anomalies of its conformation are found to be dependent simply upon the extraordinary development of its "supplemental skeleton;" its general plan of structure being much simpler than the peculiarities of its aspect would seem to indicate. The spire, as laid open by vertical section (Plate XX. fig. 1), is turbinoid; consisting usually of about five whorls (a, a^1, a^2, a^3, a^4), that start as usual from a central cell, and progressively increase in size, each whorl being applied merely to the surface of the preceding, and not investing it in any degree, the chambers being altogether destitute of alar prolongations. The aspect of the spire as seen in equatorial section is shown in Plate XX. fig. 4; this section, being taken in such a plane as to cut through the outer whorls a^4, a^3, a^2, passes entirely over the surface of the two inner whorls a^1 and a. The disposition of the chambers, as indicated by such sections, is ideally shown in Plate XIX. fig. 12. The turns of the spire are separated from each other by the interposition of a thick layer of solid shell-substance; and this is quite distinct from the proper walls of the chambers, as may be well seen in Plate XX. fig. 4, where the walls of the newest chambers are shown at b to be entirely destitute of any such addition, whilst at b^1 in the preceding part of the same whorl we observe them encrusted by a thin additional layer d, and, as we trace this layer backwards to d^1 and d^2, we perceive that it progressively augments in thickness, until it acquires its maximum at d^3, just where it is covered by the subsequent whorl. This distinction between the proper walls of the chambers and the "supplemental skeleton" can be traced to the very centre of the spire. The septa are entirely formed by the infolding of the proper walls of the chambers, which are there flattened against each other so as to form two layers, which are usually in contact, but which sometimes diverge (especially near the external margin of the chambers) to give passage to canals. There does not appear, however, to be any regular "interseptal system" as in *Operculina* and *Polystomella.* The communication between the adjacent chambers of the same whorl is effected, as in *Polystomella*, through series of pores (fig. 1, c) disposed at pretty regular intervals along the inner margin of the septum*.

203. That the spines entirely originate from, and are strictly appendages of, the "supplemental skeleton" is well seen in fig. 4, which shows their connexion with its

* Messrs. Parker and Jones say (Ann. of Nat. Hist. Ser. 3. vol. v. p. 175) of the aperture of *Calcarina*, that "in well-preserved specimens of the typical forms, the real aperture, which is essentially a slit, as in the true *Rotaliæ*, becomes bridged over by delicate bars of shell-matter." I cannot but think that they have allowed themselves in this statement to be somewhat influenced by a foregone conclusion that "*Calcarina* is a subgenus of *Rotalia*." The examination of numerous sections of the character represented in fig. 5 leaves no doubt in my own mind that the aperture of *Calcarina* is essentially such as I have above described; and that if it occasionally in perfect specimens has the character of a continuous fissure (which I would by no means take upon myself to deny), such is an aberrant rather than the ordinary form.

successive convolutions. Thus the spine *e* is one of the oldest, being traceable inwards to the earlier whorls; whilst those marked e^1, e^2, e^3, e^4, e^5 are obviously of progressively later production, their respective origins being further and further removed from the centre of the spire. It is, moreover, to be observed that each spine receives an augmentation in thickness as the convolution from which it sprang is encircled by others; this augmentation, however, is not marked (as in the spines of *Echini*) by lines of demarcation between the earlier and the later formations; and there is every reason to believe that the growth of the spines, both in length and in diameter, is continuous rather than interrupted. Although it might seem, from the examination of such sections only as are taken in the direction of the equatorial plane or in one parallel to it, as if the course of the spire must be seriously interrupted by the radiation of the spines (which sometimes appear to be so interposed between consecutive chambers as completely to separate them); yet the fact is that owing to the turbinoid form of the spire, a spine projecting from an earlier whorl is very little in the way of even the next convolution; for as this passes by the spine on a different level, its chambers are but slightly encroached-on, and this only upon the side which looks towards the apex of the spire,—as will be readily understood by examining the relation of the last half-convolution, visible in such a specimen as the one delineated in Plate XIX. fig. 4, to the pre-formed spines, or by an inspection of the ideal represented in Plate XIX. fig. 12.

204. The canal-system of *Calcarina* presents a development so extraordinary in itself, and so obviously related to that of the "supplemental skeleton," as to throw great light upon its special functional destination. We do not here observe any such peculiar but limited distribution of systematically arranged passages, as that which constitutes so remarkable a feature in *Polystomella*; but every portion of the supplemental skeleton, with the exception of certain solid cones presently to be noticed, is traversed by canals which run very close together, with frequent inosculations, and which thus form a continuous network with long narrow meshes, that commences from the parietes of the chambers and extends itself to the very extremities of the spines (Plate XX. figs. 1, 2, 4). The proper walls of the chambers, as already stated, are uniformly perforated, like those of the chambers of *Rotaliæ*, by foramina of considerable size (averaging about $\frac{1}{3000}$th of an inch in diameter); with these the canals of the supplemental skeleton do not seem to be directly continuous, for they are of about double the diameter and lie further apart from one another; but immediately round the proper walls of the chambers (as shown in Plate XX. fig. 1) there seem to be irregular lacunar spaces, into which their foramina open externally, and from which the passages of the canal-system originate. How numerous and closely-set these passages are, is shown in Plate XX. fig. 3, which is taken (under a much higher magnifying power than the rest of the figures) from a section that passes through the supplemental skeleton just outside the walls of one of the chambers, in such a direction as to cut through the passages transversely or obliquely. These passages run in different directions; some proceeding directly towards the external margin of the convolution, and being

continued into the spines where these are given off from it; whilst others pass not less directly towards the two convex surfaces of the disk. In the earlier whorls of the spire, as shown in Plate XX. figs. 2 and 7, indications of spiral canals, commencing (as in *Polystomella*, ¶ 188) in a central lacunar system, are frequently traceable; and sometimes we may make out a general distribution of the canal-system of the earlier whorls (fig. 7) that strongly reminds us of that prevailing in *Polystomella* (¶ 189), the canals of the spines originating (as seen at *a*) in diverging branches which radiate outwards through the spaces left between the two layers of the septa. But this arrangement soon seems to be merged, as it were, in the much more copious distribution of passages that arise from the lacunæ round the proper walls of the chambers. The canals which pass towards the two surfaces of the disk soon lose the general uniformity of arrangement which they elsewhere present; for they become crowded together in some situations and separated in others, so as to leave a number of columnar spaces untraversed, whilst the intercolumnar spaces are copiously penetrated by them,—as is seen at *e*, *e*, *e*, in Plate XX. figs. 1 and 5, the one figure showing the solid columns divided longitudinally, and the other showing them as they are cut transversely. The varying appearances of the external surface, as described in ¶ 199, will now be understood. When, as commonly happens, the summits of the columns rise above the general level of the surface, they will show themselves as rounded tubercles. But when they are not thus elevated, they will merely be distinguished as circular spots surrounded by the punctations which are the orifices of the canals. In the spines, on the other hand, the canals form a longitudinally inosculating system (Plate XX. fig. 2), of which the branches near the surface usually reach it so obliquely as to pass along it for some distance as open furrows (¶ 200), the punctations seen in which are the orifices of branches that strike the surface at a greater angle.

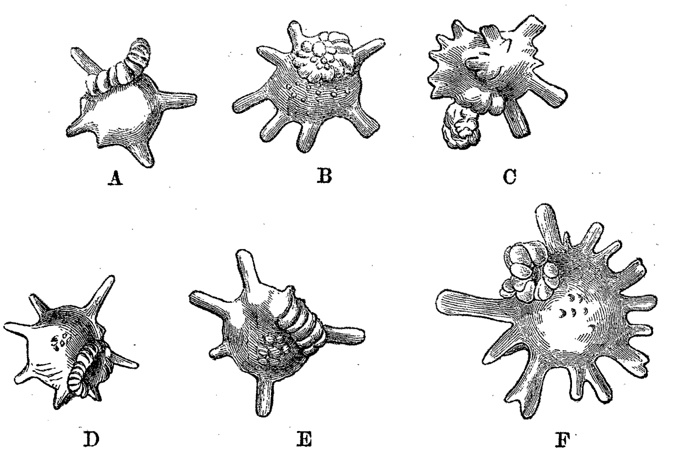
205. It is obvious from the foregoing description, that the statement of M. D'ORBIGNY as to the prolongation of the chambers into the spines is altogether erroneous; and it is further obvious that the nutrition of the spines must be provided for either through the investment of their surface by external prolongations of the sarcode-body, or through the penetration of its substance by prolongations of the sarcode-body conveyed into it by the canal-system, or through both methods jointly. That the sarcode-body is continued in the form of pseudopodial prolongations into the canal-system can scarcely be doubted, when it is borne in mind that such prolongations are known to pass through the pores which are scattered through the chamber-walls of *Rotalia*, and to extend themselves through the surrounding medium. After having made their way through the proper walls of the chambers of *Calcarina*, they will probably coalesce again in the lacunar cavities on the exterior of these, just as they coalesce to form a continuous layer of sarcode over the chamber-walls of *Rotaliæ* or *Polystomellæ*; and from the aggregation of sarcode in those cavities a new set of pseudopodial prolongations will take their departure through the canal-system of the "supplemental skeleton," just as a secondary set of pseudopodial filaments of sarcode are often seen to diverge from the little agglo-

merations formed by the reunion of some of those that primarily issue from the pores of the shell. The analogy of other Foraminifera, moreover, renders it very probable that the prolongations of the sarcode-body which reach the surface through the canal-system, will reunite upon it so as to form a continuous investment over the whole; and that this will be especially the case on the spines, appears to be indicated by the provision there is in the furrowing of the surface, for conveying the prolongations of the sarcode-body to every portion of their exterior.

206. Thus, then, by interpreting the structural phenomena presented by *Calcarina* according to the analogy of the facts which have been determined by observation of the living animals of the allied type *Rotalia*, we seem almost indubitably led to the conclusion that the canal-system is specially destined for the formation and maintenance of the "supplemental skeleton;" serving to convey prolongations of the sarcode-body from the segments which occupy the chambers, through the thick layer of solid shell-substance that is secondarily formed around those chambers, and through the prolongations of that layer which constitute the spines; and further, that it maintains a tolerably direct communication between even the innermost chambers of the spire and the external surface,—a connexion which would have been cut off by the interposition of the "supplemental skeleton," had not this been provided with some such system of intervening canals.

207. One more fact remains to be noticed, which is of much interest as showing that the growth of the spire and that of the "supplemental skeleton" are to a certain extent independent of each other:—I refer to the departure from the regular form that frequently shows itself in the later turns of the spire, which (so to speak) often "run

Fig. IV.



Abnormal specimens of *Calcarina*.

wild" in a variety of strange modes, examples of which are so well represented in Fig. IV. A–F, that it is unnecessary to refer to them in other than these general terms.

The extension of spines from the whole surface of the disk, in the mode represented in Fig. I. A, may in like manner be regarded as a sort of "running-wild" of the supplemental skeleton.

Genus Tinoporus.

208. A more remarkable example could scarcely be adduced, of the necessity of a thorough examination of the internal structure of the skeletons of Foraminifera as a guide to the determination of their true affinities, and of the danger of relying upon external characters alone, than that presented by the type I am next to describe under the name *Tinoporus*; certain forms of which present so strong a superficial resemblance to many specimens of *Calcarina*, as to be unhesitatingly associated with them by every one who has not had his attention directed to the minute features of difference they present; whilst the plan on which it is constructed will be found to be essentially diverse.

209. *History.*—My reason for adopting this name is as follows. In the 'Conchyliogie Systématique' of Denys de Montfort (Paris, 1808), there is described and figured * under the name of *Tinoporus baculatus* a small polythalamous body, which he seems to have distinguished from the other varieties of *Nautilus* (*Calcarina*) *Spengleri* figured by MM. Fichtel and Moll, partly by the fewness of its spines, and partly by the difference of its structure as displayed in vertical section. And although his figure and description are alike inaccurate (the former, as has been pointed out by Messrs. W. K. Parker and T. R. Jones†, being partly drawn from specimens of *Calcarina*), yet as I can scarcely doubt that he had before him a specimen of the type I am about to describe, I think it right to retain the distinctive designation he conferred upon it. The following is De Montfort's characterization of the genus:—"Coquille libre, univalve cloisonnée et cellulée, spirée et lenticulaire; têt granulé extérieurement; bouche semi-lunaire, placée vers la circonférence et sur un des côtés; dos caréné, armé de quatre pointes au plus; les deux centres bombés et relevés." Of the species *T. baculatus*, which served as his type of the genus, and of which he gives the fourth variety of the *Nautilus Spengleri* of Fichtel and Moll as a synonym, he says:—"Cette coquille, qui pour nous est la tête (type ?) d'un genre nouveau et assez nombreux, ressembleroit à la nummulie ou camérine tuberculée et criblée, si elle n'étoit armée de trois pointes obtuses. Ces pointes sont intérieurement sillonées et tuberculées à la manière de quelques tubipores: la bouche de la coquille, placée sur un des côtés, est très remarquable, en ce qu'elle est petite et formée en demi-lune: la spire est cachée et intérieure. Les auteurs allemands que nous avons cités dans notre synonymie, y comptèrent au moins quatre-vingts cellules. Nous avons fendu cette coquille à demi par le milieu, afin de faire apercevoir la construction de l'intérieur, qui, cellulée sur divers plans, nous conduit naturellement aux nummulies, mais elle en diffère par ses bras ou pointes, qui sont constans, quoique leur

* Tome i. p. 147.

† Annals of Natural History, Series 3. vol. vi. p. 34.

intérieur présente une organisation qui n'est point cellulée mais tubulée. La couleur du tinopore baculé est blanche, flambée et teintée de jaune; la coquille est entièrement opaque. L'individu qui a servi de sujet à notre description venoit de la mer des Indes orientales; on le trouva dans le sable dont étoit remplie une coquille du genre casque; on rencontre encore les tinopores parmi d'autres coquilles microscopiques, sur les plages du golfe Arabique, ainsi que dans quelques éponges de la mer Adriatique. D'une pointe à l'autre, le tinopore que nous venons de décrire a deux lignes de diamètre." It is from the very distinct statement of DE MONTFORT (borne out by the vertical section rudely represented in his figure) of the cellulation of the interior of this organism on different planes, so as to give to its vertical section somewhat the appearance of that of a Nummulite, that I am induced to believe that he had really distinguished *Tinoporus* from the type to which we now give the designation *Calcarina*. For, as we have seen, no such appearance is presented by vertical sections of *Calcarina*; whilst, as will presently appear, *Tinoporus* is made up of several layers of cells superimposed one upon another; and although its relation to *Nummulite* is really remote, yet the resemblance in aspect presented by vertical sections of the two may easily seem, to such as are unacquainted with the real meaning of their appearances, sufficiently close to justify the parallel.

210. I am not aware that any subsequent writer has adopted DE MONTFORT's generic definition of *Tinoporus*, which seems to have been treated as one of his many valueless differentiations which systematists have agreed to disregard. In the 'Dictionnaire Universel d'Histoire Naturelle' it is noticed as a synonym of *Calcarina*.

211. The plan of structure presented by *Tinoporus* differs so remarkably from any that has been yet described, as well to deserve being fully detailed. But it presents an additional feature of great interest, in the light which it throws upon the structure and character of the remarkable fossil genus *Orbitoides*, which, though first named by M. D'ORBIGNY, was first described by me*, and is scarcely less important in its geological relations than *Nummulites* itself.

212. Before proceeding, however, to the description of *Tinoporus baculatus*, I shall give an account of the structure of a simpler form of the same type, by which that of *T. baculatus* will be better understood. The form to which I allude has a much wider geographical range; for though the largest and best developed specimens I have seen are those which I have obtained from Mr. JUKES's Australian dredgings, yet I have met with it also in collections from the Fiji Islands, Mazatlan, and the Canaries; and Messrs. PARKER and RUPERT JONES (by whom this type has been recently noticed under what I cannot but consider the inappropriate designation *Orbitolina*†) state that it occurs also in the East and West Indies, in the Mediterranean, and on the British coast as far north as Arran. To this type, which is destitute of the projections so remarkably characteristic of *T. baculatus*, the name of *T. lævis* may be appropriately given.

* On the Microscopic Structure of *Nummulina*, *Orbitolites*, and *Orbitoides*, in the Quarterly Journal of the Geological Society, February, 1850.

† Annals of Natural History, Series 3. vol. vi. pp. 32, 33.

