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PHILOSOPHICAL TRANSACTIONS.

I. *Researches on the Foraminifera.*

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Received June 17,—Read June 17, 1858.

PART III.

ON THE GENERA PENEROPLIS, OPERCULINA, AND AMPHISTEGINA.

119. IN my preceding memoirs, I have shown that two very dissimilar types of structure present themselves among Foraminifera; one characterized by its simplicity, the other by its complexity. In the former, of which *Orbitolites*, *Orbiculina*, and *Alveolina* are typical examples, the calcareous skeleton does not present any definite indications of organization, but seems to have been formed by the simple calcification of a portion of the homogeneous sarcode-body of the animal; that sarcode-body is but very imperfectly divided into segments, the communications between the cavities occupied by these segments being very free and irregular; the form of the segments themselves, and the mode of their connexion, are alike inconstant; and even the plan of growth, on which the character of the organism as a whole depends, though preserving a general uniformity, is by no means invariably maintained. In the latter, to which *Cycloclypeus* and *Heterostegina* belong, we find the calcareous skeleton presenting a very definite and elaborate organization; the several segments of the body are so completely separated from each other, that they remain connected only by delicate threads of sarcode; each segment thus isolated has its own proper calcareous envelope, which seems to be moulded (as it were) upon it, and this envelope or shell is perforated with minute parallel tubuli, closely resembling those of dentine except in the absence of bifurcation or ramification; the partition-walls between adjacent segments are consequently double, and are strengthened by an intermediate calcareous deposit, which is traversed by a system of inosculating passages that seems properly to belong to it. The form of the segments, their mode of communication, and consequently the general plan of growth, have a very considerable degree of constancy; and altogether the tendency is strongly manifested in

this type, to the greater individualization of the parts of the composite body, which in the preceding must be looked upon rather as constituting one aggregate whole.

120. I purpose in the present memoir to carry on this contrast, by presenting a detailed comparison of the structure of two generic forms, which, whilst they so far agree in general plan of growth as not only to have been ranked by M. D'ORBIGNY side by side in his order *Hélicostègues*, but to have been placed by other systematists in close apposition, differ in the most marked manner as to all the particulars just enumerated. Both these types are of peculiar interest:—the first, *Peneroplis*, on account of the very wide range of variation it presents, which has led to the establishment of three *genera*, apparently distinguishable by well-marked differences in conformation, upon what I feel satisfied will prove to be but individual modifications of one and the same *specific type*;—the second, *Operculina*, as being the nearest existing representative of *Nummulites*, and consequently as affording not merely the key to the elucidation of the structure, but also the basis for the determination of the value of the reputed species, of that genus, by the study of the range of variation which it presents; this range being, though more restricted than in the preceding case, still quite sufficient to justify a large multiplication of species, in the estimation of those who do not practise that extended method of comparative inquiry, on the importance of which I have dwelt in a former Memoir (§ 74). With the latter of these genera, as also with *Nummulites*, I shall prove that the genus *Amphistegina* is closely allied; although M. D'ORBIGNY, misled by the marked want of symmetry and by the alternation in the disposition of the chambers, which are exhibited by certain forms of that type, has placed it in a different order, *Entomostègues*. For I shall have to show that a gradational variety in this respect, ending in complete symmetry, may coincide with such a uniformity in general structure, that even a very decided departure from symmetry must be regarded as a character of little value in classification, compared with agreement in the organization of the shell and in those peculiarities in the conformation of the animal which are indicated by it; and further, that a most marked difference in degree of organization exists between two species of *Amphistegina*, which so closely resemble each other externally that the young of one may easily be mistaken for the adult of the other.

Genus PENEROPLIS.

121. *History*.—The genus *Peneroplis* was first instituted by MONTFORT* to distinguish a peculiar type of minute polythalamous shells, which had been previously described and figured by FICHEL and MOLL†, and had been ranged by them with numerous others under the comprehensive designation *Nautilus*; and MONTFORT correctly indicates its distinctive character, as “bouche de toute la longueur de la base, et percée sérialement par une file des pores,” though he seems to have very erroneously interpreted the signi-

* BUFFON de SONNINI, 1802–1805; Mollusques, tome iv. p. 1. pl. 42; and Conchyliologie Systématique, 1808, p. 258.

† Testacea Microscopica, Vindob. 1798–1803, p. 91. tab. 16. figs. a, i.

fication of those pores. For he goes on to state, “ Cette coquille est encore pellucide, et permet de lire au travers de son têt la série et la disposition des nombreuses cellules de chaque concameration ; ces cellules deviennent plus grandes à mesure que la coquille prend plus d’accroissement. Il est probable que leur nombre repond à celui des animaux qui les habitent, et qui les constituent simultanément pour former un nouveau rang.” This subdivision of the principal chambers into cells, each occupied by a separate animal, exists only in the imagination of MONTFORT, who seems to have been misled by the peculiar markings of the surface of the shell, which, as will be presently seen, are merely superficial. LAMARCK, not adopting MONTFORT’S genus, referred the *Nautilus planatus* of FICHEL and MOLL to the genus *Cristellaria*, with which it has no relationship whatever ; and having copied their figures into the ‘ Encyclopédie Méthodique *,’ he designated one set of forms as *C. planata*, and another as *C. dilatata*, subsequently reuniting them, however, under a new specific name, *C. squammula*†. The genus *Peneroplis* has been recognized by BLAINVILLE‡ and by EHRENBERG§ ; and D’ORBIGNY has applied this name, in his various writings on Foraminifera, to the form described by FICHEL and MOLL, whilst he has created a new generic term, *Dendritina*, for a series of closely allied forms, in which there is a single large dendritic aperture instead of a linear series of separate apertures. The distinctive characters of these two genera, as last given by him||, are as follows:—“ *Peneroplis* ; coquille nautiloïde comprimée, pourvue de nombreuses ouvertures sur une seule ligne à la dernière loge seulement. Cavité simple:—*Dendritina* ; ce sont des *Peneroplis* dont les ouvertures anastomosées forment une dendrite.” In addition to these, I shall cite his definition of another genus, established by LAMARCK in 1801, which, as I shall presently show, consists, like *Dendritina*, of mere varieties of *Peneroplis*:—“ *Spirolina* ; coquille nautiloïde dans le jeune âge, projetée en crosse dans l’âge adulte.”

122. The genus *Peneroplis* is very widely diffused through warmer latitudes ; indeed few collections of Foraminifera from sands or dredgings taken from the Mediterranean, the Ægean Archipelago, the Red Sea, the East or West Indies, the Philippine seas, or the shores of Australia or the Polynesian Islands, will fail to present numerous examples of it. A few specimens have been found on British coasts ; but it is surmised by Professor WILLIAMSON that these have been brought by the Gulf-stream from the West Indian Seas. “ Amongst the multitude of West Indian seeds and other light objects thus thrown upon our north-western shores, it was to be expected that some of the tropical Foraminifera would be entangled ; and such may have been the case with the species under consideration ¶.” The finest examples I have met with were contained in

* Tab. 467, figs. 1, *a*, *b*, *c*, 2 ; *a*, *b*, *c*.

† Animaux sans Vertèbres, tom. vii. p. 607.

‡ Malacologie, p. 372.

§ “ Tabellarische Charakteristik der Bryozoën-Classe und sämtlicher Familien und Gattungen der Polythalamien,” in Berlin Transactions, 1838.

|| Cours Élémentaire de Paléontologie, 1849, tom. ii. p. 198.

¶ On the Recent Foraminifera of Great Britain, published by the Ray Society, 1858, p. 46.

Mr. CUMING's Philippine Collection; whilst the most numerous were kindly furnished me by Mr. J. GWYN JEFFERYS from his dredgings in the Gulf of Genoa. We shall hereafter find that, as in the case of *Orbitolites*, particular varieties of conformation prevail, though by no means exclusively, in particular localities.

123. *External Characters*.—The ordinary form of the shell of *Peneroplis* (of which an ideal representation is given in Plate I. fig. 2) is an extremely flat spire of about two turns and a half, opening out rapidly in its last half turn (Plate II. fig. 1). In the young shell, each whorl is merely adherent to the preceding, so that the first-formed portion is not concealed by the subsequent growth; but it very commonly happens that the last whorl spreads itself out to such a degree as partially to invest the preceding (Plate II. figs. 1, 3), the extension towards the centre, however, seldom reaching so far as to conceal the original umbilicus. Although this lateral extension is sometimes confined to the inner margin of the spire, as is seen in fig. 1, yet it often occurs along the outer margin also, as is seen in fig. 3; being usually limited, however, to the last four or five chambers. But sometimes, instead of opening out and partially investing the previous whorls, the spire is prolonged in a straight line, and several of its successive chambers present little or no progressive increase in size (Plate II. fig. 5); though even in this variety the last four or five chambers are often seen to spread themselves out rather suddenly, so as to extend along the inner margin of the straight portion. Between these different extremes of conformation, every intermediate gradation presents itself.

124. The surface of the shell is very strongly marked by depressed bands, which indicate the place of the septa between the chambers; and between these septal bands the walls of the chambers rise in flattened arches. In a direction transverse to the septal bands, we almost uniformly observe a strongly-marked striation; the striae running parallel at tolerably regular intervals, which average about $\frac{1}{1400}$ th of an inch, from one septal band to another. This striation, which imparts a very characteristic physiognomy to these minute shells, seems due to a sort of plication or ridge-and-furrow arrangement of the shelly wall (Plate II. fig. 20), which may not improbably have the effect of imparting to it increased strength. The plication generally disappears at the junction of the walls of the chambers with the septa; and consequently we do not usually see it at the mouth when the shell is viewed endways. Sometimes, however, it is continued on to the septum itself; and its character is then extremely well displayed, as in Plate II. fig. 15, which, however, represents not the typical form, but one of the varieties to be hereafter noticed. On the prominences of the plicæ, there are frequently to be seen rows of extremely minute puncta (fig. 20); these, however, are not the apertures of passages through the shell, as might not unnaturally be supposed; but are, like the punctations of *Orbiculina* (¶ 88), mere depressions of its surface,—as I have ascertained by the careful examination of very thin sections. It is remarkable that the plication of the shell is sometimes wanting, though the punctations may still present themselves in rows, as shown in fig. 23; whilst in other cases, not only are the plicæ deficient, but the punctations are distributed uniformly over the entire surface, as shown in fig. 24. That

these variations are not indicative of any specific difference, is at once proved by the fact that the shells which exhibit them in one part, present the ordinary character of surface in another. In Plate II. fig. 22 is shown a case in which similar punctations present themselves on the septum closing the mouth of the shell of a *Dendritina*, which, as will presently appear, is only a modified *Peneroplis*.

125. The septum which closes the mouth of the shell is perforated by numerous isolated pores, arranged in a single linear series (Plate I. fig. 2, Plate II. fig. 1); the number of these pores depends upon the length of the septal plane (a very convenient term which I adopt from Professor WILLIAMSON), and thus it usually increases with the age of the individual, each chamber opening externally by a larger number of pores than did that which preceded it. The typical form of these pores seems to be circular, though they are apt to present various departures from that shape; they usually lie in a sort of furrow, formed by the projection of the lateral borders of the mouth somewhat beyond the septum; and, as in *Orbitolites* and *Orbiculina*, each one is surrounded by a prominent annulus of shell.

126. The texture of the shell very closely resembles that of *Orbitolites* and *Orbiculina*, but is somewhat more porcellanous. As in those genera, the shell presents an opaque white hue, when it is viewed by light reflected from its surface; whilst thin sections examined by transmitted light are of a brownish yellow or dark amber colour. Its substance is apparently quite homogeneous, no other trace of structure presenting itself than the plications and punctations already referred to; and its texture is not nearly so firm as that of those Foraminiferous shells which possess a minutely-tubular organization.

127. On examining a thin section of a typical *Peneroplis*, taken through the median plane between the lateral surfaces (Fig. I.), the central chamber is seen to have the

Fig. I.

Section of *Peneroplis*, parallel to its surface.

globose form which has been shown to characterize the primordial segment of the Foraminifera already described; from this first chamber a *single passage* leads to the second,

which communicates in like manner by a single passage with the third, as does the third with the fourth; the fourth chamber, however, communicates by *two passages* with the fifth, as does the fifth with the sixth, and the sixth with the seventh. In the septum between the seventh and eighth, with which the second whorl may be considered as commencing, there are *three* apertures; and this number continues for the four consecutive partitions which divide the chambers forming the next half-convolution. Then, however, commences a very remarkable increase; for whilst in each of the next two partitions there are *four* passages, the numbers in the four succeeding partitions which divide the chambers completing the second turn are respectively 6, 9, 11, and 14; whilst in the last eight partitions which divide the chambers of the outer half-whorl, the numbers of the apertures are respectively 14, 20, 26, 28, 30, 35, 44, and 48. The average distance of the apertures from each other remains nearly the same throughout; so that their number pretty closely corresponds with, and may be taken to represent, the length of the septal plane which they traverse in each case; and it is not a little remarkable, that whilst this number should only increase from 1 to 4 in the first convolution and a half, it should so rapidly augment from 4 to 48 in the last half-convolution.

128. As I have not been fortunate enough to obtain any other than dried specimens of this organism, I have not had the opportunity of examining the structure and arrangement of its soft parts. Such an opportunity, however, has presented itself to Professor EHRENBURG, who collected living specimens in his expedition to the Red Sea; and by treating these with dilute acid, he has freed the animal body from its enclosing shell, precisely as I was able to do in the case of *Orbitolites*. The figure* which he has given of the animal corresponds in every important particular with what an examination of the shell would lead me to expect; for it represents a series of segments of a generally-homogeneous substance, corresponding in form, dimensions, and connexions with the successive chambers of Fig. I. The only departure that I can discover from what I should myself have anticipated, lies in this—that the successive segments are connected along the inner margin of the convolutions by a band much broader and thicker than the threads which pass between other parts of the segments; so that this band would seem to establish a principal connexion, to which the other threads might be considered as secondary. Now after a very careful examination both of the septal planes of numerous specimens, and of sections taken in the direction of Fig. I, I feel myself justified in the positive assertion that no such principal aperture exists at the inner margin of each septum, as would be required to give passage to such a band as is figured by Professor EHRENBURG. Consequently I can only account for this feature in his delineation of the animal (the idea of a difference in the conformation of the shell being negated by the precise correspondence between his figures of it and my own, as well as by my familiarity with the Red Sea type of *Peneroplis*), by supposing that, like some of his other figures, it rather represents his *idea* of the structure of the animal, than what he actually saw in

* Abhandl. der Königl. Akad. der Wissenschaft. zu Berlin, 1838. Physik, taf. 2, fig. 1.

its body, this principal band being apparently regarded by him as an intestinal canal, by which he supposed all the segments to be connected together.—Professor EHRENBURG'S figure represents a marking-out of spherules in the midst of the otherwise homogeneous substance of the body, closely corresponding to those which I have described in the animal of *Orbitolites* (§ 43); and it also shows the skeletons of various Diatomaceæ imbedded in the substance of the four outer segments, as I have myself found them in *Orbitolites* (§ 34). Consequently I can have no hesitation in the belief that the general structure and mode of life of these two forms are analogous; and that there does not exist in *Peneroplis*, any more than in *Orbitolites*, that hypothetical organization which Professor EHRENBURG has attributed to both.

129. *Monstrosity*.—The only example of monstrosity which I have met with in this type, is obviously analogous to the "monstrosities by excess" which I have described as not unfrequent in *Orbitolites*; consisting (at least apparently) in the formation of a secondary body by outgrowth or gemmation from the first. This secondary body does not seem, however, to have its origin in the primordial segment, to which similar outgrowths may always be traced in *Orbitolites* (§ 62).

130. *Affinities*.—As regards its general organization and plan of growth, it seems clear that *Peneroplis* bears a very near approximation to that form of *Orbiculina* in which the later increase takes place like the earlier upon the spiral type (§ 87), and in which there is but a single plane of chambers with a single row of marginal pores (§ 90): the only essential difference, in fact, consisting in this, that each successive increment is formed in the case of *Peneroplis* by a continuous segment of sarcode, occupying an undivided chamber of the shell; whilst in the case of *Orbiculina* each segment is subdivided into sub-segments strung like the beads of a necklace on a continuous stolon of sarcode, the chamber being correspondingly subdivided by transverse partitions having a continuous passage through all. The very close alliance of the two forms is shown by the fact, that specimens are occasionally to be met with in collections of *Orbiculina*, which, while presenting the general physiognomy of that genus, exhibit the deficiency of transverse partitions which is the distinguishing character of *Peneroplis*; so as to render it uncertain whether such specimens should be considered as *Orbiculina* in which (as certainly happens occasionally in *Orbitolites*, § 61) the usual partitions are deficient, or whether they truly belong to *Peneroplis*, their resemblance to *Orbiculina* being superficial only, and their presence among specimens of that genus merely accidental. In either case it is obvious that the affinity between these two types is very close; and in fact young *Orbiculina* frequently present such a strong external resemblance to *Peneroplis*, that their true nature cannot be determined without such an examination of their internal structure as will serve to disclose the transverse partitioning of their chambers. It may be fairly inquired whether the peculiar striation of the surface of *Peneroplis*, which so strongly suggests the idea of internal partitioning as to have led MONTFORT to assert its existence, is not really a rudiment of that structure.