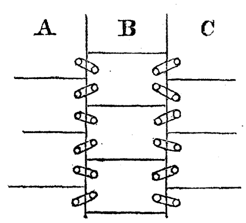
213. *External Characters.*—The largest examples I have seen of *Tinoporus lævis* present the form of a short truncated cone, much resembling the lower half of a sugar-loaf (Plate XXI. fig. 1, *a*), having its margins rounded off, and attaining at the base a diameter of about one-tenth of an inch. The base commonly exhibits a slight central depression (fig. 1, *b*). Sometimes the cone is more depressed, and spreads out more widely at the base; and in this case the basal concavity is usually wider and deeper. The examples I have seen from other localities have for the most part a spherical or spheroidal shape; but a careful examination will generally make it apparent that this shape is derived (so to speak) from that last mentioned, by the folding-inwards of its peripheral portion towards the centre of its lower surface, so as to leave a deep cavity at that part of the sphere,—the relation of the two forms being very much like that which exists between the expanded *pileus* of an Agaricus, and the same *pileus* whilst still included within its *volva.* I cannot regard these diversities of form as possessing any specific value; since they depend entirely upon mode of growth, and are not connected with any differences of internal structure.

214. In whatever form the *Tinoporus lævis* may present itself, it is recognized by the absence of projection or angularity, and by a regular areolation over its whole surface, which a good deal resembles that of the cuticles of many leaves, the areolæ preserving a tolerably constant average of size, but being very indefinite as regards form. The divisions are marked by very definite boundary lines; and in the interspaces between these, under a sufficient magnifying power, minute punctations may be seen.

215. *Internal Structure.*—When the structure of this organism is examined by means of sections taken in different directions, it is found to be composed of an aggregation of minute chambers of nearly uniform size, which are piled one upon another in pretty uniform layers, each of these presenting an approach to a concentric disposition (figs. 2, 3). Although it is difficult to make out with certainty the arrangement of the first-formed chambers, yet it is clear that as in other Foraminifera the point of departure is a spheroidal cell (fig. 3, *a*), which soon comes to be surrounded by a cluster of secondary cells (*b*, *c*) derived from it by gemmation. In what manner these are given off from the first,—whether by a spiral or by a cyclical extension of the sarcode-body,—I have not been able to satisfy myself, on account of the difficulty of precisely carrying the plane of section through this group of chambers. In *T. baculatus* I have been fortunate enough to do this in several instances, and have found that the early growth is unquestionably spiral (fig. 11),—soon, however, giving place to the cyclical, as in those varieties of *Orbitolites* whose growth commences after this fashion (¶ 54); and whether this be or be not the case in *T. lævis*, it is indubitable that before long the extension of the organism in diameter is effected by a budding-forth of new chambers from all parts of the circumference, not with such regularity, however, as to form distinct annuli as in *Orbitolites.* Whilst this extension is taking place peripherally, however, additional layers of chambers are formed, as in *Orbiculina*, above and below the central nucleus, meeting each other

on the equatorial plane; and in this manner the increase of the organism in thickness is effected. The growth on the two sides of the equatorial plane, however, is seldom or never symmetrical; and that of the more convex portion seems continually tending to overpower that of the opposite surface, so that the equatorial plane becomes more or less deeply concavo-convex. I have reason to believe that this inequality is due to the attachment of the flat or subconcave base to the surface of sea-weeds or zoophytes; in virtue of which it will naturally happen that the free side will grow faster than the other. It is by an excess of this predominating growth that the spheroidal form is acquired, with its deep residual cavity, as just now described.

216. On more minutely examining the structure of the walls of the chambers and the mode of communication between their cavities, we find ourselves carried back to the lower type of *Orbitolites* and *Orbiculina* in this particular,—that the septa are not double but single, and are formed of a simple homogeneous substance, presenting no vestige whatever of that fine tubulation which characterizes the dense almost ivory-like substance forming the walls of the chambers in the more elevated forms of this group. It will be convenient to speak of the partitions between the chambers as *horizontal*, when their general direction is parallel to that of the equatorial plane, and as *vertical* when that direction is perpendicular to it; their actual directions will of course vary with the curvature of the equatorial plane. The *horizontal* partitions or floors of the chambers are perforated by rounded apertures (Plate XXI. figs. 2, 3, 4) which closely resemble those of the shell of a *Rotalia* or a *Planorbulina* in their size and arrangement; and these will allow of free communication, by pseudopodial threads of sarcode, between the segments that are lodged in the chambers piled one over the other in a vertical direction. The *vertical* partitions are much thicker, and are not thus minutely and regularly perforated; but they exhibit a small and variable number of large apertures (fig. 4, *a*, *a*), that lead into the adjacent cells which lie in or near the same horizontal plane. I say *in* or *near*, because it is seldom if ever the case that the horizontal partitions or floors of two adjacent vertical piles of cells are on the same level; and, in fact, the typical arrangement (though frequently departed from) seems to be, that there is an *alternation* in the levels of the floors of adjacent piles (as shown in the accompanying diagram, based on some parts of fig. 3), and that every chamber in any pile B normally communicates with two chambers in each of its adjacent piles A and C, by one passage above and the other below the floor that divides them.



217. The relation of this interesting type of structure to that of *Planorbulina* appears to me so clear that it can scarcely be questioned. For, as in that genus, the first-formed portion of *Tinoporus lævis* will evidently consist of a flattened disk, consisting of numerous segments which are arranged in one plane, spirally in the centre of the disk, but clustered irregularly towards its circumference, and perforated on both sides with

numerous large pseudopodian foramina*. This relationship is admitted by Messrs. PARKER and RUPERT JONES; who state, however, that *Planorbulinæ* are differentiated by having "two or three tubular and margined apertures to each chamber, coarser pseudopodial pores, and no umbilical cells." Now I have shown that every chamber in the adult is connected with its adjacent chambers of the same or of alternate planes by two apertures; so that at the free growing margin of the young disk there would probably be at least two such pairs of apertures in the wall of every chamber. The difference in the size and number of pseudopodian pores is a very trivial character. And the superposed umbilical cells will probably be absent in the young *Tinoporus*, when as yet only a small number of rows of chambers have been formed around the central cell. I have, in fact, specimens in my possession which would be unhesitatingly characterized as *Planorbulinæ* by such as are unacquainted with the structure of the type we are considering; yet which I cannot help regarding as in all probability young forms of *Tinoporus*, having been found in the same dredging, and presenting just the characters which I should expect from analysis of the structure of the adult to find in them. Moreover, I have *Planorbulinæ* whose early growth is so distinctly spiral as to correspond in every essential particular with the young of *Rotalia*.

218. It is not a little remarkable, however, that this organism should also be very closely related to a body of which the true nature has hitherto been doubtful, viz. the *Millepora rubra* of LAMARCK†, the *Polytrema miniacea* of BLAINVILLE‡. This grows parasitically upon shells, sometimes spreading over their surface in a laminated form, sometimes rising into a sort of stem and sending off branches. I have ascertained by examination of thin sections, that it is composed of minute chambers piled together very much in the manner of those of *Tinoporus*, and having the same kind of communications; and as Mr. PARKER has in his possession a specimen of a nearly globular form, attached to a projection of a bivalve shell, it may be questioned whether the difference between the two organisms is even of specific value. For the mode of growth which ordinarily characterizes each, shows a tendency to pass into that of the other; *Tinoporus lævis* occasionally flattening itself out and extending marginally, whilst *Polytrema miniacea* occasionally restricts itself within a compact spheroidal form. The probable relationship of *Polytrema miniacea* to the Foraminiferous type has been already suggested by the sagacity of Dr. J. E. GRAY§; but as he was not acquainted with the internal structure either of *Tinoporus* or of *Polytrema*, he could not make a more particular approximation. I should add that the bodies described and figured by Professor MAX. SCHULTZE‖ under the generic name of *Acervulina* appear to me to belong to the same type. I have in my possession a specimen growing round the stem of a

* See Professor WILLIAMSON's Monograph of the Recent Foraminifera of Great Britain, p. 57.

† Hist. Nat. des Animaux sans Vertèbres, troisième edit., tom. ii. p. 309.

‡ Manuel d'Actinologie, p. 410, pl. 69. fig. 16.

§ Proceedings of the Zoological Society, April 27, 1858.

‖ Über den Organismus der Polythalamien, p. 67, plate 6. figs. 12–15.

zoophyte, like the *Acervulina acinosa* of SCHULTZE, but with more of the compactness of *Polytrema miniacea.*

219. I now return to the form of *Tinoporus* on which the genus was originally established, the *T. baculatus* of MONTFORT; which agrees closely with *T. lævis* in the fundamental characters of its organization, but differs in being furnished with a variable number of radiating appendages that give it a strong resemblance to *Calcarina*. Of the specimens in my possession, the greater part present the aspect represented in Plate XVIII. figs. 2, 3, 4, 5, and on a larger scale in fig. 6; and these were collected from coral reefs in various parts of the Polynesian Archipelago,—my earliest acquisition of them, however, having been from the contents of the stomach of an *Echinus* taken on the coast of Borneo, which were kindly put into my hands by Dr. J. E. GRAY. I am informed by Mr. DENIS MACDONALD that on certain coral islands which he has particularly examined, these organisms are so extraordinarily abundant, that they accumulate in the lagoons in regular strata, commonly alternating with strata of *Orbitolites.* The more massive and ruder forms represented in Plate XVIII. figs. 7, 8, 9, 10, occur in Mr. CUMING'S Philippine collection.

220. *External Characters.*—The typical form of the central portion of *T. baculatus* (Plate XVIII. figs. 2–6, and in section in Plate XXI. fig. 7) may be considered as an oblate spheroid; sometimes, however, it is nearly spherical, and sometimes it is much flattened out, especially when the body extends itself into the radial prolongations, as in Plate XVIII. fig. 4. Its surface is divided into areolæ (fig. 6) very much as in *T. lævis*; but the angles of junction of the partitions between the areolæ are very commonly occupied by rounded projecting tubercles, strongly resembling those of *Calcarina.* The number and size of these tubercles vary greatly among different individuals, as will be seen on comparing figs. 2 and 4, Plate XVIII*. From the marginal portion of the central disk there spring a variable number of conical prolongations having the furrowed surface of those of *Calcarina*; and these appear seated (so to speak) upon extensions of the central disk itself, which is sometimes so deeply subdivided at its margin as to resemble the body of a Star-fish (Plate XVIII. figs. 4 and 7), the areolar division being continued nearly to the extremity of each ray, and its point only being formed by the furrowed prolongation. These appendages are usually from 4 to 6 in number; I have occasionally seen only 2, and in no case have I met with more than 8. They usually diverge in or near the equatorial plane; but they sometimes come off in very different directions (Plate XVIII. figs. 8, 10).

221. *Internal Structure.*—The general organization of *T. baculatus*, brought into view by sections taken in different directions, does not differ in any essential respect from that of *T. lævis*; the origin of the whole aggregation of chambers in a central cell, their subsequent multiplication both horizontally and vertically, and their methods of communication in both directions, being all the same. As already mentioned, I have very

* They seem to be altogether wanting in the Philippine specimens, being apparently replaced by a multitude of small spines, which give to their surface a hispid aspect.

distinct evidence, in sections of this species, of a *spiral* commencement, soon giving place to an *irregularly-cyclical* growth; and sometimes the first-formed portion (Plate XXI. fig. 11, *a*) bears so close a resemblance to the innermost part of the spire of *Calcarina*, that in this earliest stage of their growth the two types could not be distinguished from each other. Thus *Tinoporus baculatus* seems to bear the same relation to *Calcarina*, that *T. lævis* does (through *Planorbulina*) to the *Rotaline* type (¶ 217). The essential difference between *T. baculatus* and *T. lævis* consists in the possession by the former of a "supplemental skeleton," which presents itself under two principal aspects. The piles of chambers extending vertically from the equatorial plane towards the two surfaces of the spheroid (Plate XXI. fig. 7) are partially separated by the interposition of pillars of solid shell (fig. 8, *a*); and it is by the projection of the summits of these pillars (as in *Calcarina*) that the tubercles of the surface are formed. The spines also, which form the extremities of the radiating prolongations, belong to the same system; and they are shown, by sections of the Philippine type that pass in a favourable direction (fig. 6), to be extended from a solid framework which begins to be formed even with the first convolution, and which adds greatly to the thickness of the partitions between the chambers, giving off a multitude of minute spines from their external surface (fig. 10, *c*, *c*). This framework is penetrated by a canal-system, which not only forms passages through the solid axis that is prolonged into the spines (fig. 10, *a*, *a*), but also extends itself into the partitions between the chambers (fig. 9, *b*, *b*). The canal-system of the solid axis, moreover, communicates freely with the cavities of the chambers that are adjacent to it, as shown at fig. 10, *b*, *b*. These chambers are arranged around it with considerable regularity, as is shown in fig. 5, which is a transverse section of the base of one of the radiating prolongations, showing the solid axis with its radiating canals, surrounded by three rows of chambers. It would seem as if, in the Polynesian variety of *T. baculatus*, the material of the supplemental skeleton were appropriated rather to the formation of the solid pillars than to that of a solid axis for the radiating prolongations; the latter being much less conspicuous than it is in the Philippine specimens, and sometimes appearing to be deficient altogether except at their extremities. On account of the variability of these differences, however, I cannot regard them as of any essential value.

222. If any further evidence had been required as to the essential relation between the "canal-system" and the "supplemental skeleton," I think that it must be satisfactorily furnished by the comparison of the two species of *Tinoporus* now described. For in *T. lævis* it is obvious that the system of communications which exists between its chambers is adequate for all the ordinary wants of an organism of this type, the structure of which is uniform throughout. But when, as in *T. baculatus*, an additional framework of solid walls is interposed in the midst of the building, for the support of the extensions into which it is prolonged, a special system of passages, originating from the cavities of the adjacent chambers, and extending throughout the solid framework, is provided for its nutrition.

223. With reference to the relationship between *Tinoporus* and the fossil genus *Orbitoides*, to which allusion has already been made, I shall here content myself with stating briefly that if the chambers of the equatorial plane of *T. lævis* were distinctly differentiated from those of the layers springing from it on either side, it would come to resemble in general conformation the simpler type of *Orbitoides* known as the *O. Mantelli*; and further that if, with this modification, there were also introduced the solid pillar-system of *T. baculatus*, we should have a corresponding resemblance to *O. dispansus**. The metamorphic condition of the shell of the fossil *Orbitoides* has hitherto prevented me from determining with certainty whether its elementary structure bears most resemblance to the inferior type presented by *Tinoporus*, or to the more elaborate structure of that of *Cycloclypeus*, to which type also it seems to be related†. On these points, however, I shall enlarge more fully elsewhere.

Genus Carpenteria.

224. Of all the Foraminifera collected by Mr. Cuming in the Eastern Seas, the last which I have to describe is perhaps the most interesting; since the type of structure which it presents is not only altogether new, but seem to furnish the connecting link (which had been previously rather suggested than supplied by *Thalassicolla* and its allies) between Sponges and Foraminifera,—two groups which accord most remarkably in their *grade of organization*, whilst they differ no less remarkably in *plan of structure*.

225. The larger number of the specimens of this type in the collection of Mr. Cuming are attached to the surface of a piece of *Porites* (coral); other specimens, however, are adherent to the shells of *Pecten* and *Cardita*; and the attention of Mr. W. K. Parker having been directed to these curious organisms, he has met with them on the surface of other bivalves, especially *Chama gigas*. It is not a little remarkable that the strong external resemblance which they present to the shells of certain sessile Cirripedes should have led not only Mr. Cuming, but other experienced conchologists, to regard them as belonging to that group. Their true nature was first suspected by Dr. J. E. Gray, who was led by his study of them to consider them as the testaceous envelopes of a Rhizopod intermediate between Sponges and Foraminifera; the grounds on which he came to this conclusion being, that he found the shell to be multilocular and minutely foraminated

* I should take this opportunity of stating that in my former description of *Orbitoides* (Journal of the Geological Society, Feb. 1850) I fell into the same mistake in regard to these pillars, that I did in regard to the analogous structure in Nummulites; regarding them as having been passages filled with solid calcareous matter in the process of fossilization,—an error which was pointed out to me by Professor Williamson at the time, and of which I have since come to be fully satisfied by the examination of the recent analogues.

† The figure given by Professor Ehrenberg, in his remarkable memoir already referred to, "Über den Grünsand und seine Erläuterung des organischen Lebens," plate iv. fig. 8, and by him designated as the internal cast of *Orbitoides javanicus*, will be seen on comparison to present a most remarkable correspondence with figs. 10, 11, 12 of Plate XXIX. (Phil. Trans. 1856) illustrating my description of *Cycloclypeus*.

like that of certain Foraminifera, whilst the fleshy substance occupying its chambers is strengthened with spicules like those of Sponges. Hence he considered this organism in the light of a *Sponge* enveloped in a shelly case with a single terminal *oscule.* My opinion as to its character having been asked by Dr. Gray, I soon found reason to accord with him in his general idea of its affinities; the structure of the shell being most characteristically *foraminiferous*, whilst the substance occupying its chambers is no less characteristically *spongeous*. In communicating this result, however, to Dr. Gray, I thought it right to suggest the possibility that this spongeous substance might be parasitic; the tendency of certain Sponges to find their way into even very minute fissures and passages having been observed by me in my researches on the structure of the Shells of Mollusks. Dr. Gray agreed with me in thinking this improbable, for reasons which will be presently stated; and he communicated a general account of this new type (to which he did me the honour of giving my own name) to the Zoological Society*; at the same time expressing the desire that I should include a fuller account of its formation and structure in my communications on the Foraminifera to the Royal Society. With this desire I have now the satisfaction of complying.

226. *External Characters.*—The ordinary external aspect of *Carpenteria*, as represented in Plate XXII. figs. 1, 10 (taken from a group on the surface of *Porites*, of which the individuals are in close proximity to each other), at once suggests a resemblance to the Balaniform type; the shell being conical, attached by its broad base, furnished with a single definite aperture at its apex, and presenting an appearance of irregular divisions into triangular segments, which might easily be supposed to be "valves" bounding a single undivided cavity. On breaking into the interior of the shell, however, it immediately becomes apparent that the foregoing resemblance is superficial only; the entire cavity of the shell being divided into numerous chambers, which are completely separated from each other by septa, whose lines of junction with the external wall (indicative of the successional additions which the shell has received) give rise to the appearance of valvular divisions. And a closer examination reveals that these chambers are disposed upon a spiral type, each whorl completely investing (save on the adherent base) that which preceded it, so that only the external wall of the last whorl is anywhere seen on the surface. In the specimen represented in fig. 5, which is one of the isolated individuals occurring on the valve of a *Pecten*, the shell has a much less regular form, owing to the more or less complete divergence of the basal portions of the chambers of the last whorl, and the partial subdivision of some of those chambers into lobes which exhibit the like divergence. The shelly surface of the wall of each chamber presents a somewhat areolated aspect, which depends upon its being raised into a multitude of low rounded elevations (fig. 8); and under a sufficient magnifying power these areolæ are seen to be pretty uniformly marked with minute punctations (fig. 6). The form of the aperture at the summit of the cone, of which two examples are shown in figs. 13 & 14, presents a striking resemblance to that of the aperture of the *Milioloid* Foraminifera.

* Proceedings of the Zoological Society, April 27, 1858.

227. *Internal Structure.*—On breaking-away a portion of the external wall of the last-formed chamber, so as to lay open its interior (as shown in fig. 8), we find that its cavity is closed-in on every side by its shelly walls, except where it has communications (b, c) with the apical aperture; and each principal chamber is partially subdivided by a system of shelly septa, of which some are more and others less complete. The more complete of these secondary septa (fig. 8, e, e^1, e^2) resemble the principal septa (d, d^1, d^2) which separate the cavities of the chambers, in running from the base towards the apex of the cone; they divide the lower portion of each chamber into three, four, or more digitations, which are sometimes marked by an external lobulation, as shown in fig. 5; they stop short, however, about half or two-thirds of the way towards the apex, leaving the upper third or half of the chamber undivided. Some of these septa do not reach the opposite surface of the chamber; and the least complete (f, f^1, f^2) form a sort of network of ridges slightly projecting from the inner surface of the outer wall into its cavity (as shown in vertical section at *b, b, b*, fig. 15), and there marking out an areolation which corresponds to that of the external surface. The areolæ of the internal surface, however, are concave instead of convex; and the punctations, which are wanting on the ridges, are set more closely on the depressions between them. The reason of this peculiarity in their distribution will be presently seen (¶ 229).

228. The cavity of the last chamber communicates with the external orifice by a passage of considerable size; and the wall of this passage is distinctly continued as an irregular ring around the apical aperture, so that this aperture may be considered in one sense (as described by Dr. GRAY) to belong to the last chamber alone. But it would be more correct to say that each cell as it is formed *conceals*, than (with Dr. GRAY) that it *closes*, the aperture of the preceding cell; for a careful examination shows that the external aperture or vent is the termination of an irregular vertical canal, formed by the superposition of the oral rings of successive cells; and that through this canal the previously formed cells retain their original connexion with the exterior. In some of Mr. PARKER'S specimens, the oral ring is extended upwards into a tube or siphon at least equal in length to the radius of the cone. The general disposition of the chambers around the central canal is well shown by sections of the cone taken parallel to its base (fig. 7); such sections, however, may only bring into view the last or superficial whorl; and they will generally show only one or two chambers in communication with the vertical canal, the communicating passage of each chamber being on a different plane.

229. The foramina which pierce the outer wall of each chamber are of considerable size, as compared with the minute tubuli of *Cycloclypeus* and *Operculina* (see ¶¶ 103, 154), and they are not nearly so closely approximated; in both respects they correspond closely with the foramina of the ordinary *Rotaliæ* and *Globigerinæ*. In fig. 12 they are shown as they appear in a section traversing the wall somewhat obliquely to its surface, whilst in fig. 15 they are shown as they appear in vertical section; and in each case they are seen to present an annulated appearance, which is due to constrictions of the tubes at tolerably regular intervals. These tubes generally pass direct from one surface to the

other; but at *a*, *a*, fig. 15, it is seen that in the neighbourhood of the ridges which project from the inner wall into the cavity of the chamber, the tubes either bend or incline themselves in such a manner, that, whilst their *external* orifices are pretty uniformly distributed (fig. 6, *a*), their *internal* orifices do not show themselves upon the ridges, but are crowded together along their bases (fig. 6, *b*, and fig. 9). The septa, whether *primary* (separating the chambers from each other) or *secondary* (partially subdividing the chambers), are obviously formed by a doubling-in of the outer wall, so as to make each septum consist of two laminæ (fig. 12, *a*, *a*); this is seen also in sections of the incomplete septa (fig. 12, *b*), as well as of the ridges which may be considered as rudimentary septa (fig. 15, *b*, *b*, *b*). The two layers sometimes separate from each other, as shown in these figures, so as to leave intraseptal spaces; and these form a tolerably regular canal-system, which may be traced throughout the network of ridges that covers the inner wall of each principal chamber, and, through the primary septa, into the ring that surrounds the vertical canal (fig. 7, *g*, *g'*).

230. Whilst, therefore, the general plan of conformation of *Carpenteria* seems to differentiate it strongly from that of the ordinary Foraminifera, so close an alliance to them is indicated by the minute structure of its shell, that it becomes of special importance to determine whether its peculiarities are original, or whether they are acquired during the progress of development. I have fortunately been enabled to determine this point by the comparison of several specimens in different stages of evolution, and by the removal from the older specimens of one whorl after another until the original nucleus was arrived at (an operation which has been very dexterously performed for me by my draughtsman Mr. GEORGE WEST); and I can state without hesitation that the early condition of this apparently anomalous organism accords with that of the *Hélicostègue* Foraminifera generally,—its approximation being the closest to *Rotalia* in general form, but its tendency being rather towards *Globigerina* in this particular, that its chambers do not seem to communicate directly with each other, but that each has a separate external orifice directed towards the umbilicus. Various aspects of this first-formed portion of the shell, two of them showing the animal substance contained in the chambers, are seen in Plate XXII. figs. 2, 3, 4. Now supposing that a *Globigerina* were to grow in such a manner, attached by one of its surfaces, that the walls of its successively-formed chambers came into mutual contact, and that these chambers were so shaped and so piled one on the other as to give to the entire shell a conical form, each chamber opening by its own separate orifice into an umbilical funnel, we should have the essential type (so far as its shell is concerned) of *Carpenteria*; and this is really the mode in which the latter type is superinduced upon the former, as the development of the organism advances. It is further interesting to observe that the great size of the chambers which form the superficial whorl of *Carpenteria*, has every appearance of being due to the deficiency of that complete segmentation, in the later stages of growth, which characterizes the earlier; for every one of the *loculi* marked out by the ridges projecting into the interior corresponds so closely both in size and general aspect

with an entire chamber of the earlier whorl, that the areolation of the outer wall may be regarded as a sort of attempt at that complete subdivision of the cavity, which we have seen to be fully carried out in *Heterostegina* (¶ 114).

231. Thus, then, it appears that not only in the minute structure of its shell, but also in its general plan of conformation, *Carpenteria* essentially approximates to the ordinary Foraminiferous type, its affinity to the *Spongiada* being rather apparent than real; for although each cone does at first view seem to resemble the papilla of a Sponge enclosed in a shelly case with a terminal oscule, yet the internal structure of that cone does not bear out that resemblance. The link of affinity, however, seems to be supplied by the spongeous character of the animal substance which occupies the chambers (fig. 9); this (according to the evidence afforded by the dry specimens which alone I have had the opportunity of examining) not only possessing far more consistence than the sarcode-body of the Foraminifera, but being supported, in the large chambers at least (fig. 6), by sponge-like spicules (fig. 16), whose form resembles that of the simplest spicules of *Halichondria*, and whose composition is siliceous.

232. The idea which had occurred to myself of the possibly parasitic nature of this sponge-like substance, has been very strenuously advocated by Mr. BOWERBANK, on the ground of the frequency with which the surface of dead coral and the valves of living as well as dead shells are covered with Sponges, and the consequent probability that any multilocular organism growing on such surfaces would be so penetrated by the sponge that all its chambers would be filled by the parasite. The following considerations, however, seem to me strongly to militate against such a view:—1st. That neither on the surface nor in the substance of the specimen of *Porites* covered with the cones of *Carpenteria*, nor on that of the valves of the *Pecten* and *Cardita* on which isolated specimens of *Carpenteria* occur, is there the least trace of spongy structure:—2nd. That, notwithstanding this marked difference in their *habitats*, all the specimens of *Carpenteria* yet examined have their cavities occupied by the same spongy substance:—3rd. That a firm brownish yellow substance of far greater consistence than the sarcode of Foraminifera, is found to occupy even the smallest and earliest chambers of *Carpenteria* (figs. 2, 4, *a*), filling them so completely that it can scarcely be supposed to be anything but the animal body properly belonging to them; and that although the substance in question is *there* destitute of spicules (the chambers being too small to accommodate them, as will be seen by the comparison of figs. 4 and 16, allowing for the difference of magnifying power), yet it is obviously the same with that in which spicules are copiously imbedded in the larger and later chambers:—and 4th. That notwithstanding the multitudes of sections of various Foraminiferous shells which I have made during the last ten or twelve years, I have never found their chambers to be occupied by a parasitic sponge of any description. I may add to these considerations the fact mentioned to me by Mr. DENIS MACDONALD, that he has met with various forms of branching Sponges*, possessing a peculiarly solid calcareous skeleton, and in many respects

* These specimens were collected during the voyage of H.M.S. 'Herald' in the Australian Seas, and

appearing to present the same kind of transition from Sponges towards Foraminifera, that, if my view be correct, is afforded by *Carpenteria* from Foraminifera towards Sponges.

233. The above reasons appear to me so strongly in favour of that idea of the essentially spongeous nature of the animal of *Carpenteria*, which had been from the first entertained by Dr. J. E. GRAY, as to leave me little room for hesitation in the belief that such is its real character; so that, until the contrary shall be proved, we seem justified in regarding this curious organism as a Rhizopod which in virtue of its shell is *foraminiferous*, whilst in virtue of the animal body which that shell contains it is *spongeous*.

CONCLUDING SUMMARY.

[Added during the printing of the Paper.]

234. In bringing to a close the present series of Researches on the Organization of the Foraminifera, I think it desirable to combine a summary of the most important results which I have obtained, with some remarks on their bearing, not merely on the method to be followed in the attempt to frame a natural classification of this group, but upon some of those higher questions relating to the origin and value of differential characters generally, which have recently been brought prominently under the consideration of the scientific world. In so doing it is my desire to confine myself strictly to the scientific and practical aspect of these questions; seeking in the first place to determine, on the legitimate basis of induction, what general principles may be either certainly or probably educed from the comparison of the large body of facts which have been brought together by myself and others as regards the mutual relations of Foraminifera; and then briefly inquiring how far the results of similar comparisons made upon other types of organized structure justify the extension of the same principles to the Animal and Vegetable kingdoms at large.

235. It may be well for me to advert *in limine* to certain features in this inquiry, that render the group to which it relates singularly adapted for a comparison at once minute and comprehensive amongst a wide range of individual forms.—The size of the greater part of these organisms is so small, that many hundreds, thousands, or even tens of thousands of them may be contained in a pill-box; and yet it is usually not too minute to prevent the practised observer from distinguishing the most important peculiarities of each individual by a hand-magnifier alone, or from dealing with it separately by a very simple kind of manipulation. Hence the systematist can easily select and arrange in series such of his specimens as display sufficient mutual conformity, whilst he sets apart such as are transitional or osculant; and an extensive range of varieties may thus be displayed within so small a compass, that the most divergent and the connecting forms are all recognizable nearly in the same glance. I am not acquainted with any other

were transmitted by Mr. MACDONALD to the Admiralty. I have not yet succeeded, however, in obtaining a sight of them.

group of natural objects, in which such ready comparison of great numbers of individuals can be made; and I am much mistaken if there be a single specimen of Plant or Animal, of which the range of variation has been studied by the collocation and comparison *under one survey* of so large a number of specimens as have passed under the review of Professor WILLIAMSON, Messrs. PARKER and RUPERT JONES, and myself, in our studies of the types to which we have respectively given our principal attention *.

236. The general fact which I desire to bring prominently forward as the result of recent investigations into this group, is, that in all the types possessing a wide geographical distribution, which have been specially studied by myself or by others, the range of variation has also been very wide; so that not only what would commonly be considered as *specific*, but such as have been regarded as *generic*, and in some cases even as *ordinal* differences, present themselves among organisms, which, from the intimacy of the relationship that is evinced by the gradational character of those differences as well as by the variations presented by the several parts of one and the same organism, must in all probability have had a common origin. And it appears to me to be a justifiable inference from this fact, that the wide range of forms which this group contains is more likely to have come into existence as a result of modifications successively occurring in the course of descent from a small number of original types, than by the vast number of originally distinct creations which on the ordinary hypothesis would be required to account for it†.

237. The greater part of my First Memoir was devoted to the investigation of the single type *Orbitolites*; and I there showed that not only as regards the size, shape, and other external characters of the organism as a whole, but even as regards the size and form of its elementary parts (in which greater constancy might be expected), is there so great a variation,—the most marked diversities being apparent even in different parts of the same individual,—that all attempts to found specific distinctions upon such variations are utterly futile. But further, I showed that a distinction on which almost any Naturalist would feel justified in relying as of at least *specific* if not of *generic* value,—that between the *simple* type in which the chambers are arranged on only one plane, and the *complex* type in which there are two superficial planes more or less strongly differentiated from the median,—is no less invalid. For although these types are usually distinguish-

* I have the authority of M. DESHAYES for the belief, that the excessive multiplication of generic and specific distinctions which so greatly impairs the value of the late M. D'ORBIGNY's labours upon this group, was due to his having based these distinctions upon specimens selected for him as *typical*, and to his having disregarded the *transitional* forms which any large collection of these organisms is sure to exhibit in abundance,—thus, to use the admirably discriminating phrase of the late Prince of CANINO, "describing *specimens* rather than *species*."

† In order to avoid misapprehension, I would here remark that the production of *any* organism seems to me just as much to require the exertion of Divine Power when it takes place in the ordinary course of generation, as it would do if that organism were to be called into existence *de novo*; the question being in reality, whether such exertion takes place in the way of continuous exercise according to a settled and comprehensive plan, or by a series of disconnected efforts.

able, the one from the other, without the least difficulty, yet they are often combined in the same individuals, and this in such a variety of modes, that the transition from the simple to the complex may be clearly seen, from the comparison of a sufficient number of specimens, to be by no means attributable to a mere advance of age. Further, having been furnished (by the kindness of Mr. H. J. Carter) with specimens of the Scindian fossil which presents the characters ascribed by M. d'Orbigny to his genus *Cyclolina*, I am now able most fully to confirm the suggestion I threw out on a former occasion (¶¶ 49, 70), that this genus is founded on a mere variety of *Orbitolites*, in which the character of the surface-marking is more than ordinarily cyclical.