131. *Varieties*.—The relationship just indicated being borne in mind, it will scarcely

excite surprise to find that *Peneroplis*, like *Orbiculina*, presents very considerable diversities of conformation. The first and simplest departure from what has been described as its typical character, consists in a duplication of the series of pores in each septum (Plate II. fig. 7 *a*), the spire being at the same time less compressed, so that the septal plane is wider in proportion to its length. Now it is not a little remarkable that this is almost uniformly the case with specimens furnished by particular localities, whilst those obtained from others not very remote exhibit almost as uniformly the extremest elongation and narrowing of the septal plane with only a single row of apertures; and hence it might not unreasonably be maintained that this difference should be accounted of specific value. In reply to this, however, there is not only the analogy of *Orbitolites* and *Orbiculina*, in which an indefinite multiplication in the rows of marginal pores may take place during the growth of the individual, but also the fact that in *Peneroplis* the two forms cannot be distinguished at an early age, either by the shape of the shell or by the disposition of the pores, which are often arranged neither in a single nor in a double row, but on a sort of mixture of both plans, as shown in Plate II. figs. 9 and 10; whilst among the more advanced examples of each type, it is not at all uncommon to meet with individuals which present a combination of the characters of both, the septal plane having a single row of pores in one part of its length with a double row in another. Sometimes, moreover, in one of the less compressed forms of the shell, although there is but a single row of pores, it is obvious from the elongated shape of these that they indicate a tendency to duplication (fig. 8). Moreover we find in the variety with a complete double row the same disposition as in the ordinary *Peneroplis* to the substitution of the rectilineal for the spiral mode of growth, as we see in fig. 7. Hence I consider that it may be unhesitatingly asserted that the duplication of the row of pores, and the increased turgidity of the spire which it accompanies, are but features of individual variation, and cannot be admitted to rank as specific differences. And in this view I am glad to find myself borne out by Professor WILLIAMSON, who defines *Peneroplis**, not (like M. D'ORBIGNY) as having only a single row of apertures, but as having "septal orifices scattered over the long narrow septal plane;" whilst his figure of *Peneroplis planatus* shows these orifices arranged for the most part in a double row, one portion having them even more multiplied.

132. What is the relationship to the typical *Peneroplis*, however, of that group of forms to which D'ORBIGNY has given the generic designation *Dendritina*, is a question of more difficulty. These are characterized, as we have seen, by the possession of a single large aperture sending out dendritic ramifications in each septum (Plate I. fig. 1, Plate II. figs. 12, 13); but this is by no means the whole of their differentiation. For the spire, instead of being compressed, is very turgid; and its successive whorls not merely surround but also invest those which have preceded them; so that what may be appropriately termed *alar prolongations* (*al*, figs. 12 *a*, 12 *b*, Plate II.) of the chambers of even the last whorl often extend nearly to the umbilicus. The geographical distribution

* The Recent Foraminifera of Great Britain, p. 44.

of *Dendritina*, moreover, is peculiar; for, so far as I am aware, this type is restricted to the tropical ocean. I have not met with it in dredgings from any part of the Mediterranean or the Red Sea, where *Peneroplis* abounds; while the largest specimens I have seen are those contained in Mr. CUMING's Philippine explorations, some of these measuring .078 inch in diameter, and .030 in thickness or breadth. To such as content themselves with glancing at strongly-marked examples of this type, the propriety of its generic, or at any rate of its specific separation from *Peneroplis*, would seem indubitable. Nevertheless I think that I shall be able to show adequate grounds for the belief, that the two forms cannot be separated by any definite line of demarcation; and that they must therefore be ranked as belonging not merely to the same genus, but even to the same species.

133. In the first place I would refer to the fact that the peculiar plication and punctation of the surface of the shell, which are such marked features in the physiognomy of *Peneroplis*, are repeated in *Dendritina* (Plate II. figs. 21, 22) in a manner so precisely similar, as strongly to impress every one who has his attention directed to the aspects of these two forms respectively, with the idea of their very close relationship.

134. Secondly, the differences of general configuration between *Peneroplis* and *Dendritina* are differences of degree, and present themselves in very variable amount in different individuals. For, starting from those forms of *Peneroplis* in which the spire is least compressed, the transition is easy to those *Dendritinæ* whose spire is least turgid, and whose septal plane is not broader in proportion to its length than it often is in *Peneroplis*. From the most compressed forms of *Dendritina* to those which have the most turgid spires and the widest septal planes, the gradation is insensible, scarcely any two individuals according in their proportions; thus we find that whilst the septal plane is sagittate in some (Fig. II. A, c), it tends to become reniform in others (B, D), the

Fig. II.

Front views of four specimens of *Dendritina*.

margin of the spire, which is almost carinated in the first case, becoming obtuse and even crescentic in the second. Again, the extent of the investment of the earlier whorls

by the later, varies as much as the degree of turgidity; for whilst in some of the most compressed forms, as in *Peneroplis*, each whorl does little more than apply itself to the margin of the preceding (Fig. III. A, c), the more turgid the spire becomes, the more completely (generally speaking) does it embrace the preceding, the alar prolongations of the chambers thus coming to bear a large proportion to their principal cavity (Fig. III. B, D).

135. Thirdly, we observe in *Dendritina* precisely the same tendency to rectilinear extension in the later period of growth, as in *Peneroplis*; for although a distinct generic term *Spirolina* has been given to the form presenting this modification, I think it must be apparent to every one that the example delineated in Plate II. fig. 11, bears just the same relation to the typical *Dendritina*, that those shown in figs. 5, 7 bear to the typical *Peneroplis*. The transition from *Dendritina* to *Spirolina* is well seen in figs. 12, 13; in the first of which we see the last whorl apparently about to disengage itself from the earlier ones, whilst in the second that disengagement has been completed. I cannot conceive that any one could refuse to regard either of these specimens as a *Dendritina*; and yet it is obvious that their continued increase upon the plan which has already manifested itself in the formation of the later chambers, would convert them into *Spirolina*. Such continued increase has obviously taken place in the specimen represented in fig. 11, which, up to the time of the substitution of the rectilinear for the spiral mode of growth, has all the appearance of an ordinary *Dendritina*.

136. Still it may be said that, notwithstanding all these points of resemblance, the difference between *Peneroplis* and *Dendritina* is clearly marked out by the difference in the modes of communication between the chambers of the two types; and that such a difference is sufficiently important to constitute a valid generic character. I freely admit that this would be the case, if the difference were constantly to present itself between all the individuals of the same type, as it does between their characteristic examples (Plate I. figs. 1, 2); but the fact is far otherwise. We have seen that among those which would be unhesitatingly ranked under the designation *Peneroplis*, there is not only a tendency to multiplication of the rows of separate pores, but also an occasional fusion of two or more pores, so as to form a single large pore of irregular shape. On the other hand, among the unquestioned *Dendritina*, we observe not merely that the form of the single large dendritic aperture is extremely variable, but that it is frequently so simple as to suggest the idea of having been formed by the coalescence of a linear series of pores. The most characteristic forms of the dendritic aperture that I have met with, are shown in Plate II. figs. 12 a, 13 a; two examples of a remarkable departure from this have just been seen in Fig. II. B, D, where the proportions of the aperture are altogether reversed, its breadth being much greater than its length, and its central part being enlarged at the expense of its ramifications; while through such an aperture as that represented in Plate II. fig. 22, we are conducted back to the ordinary type, though its form is much simplified. On the other hand, in Fig. II. A, c, we have marked examples of a narrowing and elongation of the aperture, with such a reduction

of its dendritic ramifications, that it comes to present little more than a linear fissure. From a comparison of these cases, it will be seen that the form of the aperture bears a pretty constant relation to that of the septal plane; the broadest apertures presenting themselves in the individuals which have the most turgid spire, and the narrowest in those whose spire is most compressed; whilst the proportionate development of the two principal alar prolongations seems related to the degree of that alar extension of the chambers over the whorl they enclose, of which I have already spoken. But the most satisfactory proof of the wide extent of range of variation in the form of the aperture in *Dendritina*, is afforded by a comparative examination of the apertures connecting different chambers of the same individual. Thus in the interior of the very shell that presented the peculiarly characteristic example, Plate II. fig. 12 *a*, we find a form, *b*, closely corresponding to that shown in Fig. II. *c*; and in four septa of the inner part of another shell, we have the simple forms of aperture represented in Fig. III. A, B, C, D.

Fig. III.

Septal planes and apertures from different parts of the same specimen of *Dendritina*.

137. But further, not only do we thus meet with examples of each type which present more or less of approximation towards the other, but we also not unfrequently encounter individuals in which the characters of the two types are so blended that it is difficult, if not impossible, to say to which they should be referred. Thus in Plate II. fig. 8, we have a young specimen with a linear series of apertures, the marked elongation of which shows each to be formed by the fusion of two, whilst there is an additional pair precisely in the situation of the alar prolongations in fig. 12 *b*; and it is obvious that a longitudinal coalescence of these pores would produce an aperture exactly resembling that of fig. 12 *b*. Again, in another young specimen shown in Plate II. fig. 16, a partial fusion of the separate pores into a single dendritic aperture has actually taken place (fig. 16 *a*), whilst another broad aperture is seen just below this. In fig. 10 we see numerous pores, some small and rounded, others large and irregular, each of the latter being obviously formed by the coalescence of two or three of the separate pores; and it is evident that a closer approximation of the whole would produce a single large dendritic aperture. Other varieties of the same kind are presented in figs. 9 and 14. But a yet more remarkable example is shown in fig. 15; for here the coalescence has pro-

ceeded so far as to produce a number of separate branching apertures, and nothing is wanting but the removal of the line of shell which passes down the middle of the septum, to unite these into the most characteristic form of the single ramifying orifice. This individual, like the one represented in fig. 6, was already beginning to assume the *Spirolina* form, the rounded shape of the mouth showing that the spire has detached itself completely from the previously-formed convolutions: in figs. 4 and 11 *a* are shown the mouths of more advanced examples of the same type, which present such a combination of the large dendritic aperture of *Dendritina* with the isolated pores of *Peneroplis*, as to complete (in my opinion) the proof that no valid distinction can be drawn between these two types, either from the number, the isolation, the position, or the shape of the apertures in the septa. This conclusion will probably become less surprising than it may at first sight appear to such as are accustomed to the study of the more constant characters presented by the shells of Mollusca, when it is borne in mind that the apertures seem to have no other function than to give passage to threads of sarcodæ; and that it is the general character of the Rhizopod type, for such extensions of the substance of the body to be entirely destitute of constancy either as to position or number.

138. If the foregoing conclusion be admitted, it follows that not merely must the genera *Dendritina* and *Spirolina* be relinquished, but that both these forms must be regarded as mere varieties of *Peneroplis planatus*. From the circumstance that the *Dendritina*-type is found only in tropical seas, and that it attains a far larger size than the ordinary *Peneroplis*-type, whilst the latter seems to be almost starved out (as it were) in the Mediterranean,—presenting itself there under its humblest form, and scarcely extending itself at all into northern seas,—I am disposed to think that temperature has a considerable influence in producing these varieties. I should be far, however, from attributing the entire result to this agency alone, since we find *Peneroplis* presenting itself abundantly in tropical seas, along with *Dendritina*. But as it is in the Mediterranean forms that we meet with the extreme of flattening and with the most uniform singleness of the row of pores, whilst it is among the tropical forms that we find *Peneroplis* not merely attaining its greatest dimensions, but also presenting the closest approximation to *Dendritina* in the turgidity of its spire and in the arrangement of its septal apertures, it seems obvious that the development of this type of structure is favoured by a constantly high temperature; and further, that *Dendritina* may be regarded as the highest form, towards which *Peneroplis* tends in proportion as it is subjected to that influence.—As I have not had the opportunity of examining the fossil forms of this type, I am as yet unable to say how far the foregoing conclusions will be borne out by the phenomena which they present.

Genus OPERCULINA.

139. The collection of Mr. CUMING contains a large number of Nautiloid Foraminifera, differing considerably from one another not only in size and proportions, but also

in general aspect and particular features, yet having so many structural characters in common as to be obviously referrible to the same generic type. This type I shall designate, provisionally at least, as *Operculina*; since, although it does not correspond with the definition of this genus as given by its founder M. D'ORBIGNY, it is obviously related most closely to the fossil forms which have been described under that designation by M. D'ORBIGNY himself, as well as by MM. D'ARCHIAC and HAIME, and to the recent type described as *Operculina* by Mr. CARTER.

140. *History*.—The genus *Operculina* was created by M. D'ORBIGNY in 1825, for the reception of a group of Foraminifera bearing a strong general resemblance to *Nummulites*, but considered by him as differing from it in the extreme compression of its discoidal shell, in the smaller number of its whorls, in the non-investment of the earlier whorls by the later, so that the former remain apparent on both sides through the whole of life, and also in the form of the aperture, which is a transverse slit in *Nummulites*, but triangular in *Operculina*. The following is the definition of this genus given by him in his 'Foraminifères Fossiles de Vienne' (p. 117):—"Coquille libre, équilaterale, ovale ou discoidale, très comprimée, formée d'une spire non embrassante, régulière, également apparent de chaque côté, à tours contigus, et croisant très rapidement. Loges nombreuses, étroites, la dernière formant saillie de toute la largeur de la spire, à tous les âges percée d'une ouverture visible triangulaire, contre le retour de la spire." In his 'Cours Élémentaire de Paléontologie' (tom. ii. p. 197), he defines the genus by the following characters alone:—"Coquille comprimée à tours apparents, pourvue d'une ouverture triangulaire contre le retour de la spire." I think it necessary also to quote from the same work M. D'ORBIGNY'S definitions of three other genera nearly allied to *Operculina*; since, as will presently appear, the characters which he assigns to them are based on an entirely wrong idea of the distinctive features presented by their respective types.—*Nonionina*. "Coquille nautiloïde, pourvue d'une seule ouverture en fente transversale, non masquée, placée contre le retour de la spire."—*Nummulites*. "Coquille lenticulaire à tours embrassants, pourvue d'une ouverture en fente transversale, souvent masquée, contre le retour de la spire."—*Assilina*. "Ce sont des *Nummulites* dont les tours de la spire, ne rejoignant pas le centre, sont tous plus ou moins apparents." In the admirable Monograph of MM. D'ARCHIAC and HAIME*, the genus *Nummulites* is defined as follows:—"Coquille libre, symétrique, orbiculaire, plane, discoïde, lenticulaire ou subglobuleuse, composée d'une lame calcaire pliée et enroulée suivant un même plan, criblée de pores ou canaux de trois grandeurs différentes, à tours plus ou moins serrés, plus ou moins embrassants, quelquefois simplement juxtaposés. Dans le jeune âge, le dernier est saillant; plus tard, les tours se rapprochent de telle sorte qu'à l'état adulte le dernier paraît se souder tout à fait à l'avant dernier. Canal spiral divisé par des cloisons transverses, plus ou moins nombreuses, percées à leur base, contre le retour de la spire, d'une ouverture linéaire transverse. Ces derniers caractères semblent s'être atténués vers la fin de la vie de l'animal" (p. 70). The genus *Nonionina* is said by these

* Description des Animaux Fossiles du Groupe Nummulitique de l'Inde. Paris, 1853.

authors to differ from *Nummulites* in respect of its flatter form, the comparative shortness of its spire, the smaller number of chambers, and the non-embrace of its convolutions; as also in absence of that narrowing of the later convolutions which leads to the entire closure of the spire in *Nummulites*. The genus *Operculina* is said (*loc. cit.*) to be distinguished from *Nummulites* only by the depression of its form, the small number of its convolutions, and the rapid increase in breadth of the last whorl, which seems constantly to remain open. The genus *Assilina*, having no sufficiently distinctive characters, must (according to these able investigators) be merged in *Nummulites*.—It is obvious, from these remarks, that MM. D'ARCHIAC and HAIME had fully recognized the two fundamental errors of M. D'ORBIGNY's definition of *Operculina*; viz. his statement that the convolutions are non-embracing, and his description of the form of the aperture as triangular. And although Mr. CARTER* does not allude to the discrepancy between the structure of the recent type described by him and the generic definition of M. D'ORBIGNY, yet it is evident that in assigning to it the designation *Operculina* he was guided rather by its general resemblance to the fossils on which that generic name had been conferred, than by the conformity of its structure to M. D'ORBIGNY's definition. The errors of that definition are easily accounted for; since it is only by such an examination of thin transverse sections as M. D'ORBIGNY (I have reason to believe) never made, that the fact of the earlier whorls being really embraced by the later, notwithstanding the apparent freedom of the latter, can be substantiated; and the determination of the form of the aperture is very likely to be erroneously made, when the examination is limited to fossil specimens, in which it is frequently but very indistinctly traceable.