238. Not merely, however, does the range of variation of this type confound the ordinary distinctions of systematists in regard to species and genera; it extends also to that difference in plan of growth, which has been assumed by M. d'Orbigny to be of such fundamental importance as justly to constitute the essential difference between his two orders *Cyclostègues* and *Hélicostègues*. For, as I have shown, although *Orbitolites* is typically cyclical from its commencement, yet specimens frequently present themselves in which its early development has taken place so completely on the helical plan, that if such had been collected before their assumption of the cyclical mode of growth, their essentially *Cyclostègue* character would not have been suspected.

239. Again, I have shown that a parallel variation is displayed by the genus *Orbiculina*, whose ordinarily helical plan of growth has caused M. d'Orbigny to range it among his *Hélicostègues*, notwithstanding that in fully-developed specimens its mode of growth is not unfrequently cyclical. The occasional exchange, in this type, of one plan of increase for the other, at an advanced period of life*, of which exchange I think I have given adequate evidence (¶¶ 85–87), is a fact which seems to me of very high interest, being much more decided in its nature than the corresponding change in *Orbitolites*. For whilst in the latter the tendency of the spiral form (whenever it presents itself) to pass into the cyclical, is apparent almost from the beginning, and the change is never long postponed, the helical plan is that on which the growth of the former not only commences, but continues to be carried on, often through the entire period of its increase.

240. It is important to remark that in each case the metamorphosis is simply due to the very rapid opening-out of the mouth of the spire, its two lateral extremities extending themselves round the shell on the one side and on the other, until they meet and completely enclose the portion previously formed (just as the lobes of the mantle in the adult *Cypræa* spread themselves round the shell until they meet on its dorsum); and also that the mutual relations of the chambers of the shell and of the segments of the animal body which they contain, remain essentially unchanged. Again, it is a point of no mean significance, that when an *Orbiculina* has undergone this change, the outer

* It has been remarked by Messrs. Parker and Rupert Jones, that whilst the assumption of the cyclical form in *Orbiculina* may often be the result of the continued growth of individuals under favourable circumstances, small starved forms also frequently take on the cyclical condition, leaving the young sub-lenticular stage without passing through the aduncal. See Annals of Natural History, March 1860, p. 181.

or cyclical portion of its disk can in no way be distinguished from that of *Orbitolites*; and that the only difference between these two types which has any semblance of validity, is the absence in *Orbitolites* of those successive encasings of the central nucleus, the presence of which seems to be a constant feature in *Orbiculina*. It is to be observed, however, that these successive encasings are due entirely to the extension of the later whorls of the spire over the earlier; and they are no longer formed in *Orbiculina* when the helical mode of growth gives place to the cyclical. Hence it seems not unfair to surmise that if the helical growth of an aberrant *Orbitolites* were to continue until its spire had made several turns, instead of stopping before the completion of one, its nucleus would receive successive investments from successive whorls, just as in the typical *Orbiculina*; and the only difference between these two types would thus vanish. On the other hand, if the helical growth of an *Orbiculina* were to give place to the cyclical at an unusually early period, the central nucleus would receive no investment, and would present the flatness by which that of *Orbitolites* is characterized when compared with that of the typical *Orbiculina*.

241. I cannot but believe that such as may have followed me through the details of my previous descriptions, will be disposed to agree with me in thinking it justifiable to assume that such a range of variation as to the *period* of the change in plan of growth, would be only analogous to that which both these types present in so many other particulars; and hence that the idea of the derivation of *Orbitolites* and *Orbiculina* from the same original is scarcely less probable than that of the derivation of the helical and cyclical types of *Orbiculina*, or of the simple and complex types of *Orbitolites*, from a common parentage;—particularly since, as was formerly pointed out (¶ 90), both types present analogous modifications in geological time.

242. Let us now apply the same mode of inquiry to *Alveolina*. It has been shown (¶¶ 93, 94) that this organism is closely allied in every other respect than its geometrical plan of growth to the types we have just been considering; the structure of the shell and its relations to the contained sarcode-body, and the relations of the segments of that body to each other and to the external world, being essentially the same in them all*. Now, however improbable it might seem at first sight, that an *Orbitolites* which extends itself as a flat or biconcave disk by successive concentric growths, and an *Alveolina* acquiring a fusiform shape by successive turns round a progressively elongating axis, should have had a common original, yet when the intermediate links are duly studied, a continuous gradation is found to be established. For, as has just been shown, a longer continuance of the helical mode of growth in which *Orbitolites* often commences, would really produce an *Orbiculina* with its centre so invested by successive

* I may take this opportunity of stating that the description which I based on the examination of sections of the shell has been fully confirmed by the internal casts obtained by Messrs. PARKER and RUPERT JONES from specimens whose chambers had been filled by an infiltration of silicate of iron (¶ 178); which casts most accurately represent the form of the sarcode-body and of its individual segments with their connecting stolons.

whorls as to form a vertical linear axis; and we find this axis in *Orbiculina* sometimes equalling in length the diameter of the spire, so that this organism at an early stage of its growth may be nearly spheroidal*. Now among the various types of fossil *Alveolinæ*, there are some whose shape, instead of being fusiform like that of the recent type I have described, is almost identical with that of a spheroidal *Orbiculina*; and the general structure of two such organisms will be so nearly identical, that I cannot see any difficulty in referring them to a common original. And when we examine a series of such fossil types, we see that they present a wider and wider divarication from the *Orbiculine* type in this one particular alone,—that whilst the later growth of *Orbiculina* tends to liken it to the discoidal *Orbitolites*, that of *Alveolina* tends to the continual elongation of its vertical axis, a difference which the analogies of the Foraminifera generally would indicate to be one of far too small account to be fairly adopted as a ground of original distinction†.

243. In the assemblage of forms which I have thought myself justified in re-assembling under the designation *Peneroplis*, we encounter another remarkable series of variations, the principal of which have given occasion to the formation of the two additional genera *Dendritina* and *Spirolina*. With an exceedingly close conformity in the texture and in the superficial markings of their shells, as well as in their general plan of growth, we observe a marked diversity in the form and proportions of the spire, especially in the later stages of its growth, and a still greater divergence in the form and disposition of the septal apertures. For in the type to which M. D'ORBIGNY restricts the generic designation *Peneroplis*, we usually find the spire rapidly widening and becoming proportionally compressed in each succeeding convolution; whilst in that which he distinguished as *Dendritina*, the spire widens but slowly, whilst increasing rapidly in turgidity. Further, in the one type as in the other, the later extension is often in a straight line, instead of continuing to follow the spiral course; and on this variation alone, which is of no account whatever among Foraminifera (as will presently appear, ¶ 255), has been erected the genus *Spirolina*. Now in the typical *Peneroplis*, the septal plane presents a linear series of minute rounded pores; whilst in the typical *Dendritina* we find in their place a single large orifice with radiating extensions; the difference between these two modes of communication being as great as we find between almost any two types of Foraminifera whatever. Yet I believe that no one who will go through the details of the evidence I have collected from the study of transitional forms, will have any doubt that *Peneroplis* and *Dendritina* have had a common progenitor, and that the peculiarity in the mode of septal communication that characterizes each is intimately related to the compressed or turgid form of the spire in either case; whilst the different forms of the *Spirolina* type, among which we find the most remarkable

* See Philosophical Transactions, 1856, Plate XXVIII. fig. 8.

† In this view of the relation of *Alveolina* to *Orbiculina* I am supported by Messrs. PARKER and RUPERT JONES, who remark that *Alveolina* "may be said to represent a small thick *Orbiculina* drawn out transversely at its umbilici."—Ann. of Nat. Hist., March 1860, p. 182.

transitional conditions of aperture, are so obviously related to both the foregoing, that no reasonable doubt can exist as to their derivation from them. Now the geographical distribution of the two fundamental types is so far different, that where one prevails the other is either absent altogether, or presents itself under a modified form; and thus we seem justified in the belief that, whether either of them has been derived from the other, or both have been derived from some intermediate form (such as that which seems common alike to the *young* of both), the modifications which have given rise to the marked differences they now exhibit are mainly due to diversities in the external conditions under which they have been respectively propagated.

244. But to what other type does *Peneroplis* itself present the closest approximation? By systematists in general the intimate relationship which I have shown it to possess to the helical type of *Orbiculina* (¶ 130) has been so slightly regarded, that it has been considered as at least equally related to the *Operculine* type; and yet, as I shall presently show, these two types are removed from each other in all the most essential features of their structure, as far as any two polythalamous Foraminifera can be. And the idea of the derivation of *Peneroplis* from the same stock with *Orbiculina*, seems justified by the fact that the young forms of the two are frequently so alike as not to be distinguishable by external characters alone, whilst their internal difference consists only in the presence or absence of the secondary or transverse septa, a character which I have shown reason to regard as variable in this group* (¶ 130).

245. Notwithstanding, therefore, the apparently wide divergence of the cyclical *Orbitolites*, the helical *Orbiculina*, the fusiform *Alveolina*, and the simply-chambered *Peneroplis* and *Dendritina*, these several types must be regarded as most intimately related to one another; and that relationship seems to me much more likely to have arisen from a common ancestral descent, than from the original creation of independent types capable of graduating into each other so continuously as almost to assume each other's characters. It is very important to remark that they all possess that peculiar texture of shell, which is designated by Professor WILLIAMSON as *porcellanous*; presenting an opake white hue when seen by reflected light, but a rich brown or amber colour when seen by light transmitted through thin natural lamellæ or artificial sections. This substance is entirely structureless, and possesses no great density or tenacity. Moreover in all the foregoing types, each of the septa intervening between the chambers consists of only a single layer; the passages of communication between them are for the most part so large and free, that the segments of the sarcode-body are but very imperfectly isolated from each other; and, as might be anticipated from this incompleteness of separation, it is here that variations in the mode of communication between the chambers seem to be of

* My statement on this point is fully confirmed by Messrs. PARKER and RUPERT JONES; who state that "not unfrequently, feebly-developed peneropliform varieties, as well as good-sized adunciform specimens, occur, in which the long narrow chambers are at times simple and undivided, being occupied by transversely elongate lobes of sarcode, instead of numerous minute subcubical blocks." See Ann. of Nat. Hist., March 1860, p. 180.

least account. It is in this type that we recognize the nearest approximation towards such forms as *Thalassicolla*, which seem to connect *Orbitolites* with *Sponges* (¶ 67); while the relationship which *Orbiculina* and *Peneroplis* have been supposed to bear to the ordinary *Hélicostègues*, being dependent only on plan of growth, and being utterly at variance with the essential characters of the two groups, must be regarded as one of analogy, not of affinity. Looking to the evidence already adduced in regard to the prevalence of particular modifications of *Orbitolites* in particular localities (¶ 62), and to the influence of the geographical distribution of the *Peneroplis* type upon the modifications it presents (¶ 138), we seem justified in extending the same view to those larger (though not more essential) differentiations which these types must have undergone on the hypothesis of their derivation from the same original. The following may be suggested as the mode in which the existing forms might thus have diverged from each other and from their primary type.

Orbiculine Type

diverging into

Peneroplis — Orbiculina

Peneroplis: Dendritina, Peneroplis
Dendritina, Spirolina, Peneroplis.

Orbiculina: Orbiculina, Alveolina
Orbiculina, Orbitolites, Alveolina.

246. Passing on, now, to an essentially different group, that which includes *Nummulites* and its allied forms, we find that the relation of the discoidal *Cycloclypeus* and the helicine *Heterostegina* is of essentially the same nature with that of *Orbitolites* and *Orbiculina* (¶¶ 113, 116); the minute structure of the shell and the physiological condition of the sarcode-body being essentially the same in the two organisms, and the only important divergence between them being in their plan of growth. From the rarity of *Cycloclypeus*, all the known specimens of which have been brought from one locality, I have not yet had the opportunity of ascertaining whether it ever presents in an early stage any approximation to the helical mode of growth; but such a deficiency of affirmative evidence is obviously not equivalent to a disproof of what has strong analogy in its favour.—The variations which I have described among the different forms of *Operculina*, although limited to the form of the spire and the character of the surface-markings, would be amply sufficient to justify the erection of numerous species, were it not for the connexion established between the most divergent forms by intermediate links, and the necessity for an almost indefinite multiplication of hypothetical originals which the adoption of such a method would involve. The existence of such a large extent of variation among the specimens collected in the same locality must be admitted as valid evidence of the facility with which differential characters develope themselves in this type; and a strong probability is thus afforded in favour of the varietal character of larger differences among individuals whose conditions of existence are very diverse.

Hence the analogy of *Operculina* affords good ground to surmise that many of the reputed species in the nearly-allied genus *Nummulites* have no real title to that rank; the differences among many of them being not nearly so great as those we have met with among the varieties of *Operculina*; whilst those presented by many others do not exceed what might be reasonably expected to occur under a greater variety of modifying agencies. But I have shown (¶ 162) that it may be fairly questioned whether there is adequate ground for upholding the generic distinctness of *Operculina* and *Nummulites*; the characteristic by which the latter has been asserted to be specially distinguished being not unfrequently observable as a varietal difference in the former. The form which I have described under the designation of *Amphistegina Cumingii** bears a striking resemblance to the ordinary Nummuline type in the early part of its growth, and to the ordinary Operculine in the later; and may be regarded as in many respects a connecting link between the two.

247. There appears, then, strong reason for considering *Cycloclypeus*, *Heterostegina*, *Operculina*, *Nummulites*, and *Amphistegina* as related to each other in the same manner and degree as the leading forms already enumerated under the Orbiculine group. And it is very curious to observe the perfect analogy which prevails in regard to the forms under which these two great types of structure—essentially different as they are—tend to develope themselves. As I have just pointed out, the relation of *Cycloclypeus* to *Heterostegina* is exactly that of *Orbitolites* to *Orbiculina*. So if the transverse or secondary septa of *Heterostegina* were undeveloped, we should have an *Operculina*, *Nummulina*, or *Amphistegina* (these three types being in my view essentially one and the same), just as the like deficiency actually occurring in *Orbiculina* gives to it all the essential characters of *Peneroplis*. And the parallelism seems to be completed by the existence in *Fusulina*† of the same elongated condition of this type, that *Alveolina* is of the Orbiculine.

248. The mutual accordance of all these in the highly elaborated texture of the shell, in the relation which this bears to the segments of the sarcode-body, and in the presence of an intermediate skeleton with its canal-system, is extremely close. The substance of the shell is very dense, and of almost vitreous transparence where it is not perforated by the minute closely-set tubuli which usually pass direct from the interior of the chambers towards the external surface. Each segment of the body has its own proper envelope, so that the septa between the chambers are composed of two distinct laminæ, which diverge from each other where they give passage to the canal-system, and which are often further separated by the intervention of a portion of the "intermediate skeleton." The passages of communication between the chambers are so narrow, that the segments

* It is questioned by Messrs. PARKER and RUPERT JONES whether this is a true *Amphistegina*, chiefly on account of its bilateral symmetry (Ann. of Nat. Hist. Feb. 1860, p. 111). But I have met with perfect bilateral symmetry in specimens warranted as *Amphistegina* by those excellent judges of that type.

† I have not yet been able to satisfy myself as to the precise affinities of *Fusulina*, the metamorphic condition of its shell interfering with the minute study of its structure; but my view of its nature essentially corresponds with that of Messrs. PARKER and RUPERT JONES. (See Quart. Journ. of Geol. Soc., Nov. 1860, p. 458.)

of the body are much more isolated from each other than they are in the type already described; and the proper walls of the chambers seem, as it were, to be moulded upon the segments, instead of merely filling up the interspaces between them. This filling-up, in fact, is the office of the "intermediate skeleton," which gives a solidity to the whole aggregation that would otherwise be wanting; and special provision, as we have seen, is made in the canal-system for its nutrition. Altogether this type is the one in which the Foraminiferous structure attains its highest development, and which is most completely differentiated from every other. And the morphological variations it is known to undergo seem to me fully to justify the inference, that such further variations as have been shown to occur in the Orbiculine type might be regarded as the probabl source of the divergence, from some common ancestral stock, of the several forms whose intimate relationship I have demonstrated. The analogy of that type would suggest *Heterostegina* as presenting the nearest existing approximation to such a common original; and the stages of differentiation may be thus expressed:—

Heterostegine type

diverging into

Operculina — Heterostegina

Operculina: Amphistegina, Nummulites, Operculina.