141. The minute structure of this type has been already investigated by two excellent observers. Under the designation of "an undescribed species of *Nonionina*," Professor WILLIAMSON† has given an account of the structure of a shell abounding in the Manilla sand, which, not merely from his figures and descriptions, but from a comparison of the specimens which he has kindly enabled me to make, I know to be one of the smaller forms of the Philippine *Operculina*. Mr. H. J. CARTER‡ has still more minutely described the organization of an *Operculina* which he obtained in great abundance on the south-east coast of Arabia, the shells coming up attached to the grease of the sounding lead from sandy bottoms of between ten and twenty fathoms depth; and of the identity of this with a larger form of Philippine *Operculina* I am enabled to speak, from comparison of specimens which Mr. CARTER has obligingly transmitted to me. I find the description of each to be in the main correct so far as it goes, but to be defective in some essential particulars. Thus Professor WILLIAMSON does not notice the canal-system except in the marginal cord; and Mr. CARTER, though he has more fully described the canal-system, has not only missed one important part of it, but has misapprehended the structure of the marginal cord. The investigations of each, moreover, have been limited

* Annals and Magazine of Natural History, Sept. 1852.

† Transactions of Microscopical Society, First Series, vol. iii. p. 112.

‡ Annals and Magazine of Natural History, Sept. 1852.

to one particular form of this protean type; and neither seems in the least degree aware of its extraordinary tendency to variation. The rich store of material placed at my disposal by Mr. CUMING has not only enabled me to prosecute my inquiries into the minute structure of this organism upon specimens of unparalleled size and degree of development, but has also enabled me to bring together a great body of data for comparison as to the extent of variation which it may undergo, alike in external conformation and in internal organization. And as the information hence obtained has a most important bearing upon the study of the closely-allied genus *Nummulites*, I venture to think that, notwithstanding all which has been done by Professor WILLIAMSON and Mr. CARTER, it is desirable that I should give a detailed account of my own investigations into the structure of *Operculina*, as well as a summary of the results of my comparison of its multiform varieties. It will be advantageous in the first place to examine into what appears to be the characteristic structure of the type, and then to inquire into the degree of modification to which this may be subject on each point.

142. *External characters*.—A large proportion of Mr. CUMING'S specimens accord in their general aspect with the one represented in Plate III. fig. 7, which is closely conformable to Mr. CARTER'S type of *Operculina Arabica*, except in its somewhat larger dimensions. It is a compressed spiral of about .25 inch in diameter, and about .015 inch in thickness, consisting of between three and four convolutions gradually increasing in breadth; these are in general nearly flat, but are sometimes a little arched between their inner and outer margins, sometimes depressed so as to present a slight concavity, especially near the outer margin of the last whorl. The chambers are about seventy-five in number, commencing from a primordial spheroidal cell and progressively increasing in dimensions with the widening of the spire; their septa have for the most part a radial direction, but they bend backwards near the outer margin of each whorl; and they are marked externally by bands which are distinguished by their semitransparent aspect from the dull brownish hue of the general surface. These septal bands are commonly on the same plane with the intervening portions of the shell; but sometimes the walls of the chambers are a little arched between the septa that bound them, so that the septal bands are slightly furrowed; whilst the walls of the chambers are sometimes a little depressed, so that the septal bands are prominent; and such varieties may present themselves in different parts of one and the same shell. Not unfrequently the whole surface is seen to be marked by very minute punctations; but more commonly they are larger and fewer in number, and are often arranged in pretty regular lines parallel to the septal bands,—one, two, or three rows of such punctations being seen on the wall of each chamber (Plate V. fig. 7); these punctations, when sufficiently magnified, are found to be spots of semitransparent shell-substance resembling that of the septal bands; and, as in the case of these, their surface is sometimes on the same plane with that of the general surface of the shell, sometimes a little elevated so as to form papillæ, and sometimes a little depressed into minute fossæ (fig. 8). These punctations often present themselves abundantly on some parts of the surface, whilst they are entirely absent from others. Sometimes, instead of a limited number of comparatively large and

regularly arranged punctations, we find a vast number of very minute papillæ, scattered without order over the entire surface of the chambers (fig. 6); these, again, may be absent from some parts of a shell, over other portions of which they are abundantly distributed. There is commonly a large semitransparent tubercle at the umbilicus, and smaller tubercles are often seen along the septal bands, especially of the earlier whorls: the umbilical and the septal tubercles are well seen in Plate III. fig. 6, and (less characteristically) in several other figures of the same Plate; and the septal tubercles are shown on a much larger scale in Plate V. fig. 11. Not unfrequently, however, the umbilicus is depressed, instead of being elevated into a tubercle; and the moniliform tubercles along the septal bands are wanting.

143. The departures from this typical form, however, are very wide. A glance at any considerable aggregation of specimens reveals to us an extraordinary variety of size and shape; and our attention is specially attracted by a series of which an example is represented in Plate III. fig. 9, which are not merely distinguished by a size greatly above the average—their long diameter reaching nearly $\frac{1}{4}$ inch,—but also by the extraordinary flattening of the later convolutions, and the rapidity with which the spire opens out. The approximation between the two lateral walls of the chambers is here so close, that not only are the septal bands rendered very prominent by the depression of the outer surface between them, but even the outer marginal band stands up as a ridge, from which the walls of the chambers slope down. In fact, an examination of this form leaves the observer impressed with surprise that any room can be left for the animal, the segments of which must be extraordinarily attenuated, losing in thickness what they gain in area. Now a careful comparison of this form with the ordinary type, not only makes it obvious that the former differs from the latter in no other particular than this attenuation, which (as already pointed out in the cases of *Heterostegina* and *Peneroplis*) is a common feature of the later growths in Foraminifera, but also that the attenuation takes place in such different degrees in different individuals, that any attempt to use it as a differential character is completely baffled by the continuous gradation of forms that is presented, between the one which has been assumed as the typical, and such as most widely depart from it in this particular.

144. The collection of Mr. CUMING also includes, however, a considerable proportion of comparatively small specimens, ranging from $\frac{1}{8}$ to $\frac{1}{20}$ inch in diameter, which present a very different configuration. In the smallest of these, represented in Plate III. fig. 1, the spire, instead of being flat or even somewhat hollowed, is arched from its inner to its outer margin, so that the breadth of the septal plane is equal to its length, or nearly so; and the like is seen in the somewhat larger specimens of which fig. 2 is an example. This variety of conformation, however, being limited to shells whose earlier period of growth is evinced by their smaller number of convolutions and of chambers, and being seen, moreover, in the earlier whorls of those which afterwards present the greatest flattening, may safely, I think, be regarded as a character of age. It will be recollected that the young of the flattened *Peneroplis* more resembles *Dendritina* in the comparative turgidity of its spire; but I do not find that *Operculina* ever continues long

to increase upon such a plan; for the compression of the spire always shows itself in the third whorl, if it has not previously done so, and is accompanied with a corresponding augmentation of its breadth, so that the septal plane becomes narrowed and elongated, as is seen in comparing fig. 4 with fig. 3. That no basis for specific distinction is afforded by the most marked differences in the form of the spire, as shown in the proportions of the septal plane (A, B, C, D), will be made evident by the examination of such a transverse section as is shown in Fig. V. (p. 21); in which it will be observed that differences equal to those presented by the most compressed and the most turgid forms of the spire, are exhibited by the successive convolutions of one and the same individual.

145. Another marked feature of difference among the specimens of this collection, is the depression or elevation of the central region relatively to the peripheral. In what I have assumed as the typical form, the central region presents the same general level with the rest, though the umbilicus itself is often marked by a prominent tubercle. In such forms as are represented in Plate III. figs. 1 and 2, the umbilical region is rather depressed than elevated; and this depression is often observed in older specimens whose early growth has taken place on this type. But there is a group of specimens, of which three successive ages are represented in Plate III. figs. 3, 4, 5, 8, that have the whole central region so exceedingly prominent as to form a cone, whose apex is marked either by one large tubercle, or by a cluster of smaller ones; and this conformation gives so peculiar a physiognomy to the shells which present it, that few systematists would hesitate in placing them apart as specifically different from the rest. On a careful comparison of a large number of individuals, however, it becomes apparent that this difference, like the preceding, is gradational; every degree of prominence being traceable from the individuals which have the umbilicus marked only by a tubercle, as in fig. 7, through those in which the region generally is slightly elevated, as in fig. 8, to those in which it presents the most marked projection, as in figs. 3-5. We shall presently find (§ 153) that this difference depends mainly on the degree in which the investing layer, prolonged from the later convolutions over the surface of the earlier, is separated from that surface by the extension of the alar prolongations of the chambers of the investing whorls; as to which point there is a most remarkable diversity, not only among different individuals, but between the several convolutions of the same individual.

146. A fourth very obvious character of differentiation among the individuals of this collection, consists in the presence or absence of tubercles on the septal bands. In what I have described as the typical form (Plate III. fig. 7), there are no considerable prominences over the greater part of the surface; the septal bands are generally smooth and continuous; and it is only in the central region that we observe any departure from this uniformity, the umbilicus being occupied by a small tubercle, and the smooth septal bands being replaced in the first whorl by moniliform rows of little tubercles. In other instances, however, we find not only the central tubercle, but the rows of tubercles marking the septa, much larger and more prominent; and this marking-out of the septal bands by elevated tubercles is not limited to the first whorl, but extends to the second, and even to the third, as is well shown in fig. 6. The specimens whose central region is

very prominent (Plate III. figs. 3, 4, 5), usually show this feature in the most decided manner; but it is occasionally presented also in no less a degree by those whose umbilicus is flat or even depressed. The most remarkable departure from the ordinary type is seen in a small group of specimens in which the tubercles are not only extremely large and prominent (Plate IV. fig. 6), but are distinguished by their opaque whiteness (Plate V. fig. 12), which contrasts strongly with the semi-transparency ordinarily characterizing these prominences. But even this character has no diagnostic value; for a specimen which has the tubercles opaque in one part may have them semi-transparent in another; and as to the size of the tubercles, their degree of prominence, and the proportion of the entire spire over the septa of which they occur, there is every degree of variety. In one of my largest and flattest specimens, the central region is strongly tuberculated, but the tubercles almost suddenly cease when the spire begins to open out, and the septal bands are thenceforth as smooth as in the ordinary type.

147. A less obvious but still very decided feature of individual difference, consists in the presence or absence of papillary elevations *between* the septal bands. I have already spoken (§ 142) of the frequent existence of symmetrically arranged spots, sometimes slightly depressed, but more commonly elevated, that are distinguished from the rest by the semitransparency of their shell; these spots are sometimes considerably enlarged, and their elevation increased, so that they become prominent papillæ, closely resembling the tubercles upon the septal bands. Their size and disposition vary considerably. Sometimes they are small, numerous, and scattered without any definite arrangement over the entire surface of the wall of the chamber, whilst in other cases they are considerably larger, and form single, double, or even triple rows between the septal bands (Plate V. fig. 10). Another remarkable variety of external aspect is produced by the elevation of the general surface into rounded eminences closely abutting on one another (like the pustules of the skin in a case of confluent small-pox), and distinguished from the preceding by the absence of any peculiarity in the texture of the shell. That these and other analogous variations of surface-marking have no value as differential characters, is at once demonstrated, not merely by their gradational approximation in different individuals, but by the fact that they are presented in very different degrees on different parts of the surface of the very same shell; the chambers of one part of the spire being strongly marked by certain of these peculiarities, whilst those of another may only present indications of them, and those of a third may be perfectly smooth.

148. The collection of Mr. CUMING, however, contains a group of forms which are at once distinguished from the rest by their general physiognomy (Plate III. figs. 11, 12), and which, when their characters are examined in detail, appear to be separated from them by well-marked differences. Their aspect is much more lustrous, and their hue much whiter, varied, however, by a tinge of green diffused in irregular patches; the spire does not in the largest specimens make above three turns, and it begins to open out sooner than in the type already described; the septa are usually considerably more convex anteriorly, and are also rather more distant from each other, so that the interval between them is greater in proportion to the breadth of the spire, the shape of the

chambers being thus modified, and the number of chambers in each whorl being diminished; the septal bands, not merely of the earlier whorls, but even of the last-formed portion of the shell, are raised into prominent tubercles; and multiple rows of large tubercles are seen between the septal bands. It is to this multiplication of smooth tubercles composed of a variety of shell-substance which reflects light much more strongly than the rest, that the more glistening aspect of this type is chiefly due; and I have not met in it with any instances of that general brownish coloration of the surface which is the ordinary characteristic of the other. The most constant and remarkable distinctive feature of this type, however, is the presence of a large hemispherical cluster of semitransparent tubercles in the centre of the spire (Plate III. fig. 10).

149. Having had no difficulty in setting apart a large number of specimens agreeing very closely with each other, and differing from the rest, in all the foregoing characters, I should have arrived at the unhesitating conclusion that this type deserves to take rank as a species of *Operculina* distinct from the preceding, were it not for the circumstance that every here and there I met with an example in which the differential characters were less strongly marked than usual. Thus in some individuals which preserve the general proportions of the spire, the green coloration is wanting, the large central cluster of tubercles is replaced by a single tubercle of extraordinary size, the septal bands of the neighbourhood are not more tuberculated than in many examples of the ordinary type, and the rows of tubercles over the chambers are either wanting altogether, or are not more prominent than in many individuals of the preceding type. This evidence of the negative value to be attached to the number or prominence of the tubercles as a specific character, is confirmed by a curious fact of an opposite nature; namely, that in certain individuals we find them developed to an extraordinary and obviously abnormal degree (Plate V. fig. 9).—From the difficulty of deciding to which type particular specimens are to be referred, I had been almost led to adopt the conclusion of the specific identity of this with the ordinary form; when Dr. GOULD, of Boston (N. E.), kindly placed in my hands some *Operculinæ*, which had been collected on the coast of Japan by the recent American expedition to that country. These specimens combined in so remarkable a manner the most distinctive features of the two types,—namely, the general form and proportions of the one, with the umbilical hemispheric cluster of tubercles and the general abundance of tubercular elevations characteristic of the other,—as to remove all doubt from my mind with regard to their specific identity.

150. *Internal Structure*.—The study of the internal organization of *Operculina* may be prosecuted in two modes;—by the examination, under sufficient magnifying powers, of thin transparent sections taken in different directions;—and by viewing under a low power, as opaque objects, fragments obtained by breaking the shell, especially (as Mr. CARTER was the first to suggest) after these have been allowed to absorb carmine or indigo by being placed upon water in which either of these colours has been rubbed up. By the former method alone can certain minutiae of structure be detected; but the latter is extremely serviceable (as I found in my study of *Nummulites*, op. cit.) in enabling the observer to trace out the relations of various parts, which sections exhibit to him

disconnected from one another. In Plate I. fig. 3, an attempt is made to bring together in an ideal representation the most important features of the internal structure of *Operculina*, as disclosed by these two methods of examination; the warranty for all its details being supplied by the delineations of the separate parts that are given in other figures, which are all taken from preparations in my possession.