Heterostegina: Heterostegina, Cycloclypeus.

From my imperfect acquaintance with *Fusulina*, I do not feel justified in expressing its exact relationship to either of the forms included in this scheme; and for the same reason I abstain from connecting *Orbitoides* with *Cycloclypeus*, to which it has some features of close relationship.

249. After this detailed examination of the general relations of the principal modifications of two of the most strongly marked types to be found in the whole group of Foraminifera, it seems needless for me to do more with respect to the other forms whose structure I have investigated, than to inquire how far the peculiar characters by which they are respectively distinguished show evidence of a like variability.—Thus we have seen that *Calcarina* is essentially distinguished from *Rotalia* by the extraordinary development of the "supplemental skeleton," and by the extension of this into radiating prolongations. But it has been shown (¶ 197) that the number, form, and proportions of these prolongations are subject to very considerable variations; so that whilst they are sometimes so greatly multiplied and prolonged as to constitute the principal feature of the organism, they are so little developed in other instances that the contour of the disk is scarcely interrupted by them. Further, it has been shown (¶ 207) that the development of this supplemental skeleton is in great degree independent of that of the spire; hence if this last be the essential component of the organism (as all analogy indicates), the supplemental skeleton must be regarded as a feature of minor importance. On the other hand, the development of radiating outgrowths is an occurrence not unfrequent among other helicine Foraminifera, even in species whose typical form is altogether

destitute of them (as Professor WILLIAMSON has pointed out in *Polystomella crispa*); and such forms differ much less widely, as regards this character, from the simpler forms of *Calcarina*, than these last do from the very complex forms which have been shown (¶ 197) to be connected with them by a continuously gradational series. Hence I cannot regard the remarkable development of the supplemental skeleton in *Calcarina* as affording any disproof of the idea of its genetic relationship to *Rotalia*, to which its affinity in every other particular is most intimate.

250. If, again, we inquire into the import of that remarkable development of the *canal-system*, which seems to be the distinctive feature of *Polystomella*, we find that if we base our judgment upon a sufficiently wide foundation of facts, its non-essential character becomes apparent. For although the large *P. craticulata* of the tropical and Australian seas presents the most symmetrical and extensive distribution of the canal-system that I have anywhere met with (¶¶ 187–191), the little *P. crispa* of our own seas exhibits but feeble traces of it (¶ 192); yet of the intimacy of their relationship no doubt can be fairly entertained. We have traced a parallel difference between the gigantic *Amphistegina Cumingii* and the comparatively diminutive *A. gibbosa* (¶ 171). And the like difference has been shown to exist between the two forms of *Tinoporus* (¶ 222), where its presence or absence is obviously associated with the presence or absence of the radiating prolongations and of the supplemental skeleton from which these proceed.

251. In considering the import of the canal-system as a character for the systematist, the mode of its formation must not be left out of view. I have shown that the passages which altogether go to make up this system are not true *vessels*, but are mere *sinuses*, left in some cases by the incomplete adhesion of the two contiguous walls which separate the adjacent chambers, and in other cases apparently originating in the incomplete calcification of the sarcode which forms the basis of the solid skeleton; certain portions of that substance remaining in its original condition, so as to maintain a communication between the contents of the chambers and the parts of the calcareous skeleton most removed from them, analogous to that which the Haversian canals afford in the case of laminæ of bone not in the immediate vicinity of a vascular surface. As, therefore, the development of the Haversian system is related to the thickness of the bone-substance to be nourished, so does that of the canal-system in Foraminifera seem to be related to that of the consolidating substance which constitutes the supplemental skeleton. And it is to be specially observed that nearly all the forms in which (so far as we know at present) it attains any considerable development, are denizens either of tropical or of subtropical regions, in which the influence of external conditions appears specially to favour the largest growth and the most specialized evolution of the Foraminiferous type.

252. I think it better, in the present limited state of our knowledge of two of the types to the elucidation of whose structure the present memoir has been devoted, viz. *Tinoporus* and *Carpenteria*,—to forbear to speculate further than I have already done upon their relationship to the forms already familiar to systematists (¶¶ 217, 230).

And I have now to show that the results of my inquiries in regard to such typical forms of Foraminifera as have passed under my review, are in complete accordance with those obtained by other naturalists who have proceeded upon the like method,—that of the comparison, not of selected specimens, but of entire gatherings over extended areas and through various geological epochs.

253. Long ago did those excellent observers MM. Fichtel and Moll (1803) manifest a clear perception of the wide range of variation to which certain types of Foraminifera are liable, and give admirable descriptions and figures of such varieties. But their views were too philosophical for the species-making systematists of their time: thus we find Montagu remarking of the forms which they ranked under the designation of *Nautilus* (now *Cristellaria*) *calcar*, "If these can be admitted as the same species, we may bid adieu to specific definition;" whilst out of the same series Denys de Montfort constructed no fewer than nine genera. It has been most unfortunate for the advance of this inquiry, that M. d'Orbigny should have prosecuted it under the influence of those ideas in regard to the differentiation of specific types, which he brought to the study of Foraminifera from that of the testaceous Mollusks to which he originally regarded them as allied; and that the influence of his comprehensive labours and high reputation should have given to his views, alike on the detailed arrangement and on the general classification of this group, a currency to which their entire inconsistency with its natural affinities entirely negatives their claim.—It was in studying one of the simplest types of this series, that Professor W. C. Williamson was led (1847) to perceive "the extraordinary capacity for variation which *Lagenæ* exhibit in different states and ages; extreme forms which appear to be very distinct from one another being connected together by specimens of an intermediate aspect to an extent only to be believed by those who examine a large series of specimens side by side*." And he adduced strong evidence, not only that most if not all of its reputed species are only varieties, but that the difference which separates the genus *Lagena* from *Entosolenia*,—viz. that the neck of the flask-shaped body is prolonged inwards in the latter, instead of outwards as in the former,—may be merely varietal. A like conclusion, strengthened by the results of his and my researches in regard to other types, Professor Williamson has extended to Foraminifera generally, in his beautiful Monograph of the Recent Foraminifera of Great Britain (1857). "It may now be regarded," he says, "as an established truth, that most of the external characters on which both earlier and later writers relied for distinguishing their species, possess but little value. The direction of growth in these shells, and the sculpturing of their exteriors, are alike influenced by age and local circumstances; hence a dissimilarity between the different stages in the development of the same individual, such as finds few parallels amongst the Mollusca with which Conchologists have so long identified them." Again, he remarks, "Nothing is easier than to throw the Foraminifera obtained by dredging over some limited area into defined groups, each of which has apparently a specific value. But as we extend our researches to more distant localities, new and intermediate forms perplex our minds as to what are the same

* Annals of Natural History, Jan. 1848, p. 10.

and what different species. Long before our dredging-net has swept round the British coasts, we find that what was already difficult trenches on the impossible; and when we test our results by applying them to collections made in remote parts of the globe, we become convinced that the limited amount of our information makes that impossibility absolute. *The more extensive our experience, the weaker become our convictions respecting the limits of variation in any species*.*"

254. The relations of the forms belonging to the family *Miliolitidæ* have recently been investigated by Mr. W. K. PARKER† on the same method of extensive and minute comparison; and his results are not only in perfect harmony with those obtained by Professor WILLIAMSON and myself, but even go beyond them in generality. Thus in each of the genera *Cornuspira*, *Hauerina*, and *Vertebralina*, Mr. PARKER reduces all the reputed species to one, while he shows that even their generic differences are really but of small account. And he not only in like manner reduces all the reputed species of the genus *Miliola* to the level of varieties, but brings down to the same rank the reputed genera *Spiroloculina*, *Biloculina*, *Triloculina*, and *Quinqueloculina*; the differences between which, arising from asymmetrical growth, and from variations in the form and number of the chambers, cannot be regarded as even of specific value, the Milioline plan of construction being preserved throughout. "If," he remarks, "the forms kept themselves as distinct as those represented in the diagrams, a naturalist might be excused for regarding them as distinct types; but between any two of these there may readily be found innumerable gradations, in large and small specimens, in the smooth and ornamented, in the shelly or the sanded, in attenuated and in distended individuals, and in specimens with symmetrical or non-symmetrical, or with two- or three-sided shells." I may add that I am fully prepared to endorse these conclusions; since they are entirely borne out by my own experience as to such forms of the Milioline type as have fallen under my notice.

255. In the large group of *Nodosarinæ* which has been carefully studied by Messrs. T. RUPERT JONES and W. K. PARKER, those gentlemen have felt themselves justified on the like grounds in reducing a multitude of reputed genera and species to a single type. Between the nautiloid *Cristellariæ* and the straight moniliform or rod-like *Nodosariæ*, which agree in essential characters of structure and mode of growth, they find such a continuous series of connecting links, that no line of demarcation can be anywhere drawn,—the straight, the curved, and the spiral forms passing gradationally one towards another. And the extreme forms being thus brought together, the various intermediate grades which have been distinguished by systematists under the generic names of *Glandulina*, *Lingulina*, *Dentalina*, *Rimulina*, *Vaginulina*, *Planularia*, *Marginulina*, *Dimorphina*, *Flabellina*, and *Frondicularia*, necessarily fall into the same category‡.

* Introd. pp. ix, x. † Transactions of the Microscopical Society, 1858 (New Series, vol. vi.), p. 53.

‡ Annals of Natural History, Nov. 1859, p. 477; and Quarterly Journal of the Geological Society, Aug. 1860, p. 302, and Nov. 1860, p. 454.

256. The same general doctrine having thus been shown to hold good in regard to all the chief natural subdivisions of the Foraminiferous group, it is not my purpose at present to prolong the inquiry in this direction. The systematic study of this tribe needs to be prosecuted far more extensively than my own time and opportunities have admitted, to enable even an outline-scheme to be framed, which should represent an approximation to the true relations of its principal families. But I think I have made it clear that such a scheme will be most likely to approach the truth, when the basis of it is laid in a thorough knowledge of the nature and extent of those variations which every chief modification of this type shows itself so peculiarly disposed to exhibit, and when, in building it up, the idea of *natural affinity* is accepted as expressing not only degree of mutual conformity, but *actual relationship arising from community of descent* more or less remote. For the occurrence of endless gradational departures from any types which we may assume as fixed, and of links of connexion between such as present the best-marked differentiations, seem to me to point unmistakeably to this as the only means of escape from that difficulty of indefinite multiplication which attends the doctrine of distinct specific creations when applied to a group in which scarcely any two individuals are alike. The case, in fact, is very analogous to that of the relationship between the various members of the family of Mankind; for whilst the historical evidence of actual change in them is so incomplete as well as so limited in its range, as to be quite inadequate of itself to establish their community of descent, yet when that evidence is considered in its relations to analogous facts drawn from the far greater variations of domesticated animals, and to the manifold gradations by which the extreme types are connected, physiologists of the highest eminence have felt themselves justified in accepting that community as probable. Now the modifications which any single type of Foraminifera must have undergone, to give origin to the whole series of diversified forms presented by that group, are not greater in comparison with those of which we have direct evidence, than are those which the advocate for the Specific Unity of the Human Races has no hesitation in assuming as the probable account of their present divergence.

257. This view of the case derives great force from the fact, that there is strong reason to regard a large proportion of the existing Foraminifera as the direct lineal descendants of those of very ancient geological periods;—a doctrine first advanced by Professor EHRENBERG in regard to a considerable number of Cretaceous forms; since fully confirmed and extended as regards the Tertiary fauna by the admirable researches of Messrs. RUPERT JONES and PARKER on the Rhizopodal Fauna of the Mediterranean, as well as by my own comparison of the recent and fossil types of *Orbitolites*, *Orbiculina*, *Alveolina*, *Operculina*, and *Calcarina*; and shown to be applicable also to the Secondary fauna, as far back as the upper part of the Triassic system, by the remarkable results of the investigations of the same gentlemen in regard to a well-preserved sample of it. Following out, by laborious and extended comparison, the method of inquiry I have so much insisted on, they have found ample evidence that the fact of a wide range of varia-

tion in this group is not confined to the present epoch, but that it is true also of the Foraminiferous fauna of all the geological periods to which their researches have extended. "Our own experience of the wide limits within which any specific group of the Foraminifera multiply their varietal forms, related by some peculiar conditions of growth and ornamentation, has led us to concur fully with those who regard nearly every species of Foraminifera as capable of adapting itself, with endless modifications of form and structure, to very different habitats—in brackish and in salt water,—in the several zones of shallow and abyssal seas,—and under every climate, from the Poles to the Equator. In arranging our synoptical tables of the Mediterranean Rhizopoda, recent and fossil, and in comparing their numerous specific and varietal forms one with another, we have not confined ourselves to our collections from this region, but have necessarily made comparisons of forms from almost every part of the globe, from the Arctic and the Tropic Seas, from the temperate zones of both hemispheres, and from shallow as well as deep-sea beds. Geologically, also, we have reviewed the Foraminifera in their manifold aspects, as presented by the ancient Faunas of the Tertiary, Cretaceous, Oolitic, Liassic, Triassic, Permian, and Carboniferous times; finding, to our astonishment, that scarcely any of the species of the Foraminifera met with in the Secondary rocks have become extinct; all, indeed, that we have yet seen have their counterparts in the recent Mediterranean deposits. This is still more clearly found to be the case with regard to the Chalk of Maestricht and the Tertiaries*."

258. The same excellent observers, in summing up their description of the Foraminifera of the blue clay met with in the alabaster pits at Chellaston near Derby, belonging to the Upper Triassic series, thus express themselves:—"Having thus pointed out that, judging from these specimens obtained at Chellaston, the minute *Nodosarinæ* and other Foraminifera of the Triassic period have continued to exist through the intermediate ages to the present day without losing any of their essentially specific features, we will observe that the *Nodosariæ* are present in rocks of still greater age than the Trias,—namely, the Permian and Carboniferous, and probably even the Lower Silurian. *Nodosariæ* and *Dentalinæ* abound in some of the Permian limestones of Durham and the Wetterau in company with *Textulariæ*. *Nodosaria* occurs also in the Carboniferous Limestone of Ireland, according to M'Coy; and the green sand of the Lower Silurian series near St. Petersburg has granted to Ehrenberg casts of chambers something like those of *Dentalina*, together with unmistakeable casts of Textularian and Rotalian shells. We may remark, too, that the *Fusulina* of the Russian, North American, and Arctic Mountain limestone carries back the pedigree of the *Nonionina* group to the palæozoic periods, and that it is accompanied with other Foraminifera of known types, among which *Nummulina* is not absent. This last-named type has rare representatives in the Lias and Oolite; it acquired great potency in the Tertiary seas, and is not extinct now.—Altogether we have here some remarkable instances of the persistency of life-types among the lower animals. Though the specific relations of the Palæozoic Forami-

* Quarterly Journal of the Geological Society, August 1860, p. 294.

nifera require further elucidation, we feel certain that the six genera represented in the Upper Triassic clay of Chellaston by about thirty varieties, stand really in the place of ancestral representatives of certain existing Foraminifera, that they put on their several subspecific features in accordance with the conditions of their place of growth, just as their posterity now do, and that although we have in this instance met with only the minute forms of a 700-fathoms mud-bottom, yet elsewhere the contemporaneous fuller development of these specific types may be found by careful search in other and shallower-water deposits of the Trias period*."

259. It can scarcely, I think, be questioned that such a continuity of the leading types of Foraminifera maintained through so long a series of geological periods, and the recurrence of similar varietal departures from those types, are results of the facility with which creatures of such low and indefinite organization adapt themselves to a great variety of external conditions; so that, on the one hand, they pass unharmed through changes in those conditions which are fatal to beings of higher structure and more specialized constitution; whilst, on the other, they undergo such modifications under the influence of those changes, as may produce a very wide departure from the original type. Thus we have found strong reason for regarding temperature as exerting a most important influence in favouring not merely increase of size but specialization of development: all the most complicated and specialized forms at present known being denizens either of tropical or of sub-tropical seas; and many of these being represented in the seas of colder regions by comparatively insignificant examples, which there seems adequate reason for regarding as of the same specific types with the tropical forms, even though deficient in some of their apparently most important features. The depth of the sea-bottom seems also to affect the prevalence of particular types, and to modify the forms under which these present themselves; so that Messrs. Rupert Jones and Parker feel themselves able to pronounce approximatively as to the depth of water at which a deposit of fossil Foraminifera may have been formed, by a comparison of its specific and varietal types with those characterizing various depths at the present time. And it is specially worthy of note, that in the greatest depths of the ocean from which Foraminifera have been brought by deep-sea soundings, these belong almost exclusively to one type, *Globigerina*.

260. In applying the results of the foregoing inquiry to the Animal Kingdom generally, it may be at once conceded that no other group affords anything like the same evidence, on the one hand of the derivation of a multitude of distinguishable forms from a few primitive types, and on the other of the continuity of those types through a vast succession of geological epochs. But a nearly parallel case, as regards the first of these points, is presented by certain of the humbler groups of the Vegetable Kingdom; in which it is becoming more and more apparent, from the careful study of their life-history, not only that their range of variation is extremely wide, but that a large number of reputed genera and species have been erected on no better foundation

* Quarterly Journal of the Geological Society, November 1860, p. 458.

than that afforded by the transitory phases of types hitherto known only in their states of more advanced development*. It would be very unreasonable to put aside these cases as so far exceptional that no inferences founded upon them can have any application to the higher forms of Animal and Vegetable life. For it is only in the *degree* of their range of variation, that *Foraminifera* and *Protophyta* differ from *Vertebrata* and *Phanerogamia*; and the main principle which must be taken as the basis of the systematic arrangement of the former groups,—that of ascertaining the range of variation by an extensive comparison of individual forms,—is one which finds its application in every department of Natural History, and is now recognized and acted on by all the most eminent Botanists and Zoologists. It will be sufficient for me here to refer to the views recently advanced by Dr. J. D. HOOKER in his "Introduction to the Flora of Australia;" the results of his extensive experience in the comparison of the Floras of different portions of the globe having led him to conclusions regarding the probable origin of the diversities they present, with which my own deductions from the study of the Foraminifera are in complete accordance. And I am authorized by Mr. THOMAS DAVIDSON, whose extensive knowledge of the *Brachiopoda* enables him to speak as the highest authority upon all that relates to that most interesting group (which, like the Foraminifera, is traceable through the entire series of fossiliferous rocks), to state that in proportion to the increase of his knowledge of its modifications of type, does he find reason to regard many of them as having had so wide a range of variation, as fully to justify him in making a large reduction in the number of specific types hitherto accounted distinct; whilst in the same proportion he finds himself able to trace with considerable probability the same specific types through a succession of geological periods,—certain Oolitic and Cretaceous *Terebratulidæ*, for example, being the probable ancestors of existing forms; and even the *Lingula* of the Wenlock Silurians not being distinguishable by any characters which he can recognize as constituting a valid specific difference from the *Lingula anatina* of our present seas.

261. The following are the general propositions which it appears to me justifiable to base on the researches of which I have now given a *résumé*:—

I. The range of variation is so great among *Foraminifera*, as to include not merely the differential characters which systematists proceeding upon the ordinary methods have accounted *specific*, but also those upon which the greater part of the *genera* of this group have been founded, and even in some instances those of its *orders*.

II. The ordinary notion of *species* as assemblages of individuals marked out from each other by definite characters that have been genetically transmitted from original prototypes similarly distinguished, is quite inapplicable to this group; since even if the limits

* It is among the lower *Fungi* that the researches of TULASNE and others have shown the greatest variability to prevail; whilst the recent inquiries of Dr. J. BRAXTON HICKS have brought to light a most unexpected relationship between the supposed *Unicellular Algæ* and the *Gonidia* of *Lichens*. See his Memoirs in the Quarterly Journal of Microscopical Science, October 1860 and January 1861.

of such assemblages were extended so as to include what would elsewhere be accounted genera, they would still be found so intimately connected by gradational links, that definite lines of demarcation could not be drawn between them.

III. The only natural classification of the vast aggregate of diversified forms which this group contains, will be one which ranges them according to their direction and degree of divergence from a small number of principal family types; and any subordinate groupings of genera and species which may be adopted for the convenience of description and nomenclature, must be regarded merely as assemblages of forms characterized by the nature and degree of the modifications of the original type, which they may have respectively acquired in the course of genetic descent from a common ancestry.

IV. Even in regard to these family types, it may fairly be questioned whether analogical evidence does not rather favour the idea of their derivation from a common original, than that of their primitive distinctness.

V. The evidence in regard to the genetic continuity of the *Foraminifera* of successive geological periods, and of those of the later of these periods and the existing inhabitants of our seas, is as complete as the nature of the case admits.

VI. There is no evidence of any fundamental modification or advance in the Foraminiferous type from the Palæozoic period to the present time. The most marked transition appears to have taken place between the Cretaceous period, whose Foraminiferous fauna seems to have been chiefly composed of the smaller and simpler types, and the commencement of the Tertiary series, of which one of the earliest members was the Nummulitic Limestone, which forms a stratum of enormous thickness that ranges over wide areas in Europe, Asia, and America, and is chiefly composed of the largest and most specialized forms of the entire group. But these were not unrepresented in previous epochs; and their extraordinary development may have been simply due to the prevalence of conditions that specially favoured it. The Foraminiferous fauna of our own seas probably presents a greater range of variety than existed at any preceding period; but there is no indication of any tendency to elevation towards a higher type.

VII. The general principles thus educed from the study of the Foraminifera, should be followed in the investigation of the systematic affinities of each of those great types of Animal and Vegetable form, which is marked out by its physiological distinctness from the rest. In every one of these there is ample evidence of variability; and the limits of that variability have to be determined by a far more extended comparison than has been usually thought necessary, before the real relations of their different forms can be even approximatively determined.

VIII. As it is the aim of the Physical Philosopher to determine "what are the fewest and simplest assumptions, which being granted, the whole existing order of nature would result*," so the aim of the philosophic Naturalist should be to determine how small a number of primitive types may be reasonably supposed to have given origin by the ordinary course of "descent with modification" to the vast multitude of diversified forms

* MILL'S Logic, 3rd edition, vol. i. p. 327.

that have peopled the globe in the long succession of geological ages, and constitute its present Fauna and Flora.

[*Note.*—I cannot bring to a conclusion this series of Researches, without on the one hand gratefully acknowledging the liberality of the Council of the Royal Society, whose assistance (from the Grant placed at their disposal by Government) has greatly aided my investigations, by enabling me to have every important feature of form and structure accurately delineated under a sufficient magnifying power; and, on the other, expressing my great obligation to the skill, intelligence, and patient assiduity of my draughtsman, Mr. George West, by whose careful study of these organisms under my direction I have been enabled to attain a much more thorough knowledge of their nature than my own more limited time would have permitted me to acquire.]

Explanation of the Plates.

PLATE XVII.

With the exception of figs. 9 and 10, all the figures in this Plate refer to *Polystomella craticulata.*

Fig. 1. *Polystomella craticulata,* as viewed at *a* in its peripheral aspect, showing the septal ridges and the intermediate rows of 'fossettes,' and, on the left of the figure, the septal plane with the row of minute apertures along its inner margin; at *b* is shown one of the lateral surfaces of the same shell, over the central part of which the septal ridges are concealed by an exogenous deposit that is irregularly dotted with punctations resembling the 'fossettes.' Magnified 10 diameters.

Fig. 2. Vertical section passing nearly through the umbilical axis, and laying open the outer seven whorls, but passing by those of earlier formation, so as to bring into view at *e* the external surface of the eighth (counting inwards). This figure shows the gradual increase of the distance between the two lateral surfaces of the successive whorls, of which those last formed do not invest the earlier, so that the shell would be biconcave but for the large amount of solid exogenous deposit, which not only occupies the umbilical region, but extends even to the last whorl; it also shows the continuity of this deposit with that outer portion of the spiral lamina of each whorl which presents in section a plicated aspect; and along the inner margin of each of the septa displayed in the section, is seen a row of minute septal pores, forming the only direct communication between the chambers. The relations of the various parts of the canal-system are well displayed in this section: *a*, *a*, the openings of the successive turns of one of the spiral canals transversely divided; *b*, *b*, the meridional canals, one

of which passes between each chamber and the one that succeeds, opening at each end into the spiral canal; *c*, the straight canals which come off from the spiral canals into the solid umbilical deposit, and pass through it direct to the external surface; *d*, the converging canals, which pass inwards from the meridional canals in the intraseptal spaces; *e*, the surface of the innermost whorl displayed by this section, on which are seen the meridional canals giving off their diverging branches in pairs. Magnified 30 diameters.

Fig. 3. Central portion of a section passing through the median plane of a specimen remarkable for the very *small* size of the primordial segment. Magnified 60 diameters.

Fig. 4. Central portion of a section (viewed under the same magnifying power as the preceding) passing through the median plane of a specimen remarkable for the very *large* size of its primordial segment. Magnified 60 diameters.

Fig. 5. Central portion of a section parallel to the median plane, but a little above it, showing one of the spiral canals and the central system of lacunæ in which it originates. Magnified 60 diameters.

Fig. 6. Portion of a section taken in a direction parallel to the median plane but much nearer the surface, showing parts of the canal-system of the outer whorls: *a*, *a*, portion of one of the spiral canals; *b*, *b*, portion of the succeeding whorl of the same canal; *c*, *c*, meridional canals of the inner whorl; c', c', origins of the meridional canals of the outer whorl, with their first pairs of diverging branches; *d*, *d*, origins of the canals that penetrate the solid umbilical deposit, which soon change their course and become vertical; *e*, transverse sections of vertical canals. Magnified 80 diameters.

Fig. 7. Marginal portion of a section taken in the same direction as fig. 2, and passing, in the whorls a, a^1, a^2, through the cavity of the chambers, whilst in the alternate whorls b, b^1, b^2, it passes along the septal plane; at *c*, *c*, are seen the meridional canals transversely divided near the points at which they give off their diverging branches. Magnified 60 diameters.

Fig. 8. Portion of a section taken through the median plane, showing the alternate position of the chambers *b*, *b*, *b*, with reference to those *a*, *a*, *a*, of the interior whorl, and those *c*, *c*, *c*, of the exterior whorl; at d, d^1, and d^2, are seen the external orifices of the diverging branches of the canal-system; and at e, e' are seen the junctions at their orifices of the adjacent branches of two distinct pairs, such junctions being generally connected with the septal apertures occupied by stolons of sarcode. Magnified 60 diameters.

Fig. 9. Section of *Polystomella crispa*, taken through the umbilical axis: a, a', solid umbilical deposit; $b\,b$, $b'\,b'$, transverse sections of the two spiral canals; c, c^1, c^2, portions of the meridional canals; *d*, cæcal diverticula for the 'retral processes'; *e*, septal apertures. Magnified 50 diameters.

Fig. 10. Portion of a section of *Polystomella crispa* taken through the median plane,

and showing at *a, a, a,* the cæcal diverticula for the retral processes, and at *b, b,* the meridional canals transversely divided. Magnified 60 diameters.

Fig. 11. Portion of a section of *Polystomella craticulata* taken in the same direction as that represented in fig. 2, and showing the origin of the canals which pass vertically through the solid umbilical nucleus, and whose external orifices are seen at *c*, from the successive turns *b, b, b* of the spiral canal, which are seen transversely divided at *a*. Magnified 80 diameters.

Fig. 12. Portion of a section which has passed close to the lateral surface of one of the outer whorls, in such a manner as to show a portion of its spiral canal, with four of the meridional canals passing down the intraseptal spaces, and giving off successive pairs of diverging branches; between the septa from which they proceed is seen the finely-tubular substance forming the proper wall of the chambers. Magnified 80 diameters.

Fig. 13. Portion of a section passing through the median plane of the outer whorl, showing some minute shells of the foraminiferous type in the cavity of three of the chambers. Magnified 100 diameters.

PLATE XVIII.

The figures in this Plate refer to *Polystomella craticulata*, and to *Tinoporus baculatus*.

Fig. 1. Ideal representation of a specimen of *Polystomella craticulata*, laid open to show its internal structure: a, a^1, a^2, chambers of three whorls which are laid open by the plane of section; b, b^1, b^2, b^3, septa of four whorls alternating with the preceding, which are traversed by the plane of section; c, c^1, c^2, septal apertures; dd', dd', dd', meridional canals; e, e, e, and e', e', e', orifices of the successive turns of the two spiral canals (of which the upper one is displayed by the supposed removal of the umbilical nucleus) transversely divided; *f, f,* converging canals, passing inwards from the meridional canals; gg', gg', gg', surface of the last-formed portions of the spiral lamina, showing a row of furrows passing across between the septal bands, into which the diverging canals open in immediate contiguity to the septal bands; hh', hh', older portion of the spiral lamina, showing the replacement of each series of furrows by two rows of punctations; ii', ii', surface of the interior whorl, showing the obliteration of the septal bands and the rows of dimpled depressions into which the diverging canals open.

Figs. 2, 3, 4, 5. External aspect of specimens of *Tinoporus baculatus* from Borneo and Australia, showing the irregularity of their radiating prolongations. Magnified 20 diameters.

Fig. 6. A specimen of the same more enlarged, showing the areolated character of the surface of the disk, with elevated tubercles disposed between the areolæ, and

the furrowed surface of the terminal portion of the radiating prolongations. Magnified 40 diameters.

Figs. 7, 8, 9, 10. Specimens of the Philippine variety of *Tinoporus baculatus*, showing the variability of their form. Magnified 12 diameters.

Fig. 11. Fragment of *Polystomella craticulata*, showing the furrowed internal surface of three of the chambers, *a*, a^1, a^2, the furrows being deepest at the posterior margin for the reception of the retral processes; whilst at bb^1, bb^2, are shown two of the meridional canals laid open by the fracture of the septa which contained them, with the series of orifices of the diverging canals which pass off beneath the ridges that intervene between those furrows. Magnified 40 diameters.

Fig. 12. Internal cast of the chambers and canals of *Polystomella craticulata*, representing the form of the body and the distribution of the canal-system: *a*, retral processes, proceeding from the posterior margin of one of the segments; *b b'*, smooth anterior margin of the same segment; *c*, *c'*, stolons connecting successive segments, and uniting themselves with the diverging canals*; *d*, d^1, d^2, three turns of one of the spiral canals; *e*, e^1, e^2, three of the meridional canals; *f*, f^1, f^2, their diverging branches. Magnified 40 diameters.

Fig. 13. Fragment of a similar cast, showing a portion of three segments on their internal aspect, with their connecting stolons, *c*, two of the meridional canals, *ee'*, and their diverging branches *f*, *f*. Magnified 40 diameters.

PLATE XIX.

All the figures in this Plate refer to *Calcarina Spengleri*.

Fig. 1. Disk of Philippine variety, as seen on the side nearest the apex of the spire, with the origins of the spines; showing the minute punctations and scattered tubercles of the surface of the disk, and the furrowed surface of the spines; the spire not anywhere apparent. Magnified 20 diameters.

Fig. 2. Disk of Maltese variety, as seen on the same side, showing the entire length of the spines, which in this specimen are unusually numerous and tend to subdivide at their extremities; no markings of any kind are seen on its surface, nor is the spire in the least apparent. Magnified 20 diameters.

Fig. 3. Disk of Philippine variety, as seen on the same side, with the origins of the spines, showing the punctations of the disk and the furrowing of the spines, with an unusual abundance of semitransparent tubercles; the spire not anywhere apparent. Magnified 20 diameters.

* This portion of the figure is ideal; and by a misapprehension on the part of the artist, the segments of the inner whorl have been made to range with those of the outer whorl, instead of alternating with them which seems to be the typical arrangement, though often departed from.

Fig. 4. Disk of Philippine variety, as seen on its growing side, with the origins of the spines; the last half whorl is here apparent, the newest chambers having only their own proper walls, whilst those which preceded them are more and more overgrown by the 'intermediate skeleton,' in which they gradually become imbedded; the surface of the disk shows the usual punctation, with an average development of tubercles; that of the spines is furrowed. Magnified 25 diameters.

Figs. 5, 6, 7. Young *Calcarinæ*, showing their ordinary aspect. Magnified 20 diameters.

Figs. 8, 9. Hispid varieties of Philippine *Calcarinæ* (see also Plate XX. fig. 6). Magnified 30 diameters.

Figs. 10, 11. Portions of figs. 8 and 9 more highly magnified: in fig. 10 it is seen that the spines are tubular, being formed around the pseudopodia as they issue from the passages in the shell. Magnified 60 diameters.