151. Ówing to the circumstance that large specimens of *Operculina* are rarely if ever quite flat, it is next to impossible to make a section through the median plane that shall traverse all the whorls to the central cell; a sufficiently near approach to this, however, has been made in the section represented in Plate VI. fig. 3, and Plate IV. fig. 10, to bring into view the general disposition of the chambers. This is much less regular than would be supposed from a superficial examination of the exterior. For while there is a certain general average in the proportion which their long diameter (that is, the breadth of the whorl) bears to the short (or distance between the septa), which may be stated as about $4\frac{1}{2}$ to 1, this is by no means constantly maintained, the long diameter being sometimes as much as 7 times, and sometimes no more than $2\frac{1}{2}$ times, the short. The ordinary course of the septa, too, is often strangely departed from, as is seen in Plate VI. fig. 3. There are few individuals which do not present—besides abnormal sinuosities, greater or less in degree—very marked irregularities in the conformation of the chambers, analogous to those which I have described in *Nummulites**. Frequently a septum, instead of passing continuously from the inner to the outer margin of the whorl, stops short without reaching the latter, and bends backwards to join the last-formed septum; and sometimes a second septum unites itself to the first in the same manner, as shown at *a*, Plate VI. fig. 3. The abortion is often still more marked; thus at *b* we see three septa thus interrupted, of which two do not traverse half the distance, and the third not a quarter, thus dividing the space between two complete septa into four small chambers along the inner margin, and one large irregular chamber extending to the outer. Another case of the same kind is seen in an earlier part of the same whorl; and in Fig. IV. an additional illustration on a larger scale is given of the like irregularity, for

Fig. IV.

Irregular disposition of septa in *Operculina*:—*a, a, a*, normal apertures at inner margin of spire;
b, b', b'', apertures of communication between abnormally divided chambers.

the purpose of showing the arrangement of the communicating passages. Generally speaking, the more nearly we approach the centre of the spire, the more regularly do we find the septa disposed, until we come into close proximity with the central cell.

* Quarterly Journal of the Geological Society, vol. vi. 1850, p. 23.

In Plate IV. fig. 5 we have an illustration of what may be considered the normal mode of commencement of the spire; from which it will be seen that it originates, as in Foraminifera generally, in a spheroidal cell, from which others are successively developed around it, the earlier chambers having no very definite shape, but those which succeed them gradually coming to assume the characteristic form and proportions. The like is shown in vertical section in Fig. VII. B.

152. Each chamber communicates with the neighbouring chamber on either side, by a long narrow crescentic fissure left by the non-adhesion of the septum to the outer margin of the preceding whorl (Plate I. fig. 3). This fissure (Figs. IV., VI. *a, a, a*) is frequently not to be seen in such a section as is represented in Plate VI. fig. 3, owing to the circumstance that this does not happen to pass through the plane in which it lies; and it is best brought into view either by making thin transverse sections (as Fig. V.), or

Vertical or transverse section of three outer convolutions of *Operculina*.

by breaking a specimen transversely and examining its fractured edges, by which such views will be obtained as are presented in Fig. VIII. (p. 26) A, B, C, D. Besides this principal aperture, we observe in the septa, especially of the larger chambers, a variable number of secondary pores (Plate I. fig. 3 *e*), generally circular, and of comparatively small size; these are dispersed without any regularity, as is shown in Figs. V., VI., VIII. They may or may not be brought into view in a horizontal section, according as its plane does or does not happen to pass through them; but when they are thus traversed (Fig. VI. *b, b, b*), it is seen that these secondary pores, like the principal aperture, establish a direct communication between adjacent chambers*. In the irregular formation repre-

Fig. VI.

Section of two septa of *Operculina* through the median plane, showing the secondary pores, *b, b, b*, in addition to the principal orifices, *a, a*, at the inner margin of the spire.

* These secondary pores were first observed by me in *Nummulites levigata* (*op. cit.* p. 24); I then believed, however, that they do not pass through both layers of the septa, but only establish a communica-

sented in Fig. IV., these secondary pores (b' , b'' , b''') present a disposition which would seem to indicate that they are scarcely less important for the maintenance of the communication between the chambers, than is the principal aperture itself; and it is curious to observe how exactly they repeat at b' and b'' that mode of communication—between *two* segments on the inner side and *one* on the outer—which is so characteristic of *Orbitolites* (¶ 17) and *Orbiculina*. Each septum, as in *Cycloclypeus* and *Nummulites*, is composed of two layers (Plate I. fig. 3 d , d), each being the proper wall of one of the chambers which it separates; these layers are commonly in close apposition with each other; but they separate at certain spots, to give passage to the very curious system of interseptal canals to be presently described.

153. A comparison of numerous vertical sections brings into view a most remarkable variety in the form and disposition of the chambers, not merely in different individuals, but in different parts of the same individual. Commencing with one of the flattest variety, Fig. VII. c, we observe that the breadth of the septal plane is very small in comparison with its length; and that although the spiral lamina of each whorl except the last obviously extends itself over that of the preceding whorls, the cavity of the cham-

Fig. VII.

Vertical or transverse sections of six specimens of *Operculina*, exhibiting marked variations in the form and proportions of the convolutions.

tion between the chambers and the interseptal passages. In this idea I am now satisfied, by the examination of *Operculina*, that I was in error; and I am disposed to regard these secondary pores of *Nummulites* and *Operculina* as representing the multiple communications between the chambers of *Peneroplis* (¶ 127).

bers is not so extended, those of each whorl being bounded internally by the external margin of the preceding. Passing from this, however, to forms which are slightly elevated in the centre (Fig. VII. E), we find not only that the breadth of the septal plane is increased, but that the cavity of each chamber is extended into two *alæ*, which are more or less prolonged over the enclosed whorls; so that the spiral lamina of the investing whorl is kept by their interposition from coalescing with that which it embraces, except in the central region. The degree of this extension, however, varies in different convolutions; the *alæ* being usually smaller in the chambers of each consecutive whorl, and being absent altogether from those of the last,—a transition well shown in Fig. V., which also exhibits the marked variation in the general proportions of the chambers that may present itself between the inner and the outer whorls. In forms which are distinguished by a yet more turgid spire, the proportions of the chambers are very considerably modified; but among these there is a very considerable difference in the degree in which the chambers of the later whorls are prolonged over the earlier; thus in Fig. VII. A, whose centre is on a level with the rest of the spire, we see the *alæ* prolonged so as quite to reach that region; whilst in D and F, which have the central region depressed, though the general proportions of the chambers correspond with those of the preceding, the *alæ* are so little extended that the spiral laminae of the successive whorls coalesce not only at the centre, but at some distance around it. After an attentive examination and comparison of a great number of vertical sections, I feel justified in affirming that no importance can be attached either to the form and proportions of the chambers, whether shown in the relative length and breadth of the septal plane, or in the degree in which their *alæ* are prolonged over the enclosed whorls, as furnishing characters of specific difference; seeing that it is not only found to vary gradationally when a sufficiently large series of specimens is compared, but that it is often equally inconstant in different parts of the same individual.

154. The spiral lamina, in typical specimens, is much thicker in the inner than in the outer convolutions, that of the last whorl being always comparatively thin (Fig. V.); and a careful examination of transparent vertical sections makes it apparent, that the greater thickness of the spiral lamina of the earlier whorls is partly due to the prolongation of that of the later whorls over them, and to its coalescence with them. I have not been able to satisfy myself that the spiral lamina of the last whorl is thus extended over the preceding whorls; and it has rather appeared to me to be merely applied to the margin of that which it surrounds. The difficulty of certainly determining this point, chiefly arises from the circumstance that the spiral lamina of the last whorl is reduced in thickness in proportion to its extension, as if in consequence of a limitation of the amount of calcareous matter employed in its formation. The spiral lamina is made up of a variable number of lamellæ of a minutely tubular substance (Plate IV. fig. 9), so exactly corresponding with that which I have already described in *Nummulites* (*loc. cit.*) and in *Cycloclypeus*, that any detailed description of it is unnecessary. I have to add, however, that in examining extremely thin transverse sections of this tubular shell-substance with a sufficiently high magnifying power, I have been able to perceive that the

orifices of the tubuli are separated by a very delicate areolation (fig. 9*b*), as if the whole substance were composed of an aggregation of prisms with a tubulus in the centre of each. And this circumstance appears to me to afford the explanation of an observation which I have elsewhere recorded in regard to certain fossil specimens of *Nummulites* (*loc. cit.*),—namely, that where the characteristic tubular structure is wanting, an appearance of prismatic structure is occasionally presented*; for it is not by any means difficult to conceive that the same molecular change which obliterates the one feature, should bring the other into increased distinctness. The size of the tubuli of *Operculina* is much greater at and near the inner surface of the walls of the chambers, than it is at a little distance from them, as will be seen by comparing figs. 1 and 3 of Plate IV. with figs. 2 and 4; so that when a thin lamina from the innermost part of the wall is examined under a high magnifying power, the tubes are seen almost to fill the areolæ, as is shown in Plate IV. fig. 9*a*, which is drawn on the same scale as *b*.

155. As is *Nummulites* and *Cycloclypeus*, the shell-substance over the septa is not penetrated by tubuli, and is consequently far more transparent than the rest; and it is in consequence of this difference in texture, that the septal bands are so strongly marked on the external surface, as well as in sections parallel to it (Plate IV. figs. 10, 11; Plate VI. figs. 1, 2). The same is true, also, of the substance of the tubercles, whether occurring as elevations of the septal bands, or upon intermediate parts of the spiral lamina. In the latter case, the tubercles are seated upon inverted cones of the like substance, which do not usually reach down to the inner lamina, so that the internal surface presents the orifices of the tubuli regularly disposed over the interior of the chambers (as seen in Plate IV. figs. 1, 3), even where sections passing at a little distance from these show rounded or elongated spots of transparent substance (figs. 2, 4), around which the tubuli are crowded together, as if they had been displaced by its interposition. Such spots occasionally present themselves in the ordinary type of *Operculina*, as seen in Plate IV. fig. 10; but it is of course in sections of the strongly-tuberculated variety that we find them most marked, and this especially in the investing layers of the central region, where, from the size and approximation of the tubercles, the spaces between them are rendered almost opaque by the crowding together of the tubuli (Plate IV. fig. 11). The tubuli are generally seen, moreover, to be somewhat more crowded in the neighbourhood of the septal bands.—The greatest local development of the non-tubular substance is seen in those varieties which have a large elevated tubercle in the centre (Plate III. figs. 3–5); a section of such a variety has been shown in Fig. VII. *D*, where it is seen that this tubercle springs from the spiral lamina of the

* As MM. D'ARCHIAC and HAIME, in referring to my statement as to the appearance of prismatic structure in *Nummulites*, would appear to entertain some doubt as to the correctness of my observation (see p. 61 of their Monograph), I think it right not merely to say that fig. 12, Pl. IV. of my Memoir on *Nummulites* is a most exact representation of a section still in my possession, but also to mention that the vertical fracture of well-preserved specimens of *N. laevigata* often presents an edge so strongly resembling that of the prismatic shell-substance of *Pinna* when fractured in the same direction (though on a much smaller scale), as to have led experienced microscopic observers to a belief in their similarity, before my discovery of the minutely tubular structure of *Nummulites*.

innermost convolution, but that it increases in diameter as it is built upon (so to speak) by each of the whorls by which this is subsequently invested.

156. The texture of the shell-substance which bounds the chambers at the outer margin of each whorl, however, presents a marked departure from that of the spiral lamina; a difference analogous to that which was first indicated by me in *Nummulites* (*loc. cit.*), and which has been found by MM. D'ARCHIAC and HAIME to present itself so constantly in that genus, that they give to this marginal portion the special designation "bourrelet." Mr. CARTER has already recognized in *Operculina* the speciality in the structure of this part of the shell; but he has fallen into what I believe to be an error in his interpretation of that structure, describing it as made up of an aggregation of fusiform spicules, and hence designating it as "the spicular cord." Now I am very familiar with the appearance which has led him to take this view of its nature, since it is one which is commonly presented by thin sections that pass either through the median plane or parallel to it, as shown in Plate IV. fig. 13; but this is only one out of many aspects which are presented by sections taken in various directions; and a comparison of the whole seems to me to lead to quite a different conclusion,—namely, that the supposed spicular composition of this "marginal cord" (as it may be appropriately termed) is due to the peculiar manner in which the homogeneous substance of which it is composed is traversed by the set of canals that are correctly described by Mr. CARTER as forming the "marginal plexus." For if the section should happen to traverse a portion of this plexus in which the canals form a tolerably regular network of elongated meshes in one plane, the appearance delineated in fig. 13 is presented; but just as often a less complete layer of the network is traversed by the section, and the form of the meshes is very inconstant, so that the appearance presented is rather that shown in fig. 14. Moreover the appearances exhibited by transverse sections of this marginal cord, highly magnified (figs. 15, 16), do not at all confirm the idea of a spicular arrangement, but are altogether conformable to the view I have expressed; the most complete confirmation to which is afforded by tangential sections, of which a very successful example,—giving a beautiful view, not only of the canal-system of the "marginal cord," but also of its communications with that of the septa, and of its relations with the two principal spiral canals to be presently described,—is represented in Plate IV. fig. 12. In this it is clearly seen how irregular is the disposition of the inosculating passages, whilst there is not a trace of the spicular structure, which ought, if it existed, to be as well brought into view in a section taken in this direction, as it is in the one shown in fig. 13, which is taken in a plane at right angles to it. The "marginal cord" is traversed on its external surface by longitudinal furrows, which are sometimes very shallow (fig. 15), but sometimes dip down deeply like those between the convolutions of the brain, as shown in fig. 16. These furrows usually form a kind of network with fusiform interstices (Plate V. fig. 5), whilst in other cases they run parallel to each other and inosculate more rarely (fig. 4). From the correspondence between their arrangement and that of the passages in the interior, I am inclined to think that they belong to the same system with these, being, in fact, canals not covered in by shell-substance, that communicate

with the plexus within by inosculating branches, whose apertures may sometimes be detected in the bottom of the furrows. This furrowed surface of the marginal band, and the existence upon it of apertures communicating with a set of canals in its substance, were specially pointed out by me in *Nummulites* (*loc. cit.*), although the changes produced by fossilization prevent the full extent of the "marginal plexus" from being traced out in that genus. The general relation of the marginal cord (*aa*) to the two spiral laminae (*b, b*) with which it unites itself to form the boundary of the chambers, as seen in Plate IV. figs. 15, 16, is precisely the same in *Operculina* as in *Nummulites*.

157. The "marginal plexus" of canals communicates freely with the system of "inter-septal canals," which are disposed between the two layers of the septa, as I have described in *Nummulites* and in *Cycloclypeus*, and the existence of which in *Operculina* has been already indicated by Mr. CARTER. The distribution of these is well seen, not only in vertical sections which have happened to traverse the septa, as in Figs. V., VII., and in Plate IV. fig. 8, but also in specimens laid open by fracture in the same direction, especially after the canals have been more distinctly marked out by the imbibition of a colouring liquid (Fig. VIII., and fig. 2, Plate V.). It will be seen from these delineations, all of which are faithfully copied from specimens in my possession, that the distribution of the interseptal canals, whilst presenting a certain general uniformity of plan, is by no means constant in detail. In Figs. VII. A, and VIII. D, we see two principal trunks passing from the two angles of the fissure at the interior edge of each septum, towards the marginal band at its exterior (as in fig. 2 *d*, Plate VI.), and sending out branches which ramify over the part of the septum that joins the spiral lamina (Fig. VIII. D), leaving the intervening portion untraversed; and this is the only arrangement which has been described by Mr. CARTER. But on looking at the other figures, it

Fig. VIII.

Septal planes of four specimens of *Operculina*, showing varieties in the disposition of the interseptal canals.

will be seen that much variety presents itself; thus in Fig. VIII. A (as in fig. 2, Plate V.) we observe two or more such trunks proceeding from each angle of the fissure, those of the same side frequently inosculating with each other; in Fig. VIII. c (as in fig. 8, Plate IV.) the two principal trunks on the opposite sides inosculate as they approach one another in their course towards the outer margin of the septum; and in Fig. V. (page 21) this inosculation is seen to take place much nearer the inner margin of the septum of the last whorl, so that the greater part of the septal plane is occupied by the plexus formed by their interlacement. The interseptal canals of one septum are occasionally, if not invariably, connected with those of another by loops formed between the ramifications of those canals which extend along the alar prolongations of the septa towards the centre of the shell; such inosculating loops are seen at the centre of fig. 6, Plate VI. Moreover, branches of the same system are generally found to penetrate the non-tubular shell-substance whenever it accumulates in any quantity; these branches are at once distinguished from the ordinary tubuli by their much larger size, their diameter being commonly about $\frac{1}{5000}$ th of an inch.

158. The branches of the interseptal canals which proceed towards the spiral laminae are sometimes continued onwards in the non-tubular shell-substance that constitutes the septal bands; and they are also frequently seen to diverge from the septa over the walls of the chambers,—still, however, being usually invested by a layer of transparent shell-substance, as is well shown at *e*, fig. 2, Plate VI. This arrangement, again, corresponds with what I have described and figured in *Nummulites*; but I have not been able to detect in *Operculina* the apertures by which in *Nummulites* these canals communicate with the cavity of the chamber, a circumstance which may perhaps be attributed to the relatively smaller size of these passages in *Operculina*, and the consequent facility with which their apertures may be confounded with those of the ordinary tubuli. In fig. 2, Plate VI. is represented an appearance of areolation I have several times met with in the walls of the chambers,—though usually less conspicuously than in this instance,—which has made me suspect that the ramifications of the interseptal canals sometimes (if not as a regular rule) form a network in the spiral lamina over the entire surface of the chambers.