Fig. 12. Ideal representation of *Calcarina* laid open; showing the unsymmetrical or 'turbinoid' disposition of the spire (its apex being placed downwards for more convenient display); the Rotaline aspect of the last-formed chambers, and the row of pores along the inner margin of the septal plane, which constitutes the only aperture of the last chamber; the manner in which each turn of the spire is overgrown by the exogenous deposit forming the 'intermediate' or 'supplemental skeleton' which fills up the whole interior of the cone, and conceals all but the last-formed portion of the spire; the penetration of this 'supplemental skeleton' by canals, which originate on the outside of the proper walls of the chambers, and pass in a somewhat radiating direction towards both surfaces of the disk, separated at intervals by non-canaliferous cones, whose bases appear externally as elevated tubercles; the connexion of the spines with the 'supplemental skeleton,' from which the older spines receive new investments at every turn of the spire; and the extension of the canal-system into the spines, on the furrowed depressions of whose surface it opens at numerous points.

PLATE XX.

All the figures in this Plate refer to *Calcarina Spengleri.*

Fig. 1. Section of the disk taken through the axis of the spire: a, a^1, a^2, a^3, a^4, successive whorls transversely divided; b, the proper wall of the last-formed chamber, not yet consolidated by exogenous deposit; c, row of pores at the inner edge of the septal plane, constituting the only communications between the chambers; d, d, canals passing through the supplemental skeleton to the surface of the disk; e, e, non-canaliferous portions of the supplemental skeleton. Magnified 50 diameters.

Fig. 2. Portion of a section taken through the inner whorls, transversely to the axis of the spire; showing the commencement of the canal-system in central lacunæ from which a spiral extension may be traced that gives off branches proceeding into one of the spines; and showing the free inosculation of these branches in the substance of the spine with others derived from the nearest chambers, so that the entire substance of the spine is minutely intersected by them. Magnified 50 diameters.

Fig. 3. More enlarged portion of a section passing through the 'supplemental skeleton' in the immediate neighbourhood of the surface of one of the chambers; showing the freedom with which it is traversed by the canals. Magnified 100 diameters.

Fig. 4. Section of the disk taken through the later whorls, transversely to the axis of the spire: *a*, central lacunæ of the canal-system excavated in the portion of the intermediate skeleton overlying the primordial chamber; a^1, a^2, a^3, a^4, successive whorls; *b*, b^1, b^2, the proper walls of the chambers of the last whorl, receiving successive increments in thickness from exogenous deposit; *c*, *c*, septal apertures; *d*, d^1, d^2, d^3, the 'supplemental skeleton' of the last whorl, showing its progressive increments in thickness; *e*, e^1, e^2, e^3, e^4, e^5, the spines in order of age, as determined by the portion of the supplemental skeleton from which they are outgrowths. Magnified 50 diameters.

Fig. 5. Section of a portion of the 'supplemental skeleton' taken near the surface of the disk, in a direction transverse to the axis of the spire, showing the distribution of the orifices of the canals around the non-canaliferous spaces *e*, *e*, *e*. Magnified 100 diameters.

Fig. 6. A young specimen of the hispid variety (see Plate XIX. figs. 8, 9). Magnified 30 diameters.

Fig. 7. Section of a young *Calcarina*, taken transversely to the axis of the spire, showing at *a* and elsewhere a diverging arrangement of the branches of the canal-system analogous to that of *Polystomella*. Magnified 60 diameters.

Fig. 8. Section of a young specimen of the hispid variety taken in the same direction. Magnified 60 diameters.

PLATE XXI.

All the figures in this Plate refer to *Tinoporus*.

Fig. 1. External view of a conical specimen of *T. lævis*, as seen laterally at *a*, and on its basal aspect at *b*. Magnified 25 diameters.

Fig. 2. Section of *T. lævis* in a direction parallel to the base, showing an irregularly concentric arrangement of chambers, the floors of which are perforated with numerous foramina. Magnified 50 diameters.

Fig. 3. Section of *T. lævis* in the direction of the axis of the cone; showing at *a* the spherical primordial chamber, and at *b* and *c* the chambers first connected with it on either side; showing also the manner in which the successively-formed chambers are piled upon one another vertically, with the large lateral orifices of communication between the adjacent chambers. Magnified 50 diameters.

Fig. 4. Ideal representation of a portion of *T. lævis*, to show the relations of the chambers, which are divided from one another horizontally by cribriform floors, and laterally by walls in which there are large apertures *a*, *a*, *a*, leading into the adjacent chambers.

Fig. 5. Section of the basal portion of one of the radiating outgrowths of *T. baculatus* (Plate XVIII. fig. 6), showing the manner in which the chambers are clustered around the solid axis, and in which the axis (a portion of the supplemental skeleton) is traversed by canals radiating from its centre to its circumference. Magnified 50 diameters.

Fig. 6. Section of the Philippine variety of *T. baculatus* (Plate XVIII. fig. 7), taken through its median plane, showing the mode in which the intermediate skeleton is interposed among the chambers, so as to constitute the axis of the radiating outgrowths. Magnified 25 diameters.

Fig. 7. Section of *T. baculatus*, taken in the direction perpendicular to its median plane; showing an arrangement of its chambers essentially corresponding to that exhibited on a larger scale in fig. 3; the piles of chambers partially separated, however, from each other by the interposition of the solid columns of the 'intermediate skeleton.' Magnified 40 diameters.

Fig. 8. Portion of a section of *T. baculatus*, taken (as fig. 2) parallel to the median plane, but near the surface; showing the greater thickness of the walls of the chambers, and the interposition of the solid columns transversely divided at *a*. Magnified 50 diameters.

Fig. 9. Portion of a section of the Philippine variety of *T. baculatus*, more enlarged, to show the canal-system, *b*, *b*, traversing the thick walls of the chambers. Magnified 100 diameters.

Fig. 10. Portion of the section represented in fig. 6, more enlarged, showing, at *a*, *a*, a portion of the solid axis of one of the radiating outgrowths, traversed by the canals, *b*, *b*, and invested by two layers of chambers, the walls of which are rendered hispid by spinous excrescences. Magnified 100 diameters.

Fig. 11. Section of the central portion of a specimen of *T. baculatus*, passing through the median plane; showing at *a* its regularly spiral commencement (not distinguishable from that of a *Calcarina*), the origin of the spines from the intermediate skeleton of the spire, and the early exchange of the spiral type for an irregular clustering of the chambers, as shown at *b*. Magnified 80 diameters.

PLATE XXII.

All the figures in this Plate refer to *Carpenteria*.

Fig. 1. Portion of a group of *Carpenteriæ* growing upon the surface of *Porites* (coral); a part of the external wall of the uppermost specimen having been thinned-away by acid, so as to show the areolation of its inner surface. Magnified 5 diameters.

Figs. 2, 3, 4. Interior of the first-formed chambers of three specimens, showing their Globigerine characters and arrangement; at *a*, *a*, are shown the remains of the yellowish-brown spongeous substance by which those chambers were occupied. Magnified 50 diameters.

Fig. 5. Isolated specimen of *Carpenteria* on the shell of *Pecten*, in which the chambers of the last whorl diverge so widely at the base of the cone, as to be in great degree separated from each other. Magnified 5 diameters.

Fig. 6. Portion of the external wall, showing the areolated aspect it derives from the gentle convexities into which it rises between the reticulations that project on its internal surface; at *a* is shown the natural external surface on which the foramina are regularly disposed; at *b* that surface has been removed by grinding, so as to bring into view the inner layer of the wall, on which the foramina are seen to be deficient along the projecting ribs, but to be more closely set together in the portions surrounded by these (see fig. 15). Magnified 30 diameters.

Fig. 7. Section of a very flat specimen, parallel to the base of its cone, but not far from its apex; showing at *a* the vertical funnel transversely divided, at *b* its communication with the last chamber, at *c* its communication with the penultimate chamber, at d, d^1, and d^2 three of the complete septa dividing the principal chambers, and at g and g^1 portions of the canal-system. In some of the chambers are seen spicules resembling those of Sponges. Magnified 20 diameters.

Fig. 8. Portion of a specimen partially laid open by grinding away the apical portion of the cone: *a*, *b*, *c*, *d*, as in the last figure; e, e^1, e^2, secondary septa partially dividing the principal chambers, but not extending to their central portion; f, f^1, f^2, incomplete septa projecting inwards from the external wall, but not crossing the cavity of the chamber to reach the opposite wall. Magnified 20 diameters.

Fig. 9. Portion of the upper part of the specimen represented at the top of fig. 1, much more enlarged, showing the reticulated arrangement of those incomplete septa; the spaces included in the reticulations are in some instances covered-in by a thin layer of the shelly wall which has not been removed; but in most other cases this wall has been eaten away by the acid in the central

portion of the reticulation, so as to display the dark spiculiferous substance within. Magnified 30 diameters.

Fig. 10. Portion of the group of *Carpenteriæ* growing on the surface of *Porites*, of the natural size.

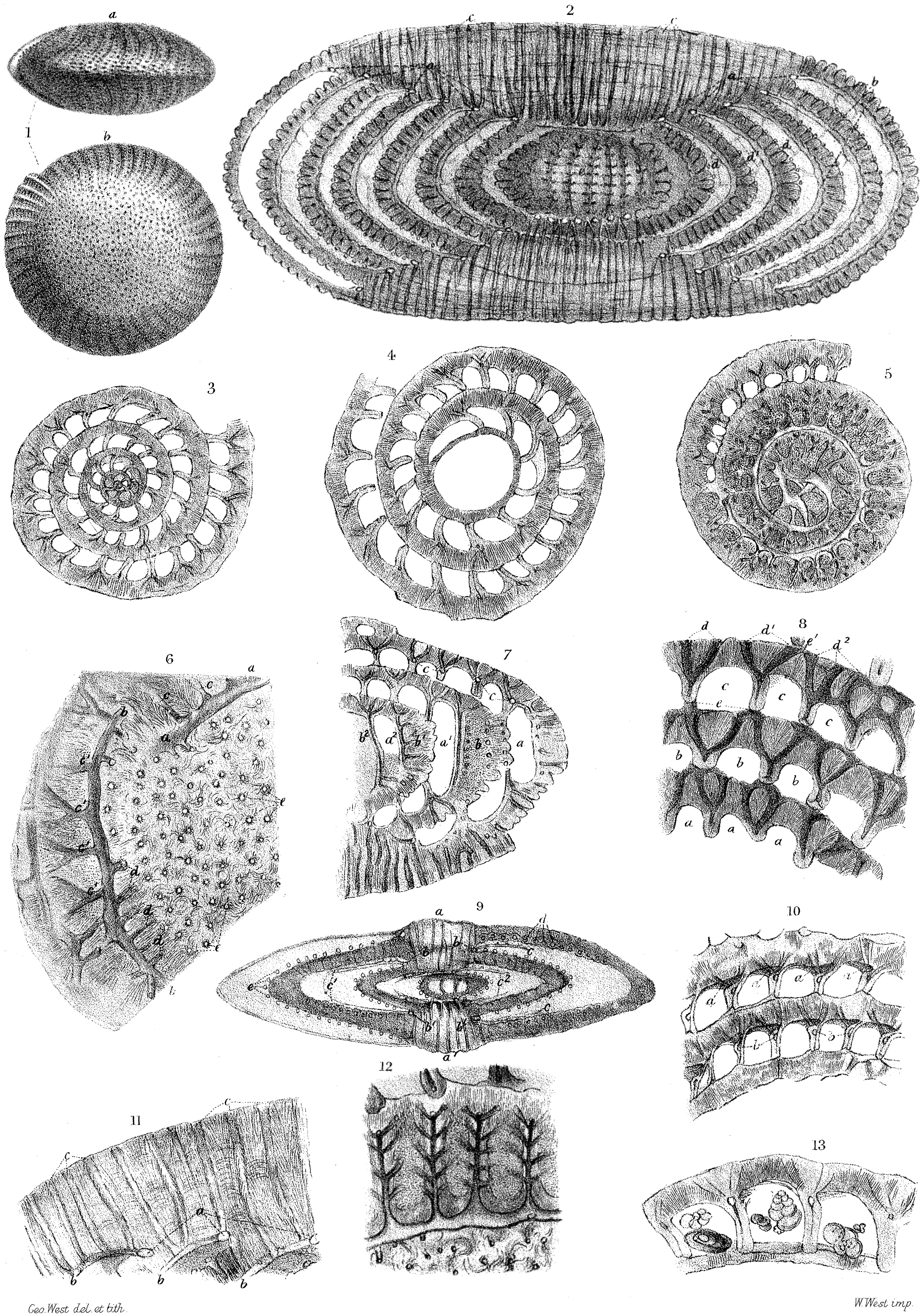
Fig. 11. An unusually large specimen, of the actual size.

Fig. 12. Portion of a section taken in the same direction as fig. 7, but represented on a larger scale, showing the annulations of the foramina that are seen obliquely traversing the shell, and the two layers, of which not only the principal septa *a*, *a*, but also the incomplete septum *b*, are formed, with the canals included between them. Magnified 75 diameters.

Figs. 13, 14. External apertures at the apex of the cone of two specimens, showing their peculiarly Milioline character. Magnified 20 diameters.

Fig. 15. Section traversing the external wall of one of the chambers perpendicularly to its surface, showing at *a*, *a*, the annulated foramina by which it is traversed, and at *b*, *b*, *b*, sections of the imperfect septa, on which the foramina do not open. Magnified 75 diameters.

Fig. 16. Siliceous spicules (resembling those of *Halichondria*) from the spongeous tissue occupying the chambers of *Carpenteria*. Magnified 75 diameters.



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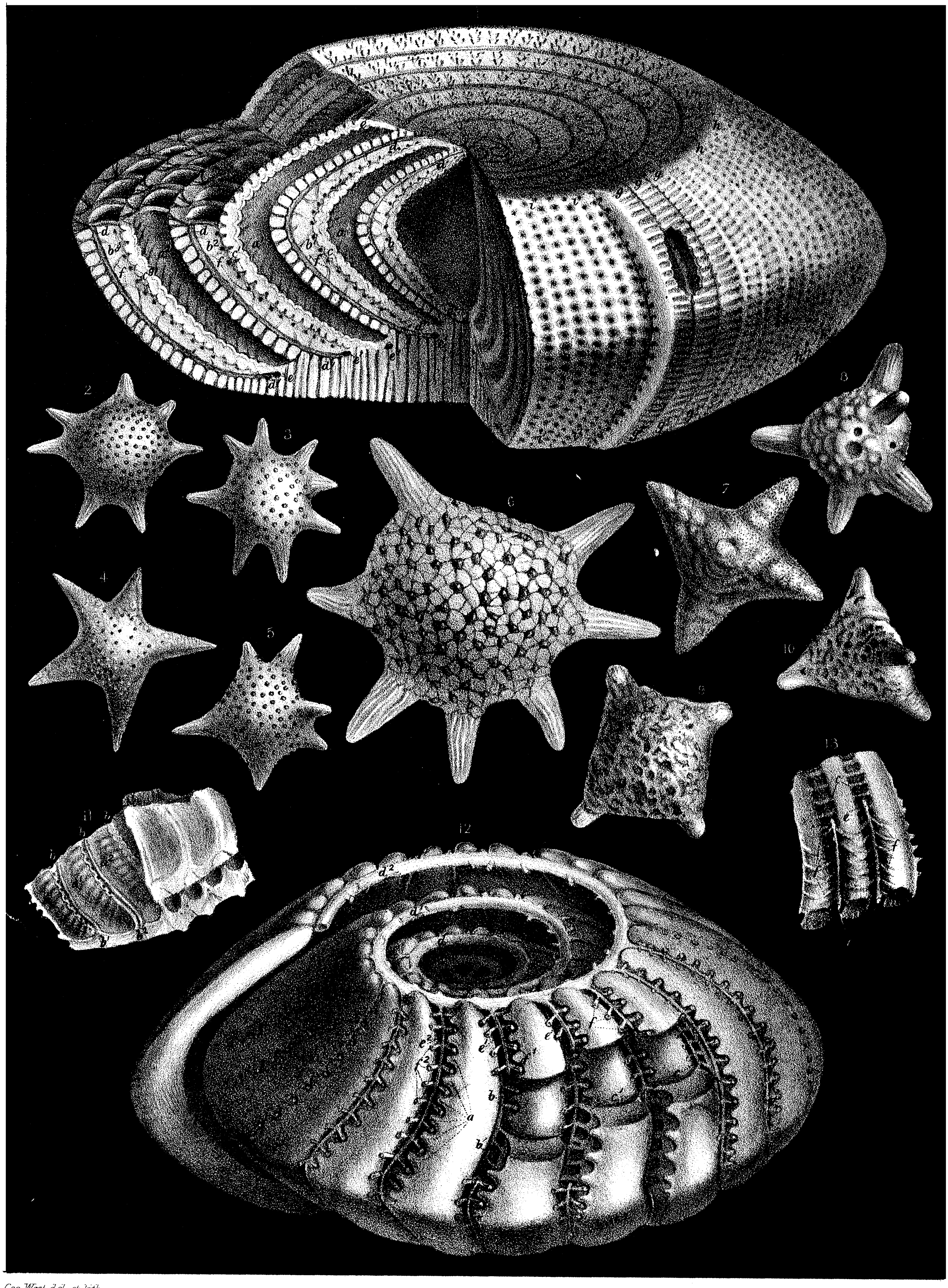
W. West imp.



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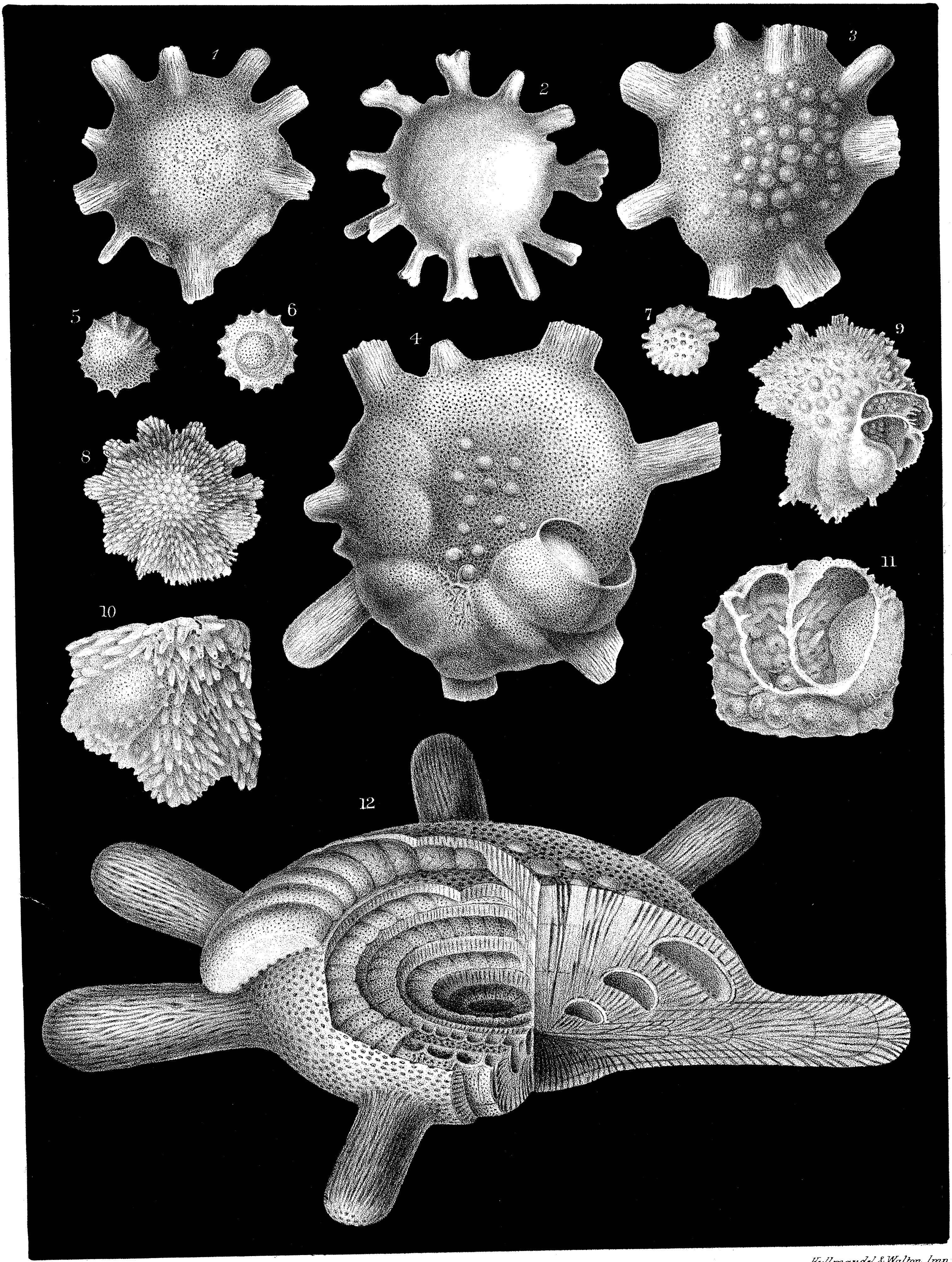

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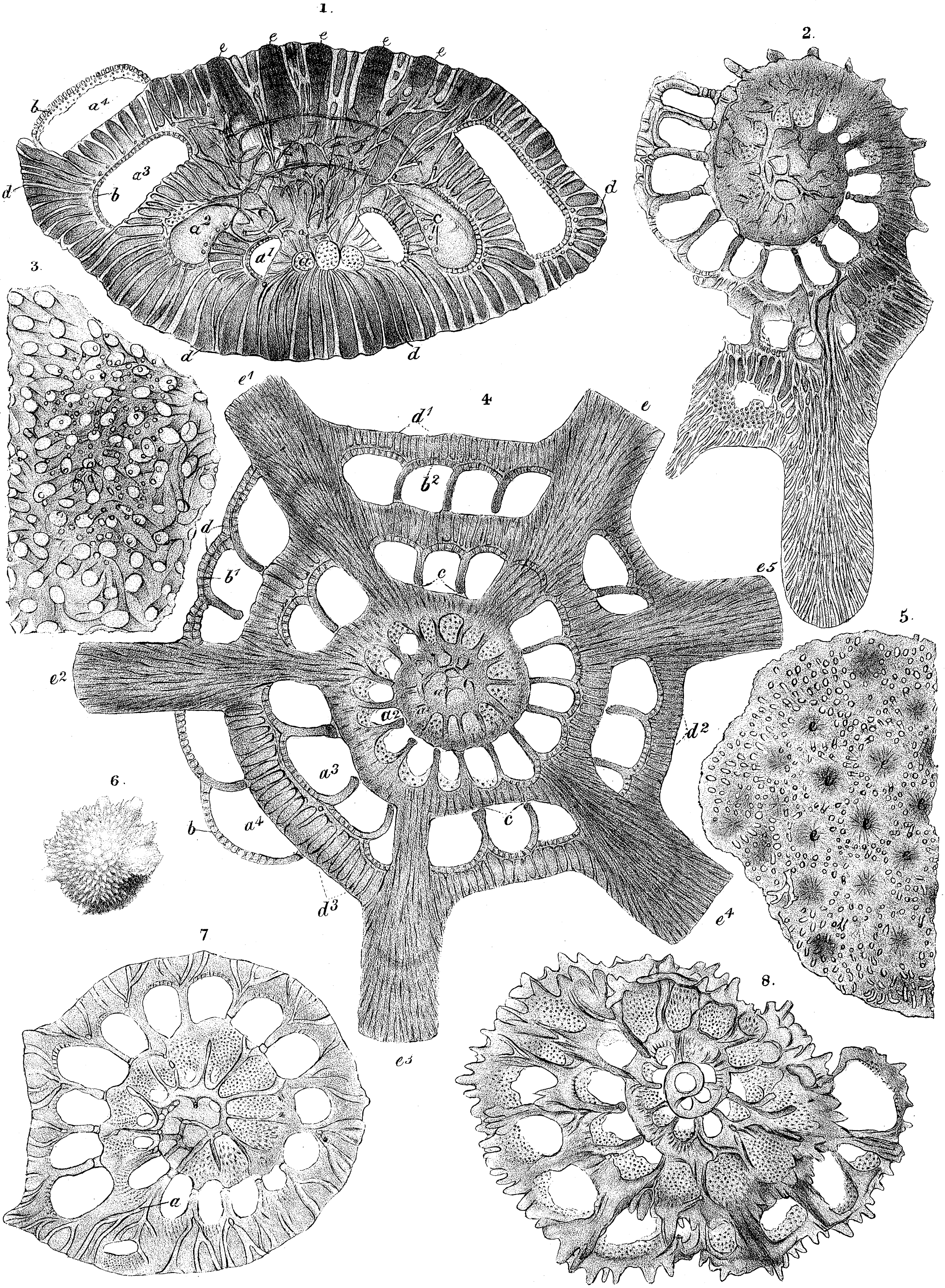
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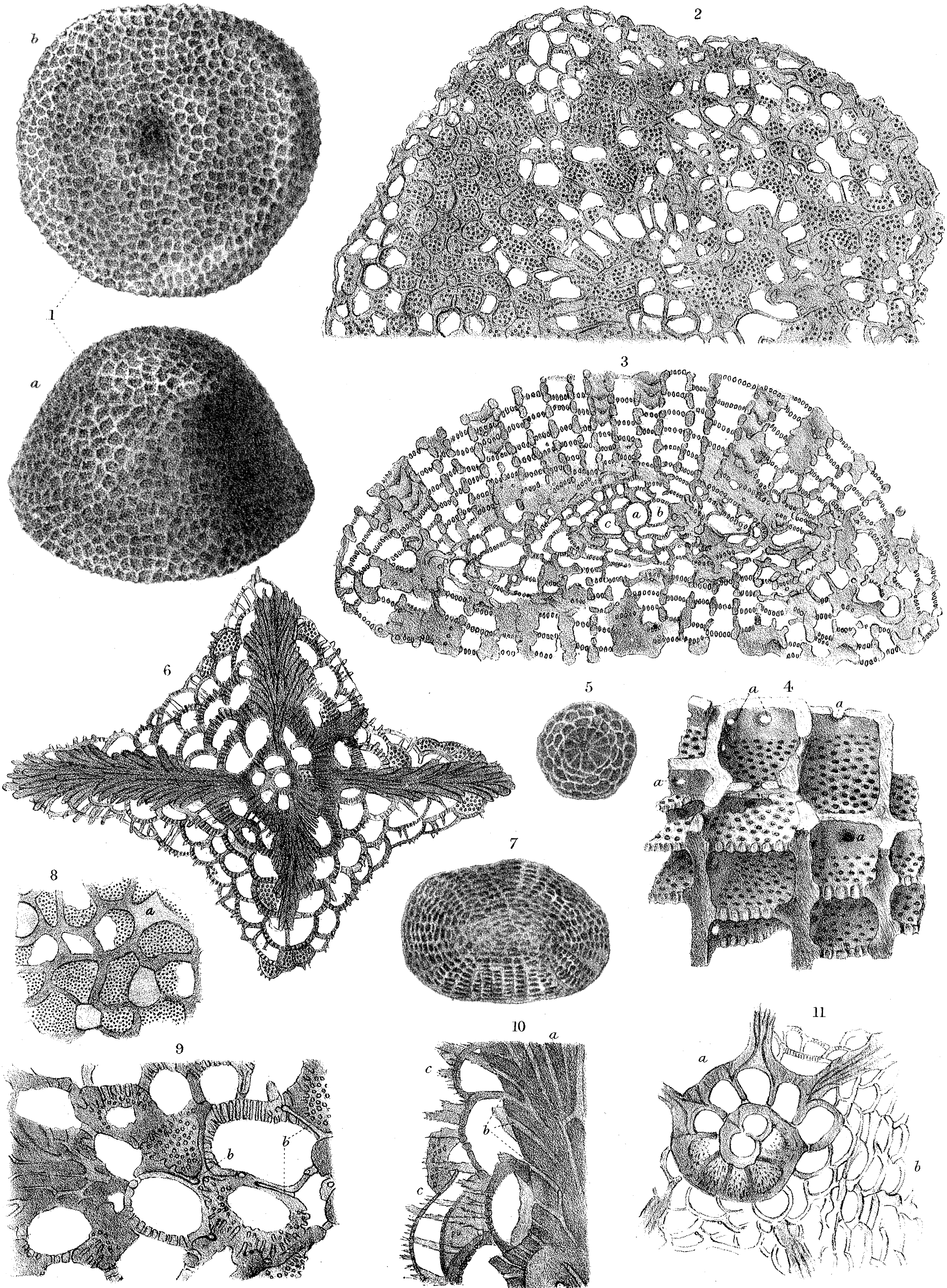
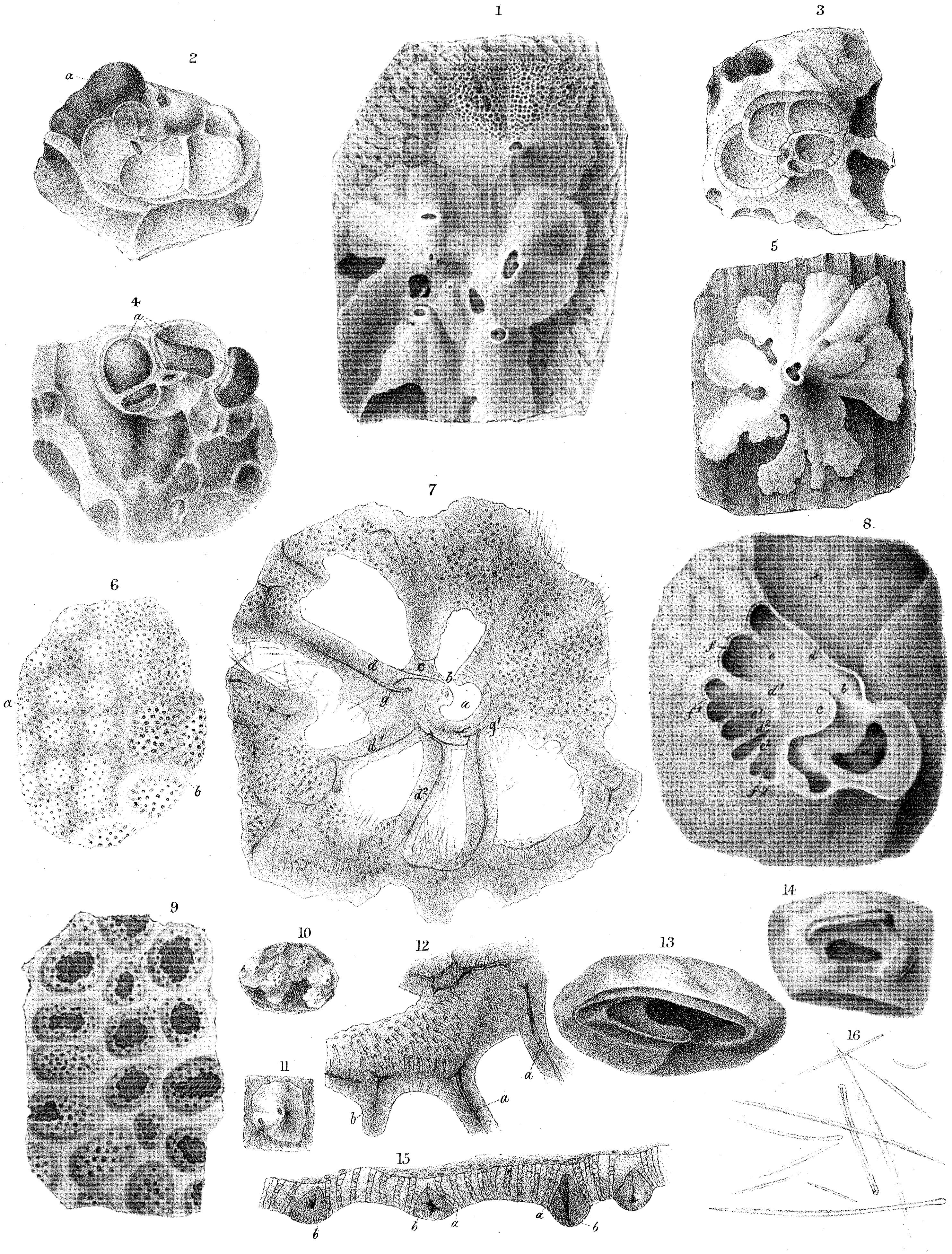


Geo. West del et lith.

W. West imp.



Geo. West, del. Lens Aldous, lith

Hullmandel & Walton Imp.