159. The interseptal system of each whorl is connected with the marginal plexus of the preceding by a very remarkable arrangement, which seems to have altogether escaped Mr. CARTER'S notice. At each junction of the marginal cord with the tubular substance of the spiral lamina, the orifice of a large canal (Plate IV. fig. 15 *c, c*) may be seen in a vertical section which divides this canal transversely; and either of these canals may be clearly traced, in sections parallel to the surface, which have happened to pass through its plane, as at *d, d*, fig. 10, Plate IV., *b, b*, fig. 1, Plate VI., and very conspicuously in fig. 5, Plate IV., in which, by a fortunate accident, one of the spiral canals has been laid open in its entire course through the inner whorls, and can be traced nearly to the central cell. In the tangential section, fig. 7, Plate IV., the two canals can be seen running on the outside of what may be called the *nucleus*, consisting of the central cell and of the chambers immediately surrounding it. The mode in which

the interseptal passages branch off from these two spiral canals, is well seen in fig. 1, Plate VI., and also in fig. 10, Plate IV.; and this arrangement is shown in fig. 5; Plate IV. to extend to the septa between the chambers of the innermost convolution. The relations of the different parts of the system are brought extremely well into view in fig. 12, Plate IV., which represents a tangential section of a young shell, the rapid curve of whose spire causes the planes of even the contiguous septa to vary greatly in their direction. The spiral canals, though only running along the angles of the marginal cord, pretty obviously communicate with the plexus of passages which it contains; and thus the interseptal system of one whorl is brought into direct connexion with that of the preceding. It is to be remembered, however, that independently of such connexion, the spiral mode of growth of itself brings about a continuity of the canal-system throughout, by means of the marginal plexus; the consecutive whorls not being added one to another like the successive annuli of *Cyclocypeus*, each of which is (so to speak) *closed* or complete in itself; but being formed by the prolongation of the spiral lamina and of the marginal cord, which may be considered as always *open* to indefinite extension.

160. In regard to the uses of this canal-system, I have not at present anything to add to what I have already stated when describing its distribution in *Cyclocypeus* (§ 107): I shall have the opportunity, however, of discussing them more fully in a subsequent Memoir upon forms in which this system is still more remarkably developed.

161. I have attempted to determine by a re-examination of my preparations of *Nummulites*, with the additional light afforded by the structure of *Operculina*, whether an arrangement of the canal-system prevails in the former at all comparable to that which I have shown to exist in the latter. In those which have undergone the ordinary fossilizing process, it is difficult to discover more than vague indications of its existence. But the peculiar process of silicification of *Foraminifera*, to which attention has been recently drawn by Professor EHRENBURG*, has afforded an unexpected verification of the anticipations which the similarity of these two genera in other points of structure had led me to form as to this. For by the infiltration of silex tinged with silicate of iron into the cavities of *Foraminifera*, whilst their calcareous shells have undergone decomposition and removal, a most perfect series of *casts* are presented, not merely of the chambers, but of the canal-system where this exists. And in his figure of such a cast of *Nummulites striata* (taf. 5. fig. 2), Professor EHRENBURG has given a most beautiful representation of the canal-system of the marginal cord, and of its communications with the interseptal canals, so closely corresponding with that which, long before the publication of his memoir, I had worked out in *Operculina*, that no doubt can fairly remain as to the essential similarity between these two types in this important feature of their organization†.

* Über den Grünsand und seine Erläuterung des organischen Lebens. Aus den Abhandlungen der Königl. Akademie der Wissenschaften zu Berlin, 1855.

† I may here remark upon the confirmation afforded by other parts of this most valuable memoir to the results of my researches upon *Orbitolites* and *Cyclocypeus*; the various figures given by Professor EHRENBURG

162. Hence it would appear that there is no other essential difference between *Operculina* and *Nummulites**, than that which consists in the closing in of the spire, affirmed by MM. D'ARCHIAC and HAIME to be a constant character of the latter, whilst in the former the spire seems ordinarily to open out so long as it continues to increase. But even this is not an invariable difference; for I have met with several specimens of *Operculina*, in which the spire closes in by a somewhat abrupt inflexion of the marginal cord, so as to produce a rapid diminution in the size of the last four or five chambers, ending (as it would appear) in a complete cessation of growth. Examples of this kind are represented in fig. 8, Plate III. and fig. 3, Plate V.; and in Fig. IX. is shown the closing septum of one of these specimens upon a more enlarged scale. Looking, however, to the circumstance that these specimens bear but a very small proportion to those which exhibit no such tendency, and also to the fact that some of the specimens in which this closing-in is seen are very far from having attained their full growth, I am disposed to regard it as an abnormal, or at least as only an occasional occurrence in *Operculina*; and I must confess that, notwithstanding the positive assertion of MM. D'ARCHIAC and HAIME, I still entertain doubts as to whether it is to be accounted as a uniform characteristic of *Nummulites*. At any rate, the occasional occurrence of this condition in *Operculina* deprives the character of that constancy which is requisite to make it good for generic differentiation; and if *Operculina* and *Nummulites* are to be retained as separate genera, I cannot perceive by what features they are to be distinguished, save by the marked compression in form, the limited number of convolutions, and the external display of the whole spire, which are the obvious though not very important characteristics of the former.

163. It only now remains to speak of certain appearances indicative of *reparation after injuries*, which throw some light upon the physiology of this type of organization. Specimens are not unfrequently met with, exhibiting such irregularities as are delineated in fig. 1, Plate V.; and we can scarcely, I think, be wrong in concluding that these irregularities have commonly been produced by fracture. A portion of the outer part of the spire being broken off, the wound heals by the formation of new shell at the margin; but in its further progress the spire often shows the effect

Fig. IX.

Front view of the septal plane closing in the last chamber of *Operculina*.

in his Fourth Plate, of the chambers and passages in different species of an organism which he designates *Orbitoides*, being in the closest conformity with my representations of the corresponding parts of these two genera, between which the form described by Professor EHRENBURG seems to be a connecting link.

* I have already (§ 104, note, Philosophical Transactions, 1856, p. 558) corrected the mistake into which I fell, when treating of the structure of *Nummulites*, in regarding the non-tubular *columns* of the fossil shell as having been *passages* subsequently filled up.

of the injury, in a narrowing of that part of the convolution which succeeds it, the new chambers being formed as it were on the contracted basis to which their predecessors have been reduced. A very remarkable feature in all these reparations is *the continuation of the marginal cord along the fractured edge*. It might have been supposed that the wound would have been healed with some rude exudation, which would have given rise to an amorphous shell-structure; but instead of this, we find the reparation chiefly effected by a new production (probably by extension from the old) of that portion which gives the most evidence in its canalicular structure of being intimately connected with the vital changes taking place in the organism. This phenomenon is beautifully displayed in the specimen represented in fig. 4, Plate VI., which exhibits another remarkable feature, for which it is difficult to account,—a reversal in the direction of growth which has taken place after the fracture. Although the specimen is unfortunately not complete, there can be (I think) no reasonable doubt that its convolutions must have taken the course indicated by the dotted lines; and it would seem that after the first two convolutions had been formed, the spire had been broken across, almost through its centre. It will be at once seen, by comparing the direction of the septa of the second convolution with that of all those which surround it, that the latter have been reversed; and although the part in which the reversal actually took place is unfortunately wanting, yet there can be little doubt that it was made as indicated in the figure (*a*). But the most curious feature in the specimen is this,—that the extension (*ac*) of the marginal cord which has closed in the fractured portion has obviously proceeded not from the later (*b*), but from the earlier (*c*) of the two fractured extremities of the second convolution; and it is in this *backward* growth that the reversal would appear to have originated. A somewhat similar retrograde increase has been already noticed among the modes in which *Orbitolites* is occasionally repaired (§ 39); and it obviously shows that every portion of the organism is equally capable of extending itself when left free to do so. It is worthy of remark, that the growth of this specimen subsequently to the injury, has taken place more after the plan of *Nummulites* than on the ordinary plan of *Operculina*; the convolutions being more numerous than usual, and their rate of increase slow. There is evidence, however, in the presence of a small fragment of the final whorl, that it underwent the thinning-out which is characteristic of its type. Notwithstanding the great number of specimens which I have examined, I have not met with one that presented any such departure from the normal type of growth as would deserve to be termed a *monstrosity*; so that it would seem as if such aberrations were more frequent in the *cyclical* than in the *helical* type.

Genus AMPHISTEGINA.

164. *History*.—This genus was first constituted by M. D'ORBIGNY in 1825, for the reception of a type of Foraminiferous shells which does not seem to have been previously noticed by those who have given their attention to this group, in consequence, it may be, of its limitation to the seas of warm latitudes. Notwithstanding the very close relationship which, as I shall presently show, it bears to *Nummulites* and other Nautiloid

forms of the order *Hélicostègues*, it was considered by M. D'ORBIGNY to depart from them in a character which he regarded of such fundamental importance as to serve as the basis of a distinct Order, that of *Entomostègues*; of which the following is his most recent definition*:—"Animal composé de segments alternes, formant une spirale. Coquille composée de loges empilées ou superposées sur deux axes alternant entre elles, et s'enroulant en spirale." The mode of increase of these shells, he elsewhere says†, presents a singular mixture of that of the *Enallostègues* with alternating chambers, and of the spiral involution of the *Hélicostègues*. I have already had occasion (§ 111) to point out, that in placing *Heterostegina* in this order, M. D'ORBIGNY has misconceived the structure of that genus; and I shall now have occasion to show that he has fallen into an equally grave error in regard to *Amphistegina*. His definitions of that genus in the 'Foraminifères Fossiles de Vienne' and in the 'Cours Élémentaire de Paléontologie,' are by no means accordant with each other: I take the last as the most authoritative.—"Coquille déprimée à spire embrassante, pourvue de loges alternes d'une coté et non de l'autre, séparées, intérieurement, par des cloisons longitudinales‡."

165. The only inquiry yet made, so far as I am aware, into the minute structure of the shells of this type, is that of Professor W. C. WILLIAMSON, in the memoir§ to which I have already had such frequent occasion to refer. His investigations were made on small specimens of the *Amphistegina gibbosa*, a species which seems to be pretty generally diffused through the tropical ocean, and which has been recently dredged up in great abundance by Mr. McANDREW in the neighbourhood of Teneriffe. Professor WILLIAMSON showed by means of horizontal and vertical sections that *Amphistegina* has the general structure of *Nummulites*, but with this marked difference (as he considered), that the shell is *inequilateral*; the spire making its convolutions obliquely instead of revolving in the same plane (in other words, being *turbinoid* instead of *nautiloid*), and the alar prolongations of the chambers being much larger, and extending further, on one side than on the other. He did not detect any indications of a canal-system in this shell; nor does he mention that division of the septa into two laminæ, one belonging to each of the contiguous chambers, which usually goes along with the other characters of this type.

166. *Organization*.—My own inquiries have been chiefly made upon a set of specimens contained in Mr. CUMING's Philippine Collection, which present this type in a condition of far higher development than it has been elsewhere seen to attain; but I have also had the advantage of examining large numbers of specimens from New Holland, Teneriffe, and various parts of the Indian Ocean, as well as (through the kindness of Mr. W. K. PARKER) numerous fossil specimens from tertiary deposits in different parts of the globe. Of these last, nearly all seem to belong to the same species, *A. gibbosa*, as that described by Professor WILLIAMSON; and it is remarkable, that whilst the average dia-

* Cours Élémentaire de Paléontologie et de Géologie, tom. ii. p. 201.

† Foraminifères Fossiles de Vienne, p. 199.

‡ *Op. cit.* p. 201.

§ "On the Minute Structure of the Calcareous Shells of some Recent Species of Foraminifera," in Transactions of Microscopical Society, First Series, vol. iii. p. 105.

meter of the recent specimens does not elsewhere exceed .065 inch, it attains in some of the Philippine examples as much as .115 inch, thus equalling that of the largest fossil specimens which have come under my notice. The general correctness of Professor WILLIAMSON'S description of this species I can fully confirm; but the comparison of a large number of sections leads me to the unhesitating conclusion that the inequilaterality which has been considered the distinctive character of this type is so inconstant, as to forbid our assigning any value to it as a *generic*, still less as an *ordinal* character. It is often very strongly marked in the fossil *Amphisteginae* of the Vienna and St. Domingo tertiaries; but it is as frequently absent altogether, the shell being perfectly equilateral; and between these two extremes of form we find every intermediate gradation. So it frequently presents itself among the small specimens of *Amphistegina gibbosa* which are common in tropical seas, and I have met with specimens exhibiting as great a want of symmetry as the one of which Professor WILLIAMSON has delineated a section; yet on the whole, I should say, that in the great bulk of the smaller specimens which have passed under my notice, the want of symmetry is but slight; whilst perfect equilaterality both of external form and of internal arrangement not unfrequently occurs; and in those large specimens from the Philippines which present this type in its highest development, there is little or no departure from exact symmetry.—But further, Mr. CUMING'S collection furnishes numerous examples of a remarkable species whose general conformity of structure to *Amphistegina gibbosa* seems to leave no doubt of its near relationship to it (the resemblance of its younger specimens to that specific type being so close as to have led me in the first instance to a belief in the specific identity of the two), and yet the most exact symmetry here presents itself as the rule, departures from it being exceptional, and never proceeding to any considerable extent. It may be considered, therefore, as satisfactorily established, that want of lateral symmetry is not to be held as an essential character of the shells of this genus, although more frequently occurring in it than in *Nummulites* or *Operculina*, to which, as I shall now show, this type bears an extremely close relationship.

167. The species to which I have just referred being hitherto undescribed, I shall designate it *A. Cumingii*. In its young state it is lenticular in form (Plate V. figs. 13, 14), and is only distinguishable from the symmetrical variety of *A. gibbosa* by the smaller number and greater angular distance of the septal bands which radiate from the centre and suddenly turn backwards as they approach the margin. (The radiating portions of these septal bands, as will presently appear, mark the direction of the portions of the septa that intervene between the alar prolongations of the chambers; whilst the recurrent portions mark the direction of the portions of septa that separate the principal cavities of the chambers.) As the *A. Cumingii* advances in life, however, a marked change presents itself in its form, corresponding to that which I have shown to occur in *Heterostegina*, *Peneroplis*, and *Operculina*; for the spire, after about its fourth turn, begins to flatten itself out, and separates itself henceforth from the central portion of the shell, to which it affords a very partial investment (figs. 15–17), the spiral lamina

being still continued over it, but the cavity of the chambers being limited to the peripheral portion of the whorl. Thus the form of the shell is so completely altered, that it would not be recognized as the same if the successive stages of this alteration could not be traced, especially as the characteristic radiating lines are no longer to be seen on the prominent centre. Its diameter undergoes an extraordinary increase; the specimen from which fig. 17 was taken measuring no less than $\cdot 30$ inch by $\cdot 25$ inch.

168. The organization of the interior of the shell, as displayed by sections passing either through the median plane or parallel to it (Plate VI. fig. 6), and by sections taken perpendicularly to the median plane, or vertically (Plate VI. fig. 5), is closely conformable to that of *Operculina*; the chief difference arising out of the extension of the alar prolongations of the chambers of each successive whorl, and of their dividing septa, over the entire surface of the penultimate whorl, except at the centre of the spire, which is commonly occupied by a solid pillar of non-tubular substance, having the general shape of a double cone, whose apex is in the primordial cell, and whose base is on the most prominent part of each surface. As it is very seldom that the successive whorls lie precisely on the same level, a section which traverses the outer convolutions in the median plane will pass above or below the plane of the inner whorls; and it will thus, in traversing the surfaces of these, bring into view the centripetal prolongations of the septa intervening between the alar prolongations of the chambers of the whorls which invest them, as is shown in the central portions of fig. 6. These centripetal prolongations are composed of non-tubular shell-substance, and the portion of the spiral lamina above them is also non-tubular; and thus it is that their position is marked on the exterior by radiating bands, which never rise in *A. Cumingii* into tubercles or ridges, though they sometimes become thus elevated in *A. gibbosa*. These septal bands are, generally speaking, those of the last-formed whorl alone, those of all the preceding whorls being concealed by the investment they have received; but in unsymmetrical specimens (as often happens in *A. gibbosa*, and occasionally in *A. Cumingii*), the alar prolongations do not extend to the centre of the flatter side; so that the septal bands which radiate from the centre are those of the penultimate whorl, and are interrupted as they approach the margin by a new series belonging to the last-formed convolution. The reason of the obliteration of the septal bands on the prominent portion of the shell in advanced specimens of *A. Cumingii* is at once explained when we look at fig. 5; for as the last whorl extends itself peripherally, the alar prolongations of its chambers and therefore of its septa are withdrawn from the central region, and thus no new septal bands will be formed; whilst the continuation of the thick spiral lamina over the whole surface of the penultimate whorl prevents *its* septal bands from displaying themselves. In this respect there is a marked contrast between *A. Cumingii* and *A. gibbosa*; for on the surface of the oldest specimens of the latter we see not only the numerous septal bands of the outer whorl, but indications of those of the penultimate whorl, which show themselves as imperfect or broken lines between the complete radiating bands. This is probably due to that elevation of the septal bands of which mention has

already been made, which causes them to unite at intervals with the spiral lamina that is subsequently formed over them; so that they are marked on its external surface by the non-tubularity of its substance in those parts which immediately overlie them.

169. Allowance being made for the differences arising out of this diversity in their plan of conformation, we find an extraordinary resemblance in the general organization of *Amphistegina Cumingii* to that of the *Operculina* already described, as will be apparent from a comparison of figs. 5, 6, Plate VI. to figs. 8, 10, Plate IV. of *Operculina*. Hence it will be quite unnecessary to enter into any minute description of its structure. In regard to the mode of communication between the chambers,—by one principal orifice in the form of a narrow slit along the inner margin of each septum, with a variable number of secondary apertures irregularly disposed in different parts of the septal plane,—there is an absolute identity with *Operculina*; as there is also in the distribution of the interseptal passages between the two layers which each septum here unmistakeably exhibits. The marginal cord, likewise, exhibits the same peculiarity of organization as in *Operculina*; being channeled out by freely inosculating passages which communicate with those of the interseptal system (Plate VI. fig. 6). This marginal system of passages is even more developed than in *Operculina*; and a study of its distribution will, I think, remove all doubt as to the correctness of my interpretation of the appearances often presented by sections of the marginal cord in that genus (§ 156). There is this difference, however, in the relation of the interseptal to the marginal system of canals in these two types,—that the interseptal canals of *Amphistegina* appear to take their origin directly from some of the large superficial passages of the marginal cord on which the septum abuts, instead of branching from a pair of regular spiral canals as in *Operculina*, no distinct evidence of such canals having here presented itself to me.

170. The relationship of *Amphistegina Cumingii* to those forms of *Nummulites* in which the alar prolongations of the chambers of each whorl are continued, with centripetal prolongations of the septa, over the whole surface of the penultimate whorl, is obviously extremely close; in fact, I can discern no distinguishing character between these two types, except that which is afforded by the tendency of the last turn of the spire of *Amphistegina* to open out, whilst that of *Nummulites* closes in. The double-coned axis of non-tubular substance would seem to be a distinctive character of *Amphistegina*; but I am not inclined to lay much stress upon it, as it presents itself in very different proportions in different individuals.

171. Whilst the type which I have now been describing is thus closely related to the highest because most specialized forms of Foraminiferous organization, it is singular that the smaller species to which I have referred under the name of *A. gibbosa* should present such a marked inferiority of conformation. Its spiral lamina is as minutely tubular as that of its congener; but I have not been able to detect the least trace of a system of interseptal canals; and it is especially to be noticed, that the marginal cord, which exhibits such a high development of the canal-system in *A. Cumingii*, consists in *A. gibbosa* of homogeneous non-tubular shell-substance, without any vestige of canals,

though traversed here and there by a stray tubulus resembling the straight parallel tubuli of the spiral lamina. I am inclined to attribute this difference in part to the smaller scale of the last-named species, which prevents any part of its shell from being far removed from the contact of sarcode; the absence of a canal-system being analogous, under this point of view, to the absence of Haversian canals in laminae of bone which are thin enough to draw their nourishment directly from the nearest vascular surface. The smaller species may thus be considered as—so to speak—a degraded form of the larger; the other differences in its structure being of very subordinate value. These differences, however, serve for its recognition by external characters; for whilst the number of radiating septal bands to be seen in *A. Cumingii* is never much greater than twenty, and in young specimens does not reach half that amount, that of the radiating septal bands in *A. gibbosa* commonly exceeds thirty; besides which, the backward turn which these bands take, when they have passed the margin of the penultimate whorl, is far more striking in the last-named species than in that which I have been specially describing. The granular character of the surface in the neighbourhood of the mouth, which seems due (as Professor WILLIAMSON has pointed out) to a secondary deposit of minute papillae of non-tubular shell-substance, is another distinguishing feature of *A. gibbosa*. To this species I am disposed to refer all the three fossil forms of *Amphistegina* that are described by M. D'ORBIGNY* under the names of *A. Hauerina*, *A. mamillata*, and *A. rugosa*, since these differ no more from each other than do the recent examples of the species,—their chief distinctions being based on the degree of their departure from bilateral symmetry, and on the limitation of the alar prolongations on the flatter side to the marginal portion of the included whorl; characters, which I have shown to possess no constancy, and to be therefore quite valueless for systematic purposes. I have examined several large *Amphisteginae* from the miocene of St. Domingo, which seem to conform to the same type; but in consequence of the alterations brought about by fossilization, I have not been able to determine satisfactorily whether the apparent absence of a canal-system indicates that it had no existence in the recent organism; so that the identification of the species must rest on the less satisfactory characters furnished by the number and direction of the septal bands.

* Foraminifères Fossiles de Vienne, pp. 207–209.

EXPLANATION OF THE PLATES.

PLATE I.

- Fig. 1. Ideal figure of *Dendritina*, partly laid open, so as to show the arrangement of its chambers, the nature of their communications by a single fissure of irregular form (simpler in the earlier whorls, but more complex in the later), the overlapping of the earlier whorls by the alar prolongations of the chambers of the later, and the manner in which the last turn of the spire tends to detach itself from the earlier convolutions.
- Fig. 2. Ideal figure of *Peneroplis*, partly laid open, so as to show the arrangement of its chambers, the nature of their communication by isolated pores, which are arranged in a single row in the later whorls, but frequently form a double row in the earlier, the rapid increase in the breadth of the spire coincident with its very extraordinary flattening in the last convolution, and the very slight degree in which the earlier whorls are covered in by the later.
- Fig. 3. Ideal figure of *Operculina*, laid open to show the details of its structure:—*a a a*, marginal band (the “spicular cord” of Mr. CARTER, the “bourrelet” of MM. D’ARCHIAC and HAIME), divided transversely at *a'*, so as to show the orifices of its canals, the distribution of which is seen at *a''a''* in a tangential section of the band, and at *a'''a'''* in a section through the median plane; *b, b, b*, external surface of the chambers, marked out by the septal bands; *c, c, c*, interior of the chambers of the outer whorl, the alar prolongations of which extend, as shown at *c', c'*, over the surface of the interior whorl, reaching nearly to the centre of the spire; the chambers are separated by the septa *d, d, d*, formed by the union of two layers of shell, one belonging to each chamber, and having spaces between them in which lie the interseptal canals, whose smaller branches are seen irregularly divided in the septa *d', d'*, whilst in the septum *d''* one of the principal trunks is laid open through its whole length; at the approach of each septum to the marginal cord of the preceding whorl is seen the fissure which forms the principal connexion between the chambers; at *e, e* are seen the secondary orifices of communication, and in the same septa is shown the distribution of the interseptal system of canals, branching from *f, f*, the two spiral canals; and at *g, g* are seen the conoidal columns of translucent shell-substance, forming tubercular projections on the surface, which frequently overlies the septa, and are penetrated by branches of the interseptal system of vessels.

PLATE II.

- Fig. 1. Side view of a characteristic specimen of *Peneroplis*:—1 *a*, front view, or septal plane, of the same, showing its single row of isolated pores:—40 diam.
- Fig. 2. Front view of a young specimen, intermediate in its characters between *Peneroplis* and *Dendritina*:—40 diam.
- Fig. 3. Side view of a specimen of *Peneroplis*, of which the later chambers are widely extending themselves laterally:—40 diam.
- Fig. 4. Septal plane of cylindrical prolongation of *Spirolina* (see fig. 11), showing transition between the isolated pores of *Peneroplis* and the coalesced fissures of *Dendritina*:—40 diam.
- Fig. 5. Side view of a specimen of *Peneroplis*, of which the later chambers are extending themselves longitudinally:—40 diam.
- Fig. 6. Front view of a young specimen, intermediate in its characters between *Peneroplis* and *Dendritina*:—40 diam.
- Fig. 7. Side view of a specimen of *Peneroplis*, of which the later chambers are extending themselves longitudinally, and of which the spire is more turgid, and the pores arranged in a double row, as shown at 7 *a*:—40 diam.
- Figs. 8, 9, 10. Front views of young specimens of *Peneroplis*, showing various departures from the normal type in the form of the septal plane and the disposition of the apertures:—40 diam.
- Fig. 11. Side view of *Spirolina*, which bears the like relation to the *Dendritina*-type shown in figs. 12 and 13, that the specimens represented in figs. 5 and 7 bear to the ordinary *Peneroplis*-type; the septal plane of its cylindrical extension, with apertures of intermediate form between those of *Peneroplis* and of *Dendritina*, is shown at 11 *a*:—40 diam.
- Fig. 12. Side view of a typical specimen of *Dendritina*:—at 12 *a* is shown the septal plane and single large dendritic orifice of its last chamber, and at 12 *b* the same, from the preceding whorl; *al*, *al*, alar prolongations of the chambers, which bear a much larger proportion to the principal cavity in the middle than in the later part of the growth:—40 diam.
- Fig. 13. Side view of a specimen of *Dendritina* tending towards the *Spirolina*-type, the last turn of the spire having already detached itself, and the last chamber having completely lost its alar prolongations, as seen at 13 *a*:—40 diam.
- Fig. 14. Front view of a young specimen of *Peneroplis*, presenting a very marked departure from the ordinary type in the form of its septal plane and the disposition of its apertures:—40 diam.
- Fig. 15. Septal plane of a specimen resembling in general form that represented in fig. 13, but showing a want of coalescence of the fissures of which the dendritic orifice is made up: the ridge-and-furrow arrangement of the walls of

the chambers is here prolonged in an unusual manner over the borders of the septal plane:—100 diam.

- Figs. 16, 17, 18, 19. Side and front views of young specimens of *Peneroplis*, showing various departures from the normal type in the form of the septal plane and in the disposition of the apertures:—40 diam. (See also figs. 2, 6, 8, 9, 10, 14.)
- Fig. 20. Portion of the ordinary surface of *Peneroplis* more highly magnified, showing its ridge-and-furrow plication, and its rows of minute punctations:—100 diam.
- Fig. 21. Portion of the ordinary surface of *Dendritina*, showing precisely similar characters:—100 diam.
- Fig. 22. Septal plane of a specimen of *Dendritina*, showing the punctations continued over its surface:—100 diam.
- Fig. 23. Portion of the surface of a specimen of *Peneroplis*, on which the plications had become obsolete, but the punctations are still arranged in rows corresponding to them in distance:—100 diam.
- Fig. 24. Portion of the surface of a specimen of *Peneroplis*, over which the punctations are scattered without definite arrangement:—100 diam.

PLATE III.

- Figs. 1–9. Side and front views of specimens of *Operculina* at various ages, showing differences in the form and proportions of the spire, in the surface-markings, and in the number and arrangement of the tubercles marking the septal bands:—10 diam.
- Fig. 10. Hemispherical cluster of tubercles occupying the umbilicus of the variety of *Operculina* represented in figs. 11, 12:—25 diam.
- Figs. 11, 12. Side and front views of young and mature specimens of peculiar variety of *Operculina*, characterized by the rapid opening-out of the spire, and by the extraordinary development of tubercles, not only along, but also between the septal bands:—10 diam.

PLATE IV.

- Fig. 1. Part of the internal surface of one of the chambers of an *Operculina* that presented large tubercles on its exterior, showing the uniform distribution of the tubuli except along the septal bands, and the comparatively large size of their orifices:—120 diam.
- Fig. 2. Section through the wall of a contiguous chamber of the same, showing the partial deficiency of tubuli in certain spots, with their crowding together in

the neighbourhood of these, and the diminution in the size of the tubuli as they pass towards the outer surface:—120 diam.

Fig. 3. Part of the internal surface from another *Operculina*, presenting smaller and more numerous tubercles on its exterior:—120 diam.

Fig. 4. Section through the wall of a contiguous chamber of the same:—120 diam.

Fig. 5. Section through the median plane of the earlier convolutions of an *Operculina*, showing the spheroidal form of the primordial chamber, the irregular forms of the chambers that immediately succeed it, and one of the spiral canals, which may be traced in the marginal cord almost to the centre of the spire:—75 diam.

Fig. 6. Portion of the external surface of an *Operculina*, of which the tubercles were particularly prominent:—75 diam.

Fig. 7. Vertical section of the inner convolutions of an *Operculina*, which has happened to pass close to the primordial chamber and the one that springs from it, and which shows at *a* the two spiral canals running along their exterior:—100 diam.

Fig. 8. Vertical section of a typical *Operculina*, passing through nearly the centre of the spire; showing at *a, a* the spiral lamina of the second whorl, separated from that of the whorl which it invests by the alar prolongations of the chambers of the latter, which extend nearly to the centre of the spire; *b*, the spiral lamina of the last convolution, thinned away in proportion to its extension, and coalescing with that of the preceding convolution near the margin of the latter, the alar prolongations of the outer chambers being comparatively small; *c*, septum between contiguous chambers, traversed by the interseptal system of canals; *d, d*, marginal cord divided transversely (see figs. 15, 16); *e, e*, fissure of communication between contiguous chambers; *f, f*, spiral canals divided transversely:—40 diam.

Fig. 9. Very thin section of a lamina of the tubular shell-substance of *Operculina*, magnified 120 diameters, cutting the tubuli transversely, and showing a delicate areolation between them; *b*, prismatic appearance of a portion of the same, magnified 250 diameters; *a*, another portion, magnified 250 diameters, showing the comparatively large size of its tubuli close to the internal surface.

Fig. 10. Portion of a section of a typical *Operculina* (see Plate VI. fig. 3), taken through the median plane:—*a, a*, marginal cord traversed by canal-system; *b, b*, walls of the chambers, composed of minutely-tubular substance; *c*, septal bands with their lateral branches, composed of transparent non-tubular shell-substance; *d, d*, one of the spiral canals:—50 diam.

Fig. 11. Portion of a similar section of a tuberculated specimen of *Operculina*, showing the clear spaces left by the absence of tubuli in the spots beneath the tubercles, and the semi-opacity produced by the crowding together of the tubuli elsewhere:—50 diam.

Fig. 12. Portion of a vertical section passing tangentially along the exterior of the inner-

most convolution of a young *Operculina*, and affording a most advantageous display of its canal-system:—*a a*, marginal cord of the inner convolution; *b b*, *b b*, spiral lamina of the outer convolution; *c c*, *c c*, spiral canals; *d d*, *d d*, origins of the interseptal canals from the spiral canals; *e*, *e*, *e*, projection of the septal bands of non-tubular shell-substance into ridges on the surface:—120 diam.

Fig. 13. Portion of the marginal cord, *a a*, of *Operculina*, as seen in a section passing through the median plane, showing the fusiform spaces formed by the inosculation of the canals:—120 diam.

Fig. 14. Another portion, showing more elongated and less regular spaces:—120 diam.

Fig. 15. Transverse section of the marginal cord, *aa*, as seen in a vertical section of *Operculina* (fig. 8), showing its slightly furrowed external surface, the canal-system which traverses its interior, its junction with the ordinary tubular substance, *b b*, of the spiral lamina, and the spiral canals, *c c*:—120 diam.

Fig. 16. A similar section from another specimen, showing deep furrows upon the external surface of the marginal cord:—120 diam.

PLATE V.

Fig. 1. Side view of an *Operculina*, of which a portion of the last whorl has apparently been broken off, and the injury repaired by the continuation of the marginal cord along the line of fracture:—10 diam.

Fig. 2. Portion of the outermost and penultimate convolutions of *Operculina*, laid open by vertical fracture:—*a*, external surface of marginal cord of the convolution inclosed by them; *a'*, *a'*, transverse sections of the marginal cord in the outer convolutions; *b b*, the two marginal canals, whose transverse sections, *b' b'*, are seen in the penultimate convolution; *c*, septum between the contiguous chambers of the penultimate convolution; *c'*, the same in the outer convolution; *d d*, origins of interseptal system of canals; *e*, *e*, fissures of communication between contiguous chambers; *f*, secondary pores; *g g*, thick spiral lamina of tubular substance, formed by the coalescence of that *g' g'* of the last whorl over that of the penultimate whorl:—75 diam.

Fig. 3. Side view of an *Operculina*, of which the last whorl has closed in by a gradual diminution in the size of its chambers:—10 diam..

Figs. 4, 5. External surface of marginal cord, *aa*, showing two modes of disposition of its furrows, in which are seen the orifices of some of the canals; at *a'a'* the cord is seen in transverse section; and at *b b* is shown its junction with the spiral lamina:—75 diam.

Figs. 6 to 8, 10 to 12. Varieties in the superficial characters of *Operculina*:—40 diam.

Fig. 9. Young specimen of the tuberculated variety of *Operculina*, showing an extraordinary development of the central clusters of tubercles:—10 diam.

Figs. 13 to 17. Successive stages of growth of *Amphistegina Cumingii*:—10 diam.

PLATE VI.

- Fig. 1. Section of a portion of the outer whorl of *Operculina*, parallel to the surface, showing a marked irregularity in the disposition of the septa:—*a a*, marginal cord; *b b* one of the spiral canals; *c, c*, septal bands of transparent shell-substance; *d*, tubular shell-substance of spiral lamina forming the walls of the chambers; *e, e*, prolongations of interseptal canals in spiral lamina:—100 diam.
- Fig. 2. Similar section from another specimen, showing an appearance of reticulation in the spiral lamina:—*a a*, marginal cord; *c*, septal band; *d*, one of the interseptal canals communicating with canal-system of marginal cord; *e*, prolongation of interseptal canals in spiral lamina:—100 diam.
- Fig. 3. Section of *Operculina*, traversing its median plane except in its central portion, and showing, especially at *a* and *b*, great irregularities in the disposition of its chambers:—12 diam.
- Fig. 4. Portion of a specimen of *Operculina*, which seems to have undergone fracture at an early age, and to have thenceforth grown in a reversed direction, as will be seen on comparing the direction of the septa in the whorls *a* and *b*; the marginal cord appears to have been continued from *c* to *a* along the line of fracture, and thence to have grown onwards to *b*:—50 diam.
- Fig. 5. Vertical section of *Amphistegina Cumingii*, showing its conformity in all essential respects to the type of *Operculina*, and the differences produced by the smaller size of its chambers in proportion to the thickness of its spiral lamina:—50 diam.
- Fig. 6. Portion of section of *Amphistegina Cumingii*, traversing its outer whorls in the median plane, but passing along the surface of its inner convolutions, so as to bring into view the alar prolongations of the septa in their passage towards the centre, and the occasional inosculation of their canal-systems by loops in that region:—50 diam.

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X. *Researches on the Foraminifera.*

By WILLIAM B. CARPENTER, M.D., F.R.S., F.G.S. &c.

Received May 21,—Read June 14, 1855.

PART I.

CONTAINING GENERAL INTRODUCTION, AND MONOGRAPH OF THE GENUS ORBITOLITES.

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General Introduction.

THE tribe of Animals in regard to certain members of which I propose to offer to the Royal Society the results of my detailed investigations, is almost unknown, save by name, to many well-informed Naturalists; and has only of late received even a small measure of that attention, which its zoological and its geological importance, and its physiological interest, may fairly claim for it. Of the bodies which are now, on account of their general conformity to a certain plan of organization, grouped together under the designation *Foraminifera*, the greater proportion, being spiral multilocular shells, were long associated with *Nautili* and *Ammonites*, and were thus ranked as *Cephalopodous Mollusks* in the classifications of LAMARCK and CUVIER; whilst a few others, bearing more resemblance to certain kinds of corals, seemed naturally to take their places among *Zoophytes*.

Down to a comparatively recent period, scarcely anything has been known beyond the external characters presented by these testaceous or coral-like bodies; their internal organization has been very imperfectly examined; of their intimate structure, no attempt at elucidation has been made; and as to the nature of the animals of which they are the skeletons, the grossest misapprehensions and errors have prevailed. And though many important steps have been recently made in this direction, it is obvious that the methods which have been proposed for the classification of the large number of forms (apparently distinct from each other) that have been collected, described,

and systematized, must be provisional merely. No general foundation has yet been laid for that due appreciation of the *value of characters*, which, in the case of every natural group, must be based on the careful study of its own plan of organization, and of the modifications which this may undergo, and which cannot be safely deduced by analogy, from the study of any other group, however closely related. Far less can any such analogy be truly available, that is drawn from the higher forms of *Mollusca*, and applied to one of those simple types of animal structure, which are now commonly included under the general designation *Protozoa*.

Having been myself convinced, by the careful examination and extensive comparison which I have had the opportunity of making, as to the external characters and internal structure of certain Foraminifera, that neither in regard to the limitation of *species*, nor the association of these into *genera*, nor the grouping of genera into *Families* and *Orders*, is such an analogy to be in the least degree relied upon, I am prepared to show that the whole fabric which has been erected on the basis of it, is utterly insecure; and that every attempt to erect a new classification of the group, without a far more intimate knowledge of the anatomical structure and of the physiological history of the animals composing it, than has yet been sought for, must necessarily be premature and therefore unsound.

If, therefore, notwithstanding the large amount of labour which has been given to the study of this group, we are really as yet only at the very commencement of an exact acquaintance with it, I venture to think that any contribution towards a more intimate knowledge will be welcomed, by all such as consider that systematic arrangements can only be of value, when based on an extensive comparison, not merely of the external forms, but of the internal organization, of the objects to be classified, and when carried out under the guidance of a competent knowledge of their Physiology as living beings. It may be well for me here to state, that the greater part of the results which I purpose to communicate in successive Memoirs, are based upon the examination, not of a limited number of individuals, but of three very extensive suites of specimens, which have been liberally placed at my disposal; the first of these series having been formed from the dredgings of Mr. J. BEETE JUKES on the coast of Australia, into the possession of which I came through the instrumentality of my late friend Professor E. FORBES; the second having been furnished by the collection of Foraminifera made by Mr. HUGH CUMING on the shores of the Philippine Islands, and unreservedly given up to me by that gentleman for the purposes of scientific investigation; and the third being the admirably-arranged series in the possession of my friend Mr. W. K. PARKER, who has for several years been patiently and industriously bringing together from various sources a set of illustrations of this group, which in many departments may be safely pronounced to be quite unique. The importance of the first two of these collections consists, not in the number of *species* they include, for this is comparatively limited; but, on the one hand, in the extraordinary development as to *size* which most of these species present; and on the other,

in the immense aggregation of *individuals* they contain, thus presenting the materials for a most full and complete investigation into that hitherto comparatively neglected subject, *the range of variation within the limits of species*. And the great value of Mr. PARKER's collection lies in his having followed out this inquiry (first suggested to him by myself as the result of my examination of the other two collections) in regard to a much larger number of species, and with materials brought together from a much wider geographical area.

The question has been anxiously considered by me, in what mode I might render these materials most beneficial to the progress of science; and I have come to the conclusion, with the full concurrence of some of the most eminent Naturalists both of this country and of the continent, that I should be doing the most acceptable service, by instituting *a searching investigation into the entire history of such typical forms* of this remarkable group, as should be most fitted to afford satisfactory data for reasoning with regard to the rest;—including in this history, a minute examination of the structure, not only of the testaceous skeletons, but also (where this might be possible) of the soft animal body; a careful survey of the differences of form and aspect presented at different ages, so as to enable the history of any individual to be traced from its origin to its decline; a comparison of the variations both in external form and internal structure, presented by different specimens, sufficiently extensive to admit of the determination how far these variations are of value as *specific* characters, or how far they must be accounted merely individual departures from the ordinary type; a like comparison between the series collected in different geographical areas, so as to afford a safe basis for the determination of the range of the species, and the amount of its variation in *space*; and a further extension of this comparison to similar series obtained from the various geological strata in which the like forms may present themselves, so as to ascertain the range of the species and the extent of its variation in *time*. And if I should seem, in following out this plan, to have erred on the side of *over-minuteness*, I trust to receive credit for the real motive which has induced me to bestow so much elaboration on the work I have undertaken,—namely, the desire to furnish a thoroughly secure foundation, on the basis of which the labours of others, in whatever department of the inquiry, may be safely utilized in building up a complete and harmonious superstructure.

It had been my intention to preface the account of my own Researches, with a summary of the History of our knowledge of the group generally. This subject, however, has been so fully and satisfactorily worked out, in two of the most recent treatises on the subject,—that of MM. D'ARCHIAC and HAIME on Nummulites*, and that of Professor SCHULTZE on certain forms of existing Foraminifera†, the latter

* See their "Monographie des Nummulites," forming part of their "Description des Animaux Fossiles du Groupe Nummulitique de l'Inde," Paris, 1853.

† Über den Organismus der Polythalamien (Foraminiferen) nebst Bemerkungen über die Rhizopoden im allgemeinen. Leipzig, 1854.

containing a most complete Bibliography,—that I do not feel it necessary to offer more than a mere sketch, marking out the principal periods into which this History may be divided.

The *first* period includes all the observations made and published in regard to these minute polythalamous bodies, from the time when they first attracted attention, down to the date (1825) when M. D'ORBIGNY grouped them together, as constituting a distinct type of structure. The observers whose labours during this period did most to prepare the way for their successors, were SOLDANI*, FICHEL and MOLL†, MONTAGUE‡, and DENYS DE MONTFORT§.

The *second* period commences with the presentation to the Académie des Sciences, in 1825, of M. D'ORBIGNY's "Tableau Méthodique de la Classe des Cephalopodes;" in which he first separated these chambered shells, under the title of *Foraminifera*, from the *Siphonifera*; still retaining the former, however, like the latter, as an order of Cephalopods. A large number of new forms were added by M. D'ORBIGNY to the list of those previously known; and he laid the basis of the classification which he has since more fully elaborated. No suspicion appears then to have crossed his mind, that the place of these bodies might be amongst the lowest, instead of among the highest, of the Invertebrata; and if his determination of their Molluscous nature was based on any actual observations of these animals in their living state, it is certain that such observations must have been of the most superficial character.

The *third* period, with which our knowledge of the true nature of the Foraminifera really commenced, is inaugurated by the discovery, first announced by M. DUJARDIN to the Académie des Sciences in June 1835, of the *Rhizopodous* nature of the animal of certain simple forms of Foraminifera, and, by inference, therefore, of that of the group generally; and in the following year he demonstrated the essential identity between the *Amæba* and other simple freshwater Rhizopods (described by Professor EHRENBURG among the Polygastric Animalcules) and the *Cristellaria* and similar composite forms of marine Foraminifera, which had been previously ranked among Cephalopod Mollusks||.

The general results of M. DUJARDIN's observations was, that the animal body consists, in every instance, of a mass of *sarcode*,—a gelatinous, somewhat granular substance, not enclosed in a distinct membrane, and capable of extending itself into threads of extreme tenuity; that there is neither mouth nor digestive cavity, but that alimentary particles, received into the very substance of the body, are gradually incorporated with it; and that both the introduction of these particles, and the move-

* Saggio orittographico, ovvero osservazioni sopra la terra Nautiliche e Ammonitiche della Toscana. Sienne, 1780.

† Testacea microscopica aliaque minuta ex generibus Argonauta et Nautilus, ad naturam picta et descripta. Vindob. 1798, 1803.

‡ Testacea Britannica, or Natural History of British Shells. London, 1803–1808.

§ Conchyologie Systematique. Paris, 1808.

|| See Annales des Sciences Naturelles, 2 sér., Zool. tom. iii. p. 312.

ments of locomotion, are effected by means of pseudopodial prolongations of the *sarcode*, put forth through apertures in the shell, and capable, when retracted again, of coalescing with the general mass. In the case of the composite forms, he considered the entire animal to be made up of a series of segments which are essentially repetitions one of another, each possessing an independent vitality of its own*. These statements have been subsequently confirmed and rendered more precise by several other observers; their truth has been admitted by M. D'ORBIGNY, who, in all his recent works, has described the animals of the Foraminifera in accordance with them (though without any allusion to the fact, that he had himself previously laboured under an entire misconception of their character, and without any mention of the discoverer of their real nature); and they have been recently placed beyond all doubt, by the admirable researches of Professor SCHULTZE (*Op. cit.*).

It cannot but seem surprising, that notwithstanding the light thrown upon this inquiry by M. DUJARDIN in 1835, Professor EHRENBURG should in 1838 have announced to the Academy at Berlin, his conclusion, professedly based on observations of certain forms of these animals in their living state, that their true place in the animal kingdom is among the *Bryozoa*†. He described them as possessing a distinct alimentary canal, which extends from segment to segment; this, however, instead of being single, as in *Nonionina*, may (he tells us) be multiple, as in *Geoponus*; so that we must regard each segment of the latter, however apparently resembling the simple segment of the former, as in reality composed of several adhering bodies. In one instance (he affirms) he found the mouth surrounded by a plumose sensory and prehensile apparatus, like that of the *Flustræ* and *Halcyonellæ* (see *ultra*, ¶ 4.), but generally speaking he admits that this is altogether wanting, the mouth being a simple aperture. He saw minute extensile tentacula proceeding from all parts of the sieve-like shell, as described by DUJARDIN, and admitted their resemblance to the pseudopodia of *Diffugia*, &c., but he remarks, "the rest of their organization, which DUJARDIN has overlooked, removes them from the Infusoria, quite as far as from a chaotic primitive substance." Besides the alimentary canal, Professor EHRENBURG describes a yellowish-brown granular mass as accompanying and sometimes surrounding it up to the last of the spirals; this he considers as an ovary.

As I have reason to believe that Professor EHRENBURG stands quite alone in this opinion (if, indeed, he still maintains it), and that the real nature of the segments of sarcode and of their connecting threads, is no longer a matter of question among those Naturalists who have given their unprejudiced attention to the subject, I do not think it requisite to occupy either time or space with any further discussion of the question, and therefore dismiss it with this brief mention.

* See his "Histoire Naturelle des Infusoires," Paris, 1841; and Art. *Rhizopodes* in Dict. Univ. d'Hist. Nat., tom. xi. p. 115, Paris, 1848.

† See his Memoirs in the Transactions of the Royal Academy of Berlin, for 1839 and 1840; also TAYLOR'S Scientific Memoirs, vol. iii. p. 319.

It may, however, be well here to remark *in limine*, that it obviously makes a most essential difference in our appreciation of the value of the characters afforded by the form, position, and multiplication of the apertures of communication between the chambers of the shell, whether we regard these as giving passage to an organ of such fundamental importance as an alimentary canal, or whether they merely serve for the connexion of the different segments by *stolons* of sarcode. For variations, which in the former case must be regarded as indicative of such essential differences, both in structure and function, as would rightly characterize distinct genera or even distinct families, may easily be admitted, on the latter view, to be of such comparatively trivial moment, as to rank no higher than specific characters, or perhaps even to be matters of individual difference. That the latter is the true view of the case, I have become completely assured in the course of my researches; and I shall hereafter be able to adduce some curious illustrations of it.

Turning now to the more recent History of research, I shall briefly notice those investigations which have done most towards the advance of our knowledge of the organization and physiology of the Foraminifera; the mere collection, description, and systematic arrangement of new forms, without any such advance, being no more a feature of progress, than is the building-up of an edifice, which must necessarily fall, through the insecurity of its foundation, before it shall have been completed.

The first series of these, made by Professor W. C. WILLIAMSON of Manchester, upon *Polystomella crista**, not only established several important facts in regard to its minute structure, but may be regarded as having furnished the starting-point for all future investigations of a like kind. Among these facts were several that became of essential value to myself, in the inquiry on which I was engaged at the same time, in regard to the structure of *Nummulites*; and served to confirm the inferences which I had deduced from the other features of that important type, as to its participation in the characters of the Foraminifera generally. In the course of that inquiry I made the discovery†, not only of a most elaborate and previously-unsuspected structure in the shell itself, but also of a system of interseptal canals, which established a communication between the inner segments and the external surface, much more direct than that which they possess through the series of segments which form the outer turns of the spire. The existence of this system of canals has been verified, not merely in *Nummulites* by MM. D'ARCHIAC and HAIME (*Op. cit.*), but also in several recent types; thus Professor WILLIAMSON has detected it in *Amphistegina* and *Nonionina*‡, and more recently in *Faujasina*§ (which furnishes one of the most remarkable examples of it); whilst Mr. CARTER of Bombay has discovered it in *Operculina*||. My own inquiries, which have been carried-on with scarcely an intermission, from the time of my first

* Transactions of the Microscopical Society, 1st ser. vol. ii. p. 159.

† Quarterly Journal of the Geological Society of London, vol. vi. February 1850, p. 22.

‡ Transactions of the Microscopical Society, 1st series, vol. iii. p. 105.

§ Ibid. 2nd series, vol. i. p. 87.

|| Annals of Natural History, 2nd series, vol. x. p. 161.

discovery of this remarkable point of structure, have been specially directed to the determination of the extent to which it presents itself in the different sections of the group, and of its value as a distinctive character; and I think that I shall be able to show that it is a feature of the utmost importance, the presence of which marks an elevation of type, and its absence a corresponding degradation.

It is much to be regretted, that the recent investigations of Professor SCHULTZE should have been so entirely restricted to the structure of the *animal*, which can only be ascertained in a comparatively small number of cases; and that he should have failed so completely in the determination of the internal organization of the *shell**, which in a large proportion of instances is the only guide we possess to the nature of the being which formed it. The new classification which he proposes, whilst in many respects an improvement upon that of M. D'ORBIGNY, is essentially vitiated by this defect; and being in itself, therefore, just as provisional as that for which it is proposed as a substitute, can scarcely be expected to supersede it. My own researches I offer simply as *materials* to serve as a *basis for classification*; feeling assured that the time is not yet come, in which the superstructure can be erected with any prospect of permanent stability.

I shall commence with a minute analysis of one of the lowest types, *Orbitolites*; and propose to show hereafter, that *Orbiculina* and *Alveolina*, though ranked in a different order by M. D'ORBIGNY, are in reality closely allied to it; whilst a new genus (*Cycloclypeus*), which, in M. D'ORBIGNY's arrangement, would rank close to *Orbitolites*, is physiologically separated from it by the widest possible interval.

Genus ORBITOLITES.

I. *History.*

1. The Orbitolite has been chiefly known, until very recently, rather by its fossil, than by its existing forms. The abundant occurrence of its disks in the *Calcaire grossier* of the Paris basin, early attracted attention; but *Orbitolites* were not clearly distinguished by the older observers from *Nummulites*, and their true nature was entirely misunderstood. Thus we find them designated, often in association with *Nummulites*, under the title of *Umbilicus marinus* by PLANCUS (BIANCHI), who

* Professor SCHULTZE states (*op. cit.* p. 15) his inability to discover the canal-system above described; and as there is no question of his competency and accuracy as an observer, I can only impute his failure to his ignorance of the proper mode of preparing thin sections of these minute shells;—which consists in cementing them to a slip of glass by hardened Canada-balsam; grinding them down as far as may be desirable on one side; then loosening them by heat and turning them over, so that the flattened surface shall now be attached; and finally grinding down the other side, until the requisite degree of thinness shall have been attained; after which a drop of liquid Canada-balsam is laid upon the specimen, gentle warmth applied, and a cover of thin glass put on. Having myself thus prepared sections of *Faujasina*, which answer in every respect to the figures accompanying Professor WILLIAMSON's memoir above cited, I can bear the most explicit testimony to their exactness.

imagined them to be opercula of Ammonites*; of *Porpitæ nummulares* by STOBÆUS† and BROMELL‡, who seem to have regarded them as representing the disks of the existing Porpitæ; of *Helicites* and *Operculites* by GUETTARD§, who considered them as opercula of Gasteropods; of *Discolithes* by FORTIS||, who supposed them to be skeletons of mollusks; of *Madreporites* by DELUC, and of *Milleporites* by FAUJAS DE ST. FOND, whose idea of their nature is sufficiently indicated by the names they assigned to them.

2. The genus *Orbitolites* seems first to have been erected, and distinctly separated from Nummulite, by LAMARCK, in the first edition of his 'Animaux sans Vertèbres,' its type being the *O. complanata* of the Paris basin. The following is his definition of the genus, which he ranks between Lunulites and Millepora, among his "Polypiers Foraminés":—"Polypiarium lapideum, liberum, orbiculare, planum seu concavum, utrinque vel margine porosum, nummulitem referens. Pori minimi, admodum dispositi, conferti, interdum vix conspicui." These bodies, he says, are distinguished from Nummulites by the opening of their marginal pores, and by the absence of spiral arrangement in their minute chambers or cells. In his second edition (1816), he altered the name from *Orbitolites* to *Orbulites*; but the latter designation having been previously employed in Malacology, the first appellation has been restored by M. MILNE-EDWARDS in his posthumous edition of LAMARCK's work. Under one of the designations, *Orbitolites* or *Orbulites*, the genus has been recognized by SCHWEIGER¶, BRONGNIART and CUVIER**, LAMOUREUX††, DESLONGCHAMPS‡‡, DEFRANCE§§, BLAINVILLE|||, BRÖNN¶¶, GOLDFUSS***, MICHELIN†††, PICTET††††, and DUJARDIN§§§; none of whom, however, have either given any account of its internal structure, or made any essential modification in the definition of the genus, which they all left in the place which LAMARCK had assigned to it.

3. The existence of more than one recent species of the same type was indicated or expressly mentioned by several of the foregoing writers. Thus FORTIS tells us

* De Conchis minus notis, 1739 (*fide* D'ARCHIAC et HAIME), and App. Phytol. F. Coll. 1764 (*fide* RUPERT JONES).

† Dissertatio epist. ad W. GROTHAUS de nummulo Brattenburgensi, 1732; Opera petrefactorum, 1752; Opusculis, p. 6 (*fide* D'ARCHIAC et HAIME).

‡ De Nummulo Brattenburgico, in Act. Litt. Suec., vol. ii. p. 50 (*fide* D'ARCHIAC et HAIME).

§ Mémoires sur différentes parties des Sciences et des Arts, 1770.

|| Mémoires pour servir à l'Hist. Nat. de l'Italie, 1816, vol. ii.; and Journal de Physique, 1801, vol. lii. p. 106.

¶ Beobacht. auf Naturg. (1819), pl. 6.

** Ossements Fossiles (1822), vol. ii. pt. 2. p. 270.

†† Expos. Méthod. des gen. des Polypiers (1821), p. 44. pl. 73.

‡‡ Encyclop. Méthod., Zooph. (1824), p. 584.

§§ Dictionn. des Sci. Nat. (1825), vol. xxxvi. pp. 294, 295.

||| Manuel d'Actinologie (1830), p. 411. pl. 72.

¶¶ Lethæa Geognostica (1836-37), pl. 35.

*** Petrefacten (1826-33), vol. i. p. 41. pl. 12.

††† Icon. Zoophyt. (1845), p. 167. pl. 46.

†††† Traité Élément. de Paléontologie (1844-45), tom. iv.

§§§ Dict. Univ. d'Hist. Nat., tome ix. (1847), p. 162.

(*op. cit.*), on the authority of a voyager in the Indian seas, that living Discolites have been found there; and as there are no existing Nummulites, this statement probably refers to an Orbitolite. LAMARCK, in his second edition, describes, under the title of *O. marginalis*, a small form of Orbitolite, only 2 millims. (.08 inch) in diameter, found upon fuci, corallines, &c. in the European seas; this he speaks of as the only living example of the genus then known, and he defines it as *O. utrinque plana, margine poroso*. Besides this species, however, DEFRANCE (*loc. cit.*) mentions another, more closely resembling the *O. complanata* of the Paris basin, as existing on the shores of New Holland; and this seems the first clear indication of the body (afterwards found by MM. QUOY and GAIMARD in that locality, and erected by them into the distinct genus *Marginopora*), the structure of which constitutes the chief subject of my present communication. Both these existing forms are described by BLAINVILLE (*op. cit.*), the first from actual observation, the second on the information of MM. QUOY and GAIMARD, to the manuscript of whose 'Voyage de l'Astrolabe' (then unpublished) he refers as his authority. It is singular, however, that after an attentive search through the published "Zoology" of that work, I have not been able to find, either in the text or in the plates, any mention of *Marginopora* or of *Orbitolites*. Of the *Orbitolites marginalis*, M. DE BLAINVILLE says (*op. cit.* p. 412),—"Nous l'avons étudiée avec soin; et nous sommes presque convaincu que ces petits corps crétacés ne sont pas de véritables polypiers; mais bien quelque pièce intérieure, qui s'accroît par la circonférence. Il est en effet évident, qu'il n'y a pas de cellules proprement dites, à moins qu'on ne veuille regarder comme telles les deux plans de locules qui occupent le bord, et qui n'offrent rien déterminé. Tout le reste est couvert d'une légère croûte crétacée, qui ferme les anciens pores." I think it obvious, from this description, that it was founded on specimens resembling that in Plate VII. fig. 8, in which the marginal row of cells has been laid open above and below by accidental abrasion; and that the true marginal pores, opening *between* the protuberances formed by the cells (Plate V. fig. 1), were overlooked. The genus *Marginopora*, placed by M. DE BLAINVILLE in immediate sequence to Orbitolites, is thus characterized (*loc. cit.*):—"Animaux inconnus, contenus dans les cellules poriformes, excessivement petites, rondes, serrées, éparses dans les sinuosités, très fines et tortueuses, qui guillochent la circonférence d'un polypier calcaire, libre, un peu irrégulier, discoïde, concave ou concentriquement strié en dessus comme en dessous, et plus épais sur les bords." The two surfaces, M. DE BLAINVILLE further tells us, only exhibit striæ of increase, without any trace of pores; but the turned-up edge is entirely riddled with very fine rounded pores, which are situated in the sinuities of a very close but shallow engine-turning (guillochis). And when one of its surfaces is rubbed away, the disk is found to be formed of concentric canals, separated by partitions, and themselves divided into cells, thus recalling in some degree the structure of Orbitolites. Having myself had the opportunity of inspecting, by the kindness of M. VALENCIENNES, the specimens of *Marginopora* on which the foregoing

description was founded (these being now contained in the 'Musée d'Histoire Naturelle'), I have been able to compare them with my own; and finding that they correspond with the peculiar type of the latter, which is represented in Plate V. figs. 2 & 3, I have no hesitation in saying that in this description also the *true marginal pores*, represented in Plate V. fig. 6, have been overlooked; and that what are described by M. DE BLAINVILLE as pores, are nothing else than incomplete cells left open in the frilled edges which bound the marginal furrow above and below (see ¶ 25). A similar description has since been given by M. DUJARDIN *, who does not hesitate to regard the disk as a polypary, and to speak of the animals whereby it is formed, as polypes.

4. In the Memoir of Professor EHRENBERG already referred to, we find the genus *Orbitolites* for the first time associated with true Foraminifera, as a member of his class BRYOZOA, order *Polythalamia*, suborder *Polysomatia*, family *Asterodiscina*, wherein it is placed next to *Lunulites*, which undoubtedly belongs to the group of Bryozoa (Pölyzoa) as now restricted. This family he characterizes as follows:—"Gémis in eodem plano prodeuntibus, polypiarum plana, discoidea, formantibus, osculis distinctis post mortem apertis;" and it is by the last of these characters that he distinguishes it from the family *Soritidæ*, consisting of the two genera *Sorites* and *Amphisorus*, of which he says,—"*Osculis contracto corpore, tanquam operculo duro clausis.*" If any faith whatever is to be placed in Professor EHRENBERG's figures and descriptions, his *Sorites* is nothing else than LAMARCK's *Orbulites marginalis*; whilst his *Amphisorus*, which differs from *Sorites* merely in having two layers of cells instead of one, is (as I shall hereafter show) the same type in a higher grade of development. I cannot conceal my astonishment, however, that so practised a microscopic observer should have entirely overlooked the real marginal openings between the cells; still more, that he should have described the entirely-closed cells of the surface as covered in by a moveable operculum, which merely shuts their orifices when the animal is contracted; and further, that, mistaking an accidental for a normal opening of some of the cells, he should have ventured to figure an eight-armed Bryozoon as issuing forth from one of them,—a phenomenon which, I do not hesitate to say, is entirely irreconcilable with our existing knowledge of the organization of the animal of which these disks are the skeletons.

5. The earlier publications of M. D'ORBIGNY on the subject of the Foraminifera do not include any notice of this genus; and neither in the systematic arrangement which he put forth in his article in the 'Dict. Univ. d'Hist. Nat.' tome v. (1844), nor in that contained in his 'Foram. Foss. de Vienne' (1846), is the order *Cyclostègues* recognized, which makes its appearance for the first time in his 'Cours Élémentaire de Paléontologie,' tome ii. (1852), between the Monostègues and the Helicostègues, with the following definition (p. 192):—"Animal composé de segments nombreux, placés en lignes circulaires. Coquille discoïdale, composée de loges, concentriques,

* Dict. Univ. d'Hist. Nat., tome vii. p. 777.

simples ou multiples; point de spirale." Under this order are ranged the genera *Cyclolina* (D'ORB. 1839), *Orbitolites* (LAMARCK, 1801, and *Marginopora*, QUOY et GAIMARD, 1836), *Orbitolina* (D'ORB. 1847), and *Orbitoides* (D'ORB. 1847). As I shall have occasion to show that the first three of these genera cannot be separated from each other by any valid distinctions, and that the greater number of the species ranked under them by M. D'ORBIGNY (see his 'Prodrome de Paléontologie Stratigraphique') really belong to the same specific type, I must here cite the generic characters which he assigns to them:—" *Cyclolina*, Coquille discoïdale, chaque loge percée de nombreux pores, faisant un cercle entier autour des autres. L'espèce connue est de l'étage cénomanien.—*Orbitolites*, Coquille discoïdale, plane, égale, et encroûtée des deux côtés, pourvue de lignes concentriques. Loges nombreuses, par lignes irrégulières, transverses, visibles seulement au pourtour. Nous connaissons deux espèces; les premières, de l'étage suessonien; le maximum, dans les mers actuelles.—*Orbitolina*, Ce sont des Orbitolites à côtés inégaux; l'un, convexe, encroûté, à lignes concentriques; l'autre, concave, non encroûté, montrant des loges nombreuses, par lignes obliques sur le côté, au pourtour. Nous connaissons de ce genre perdu six espèces; les premières, de l'étage albien; les dernières, de l'étage senonien."

6. The first approach towards a more accurate knowledge of the real nature of the Orbitolite, through an examination of its internal structure, was made (I believe) by myself, in my Memoir "On the Microscopic Structure of *Nummulina*, *Orbitolites*, and *Orbitoides*," read before the Geological Society of London in November 1849, and published in its Quarterly Journal for February 1850. The place assigned to this genus in the system of M. D'ORBIGNY not having been at that time made public, and all other zoologists and palæontologists having ranked it in close approximation to *Lunulites* and other Polyparies of the Bryozoic (Polyzoic) kind, I entered upon the examination without the least suspicion that this organism was to be regarded in any other light; and that I was not undeceived in the course of it, may be attributed to the small number of specimens then placed at my disposal for the inquiry by my late friend Professor E. FORBES, and to the circumstance that these specimens were of the type that presents most resemblance to that of a Bryozoic polypary, and were all deficient in the central nucleus, which is the portion most indicative of their Foraminiferous nature. Nevertheless, the marked dissimilarity in structure which I found to exist between the disk of Orbitolite and the polypary of Lunulite or of any other undoubted members of the Bryozoic group, made me even then express myself doubtfully as to its title to be associated with them. In this Memoir, published two years previously to M. D'ORBIGNY's first announcement of the fact, I showed that the genus *Marginopora* must be abolished, since its sole representative is so closely allied in structure to the *Orbitolite* of the Paris basin, that no doubt of their generic identity can be entertained; the existing *M. vertebralis*, in fact, being only specifically distinguishable from the fossil *O. complanata*, by a difference in the form of its super-

ficial cells,—a character to which the more extended knowledge of this type has made it clear to me that not the slightest value is to be attached (see Sect. IV.). I showed that in one as in the other, the cells are normally closed-in over the whole surface; that the cells of the two surfaces are separated from each other by an intervening stratum, traversed by a set of round cells or passages of its own, with which each superficial cell communicates by two small apertures; and that the only real external orifices are the minute pores at the margin of the disk, which communicate, not directly with the cells of the superficial layers, but with the passages of the intermediate stratum.

7. A very important addition to this limited measure of information was made not long afterwards by Professor WILLIAMSON of Manchester, who, in a paper read before the Microscopical Society of London, June 12, 1850, and published in its Transactions (First Series, vol. iii. March 1851), first gave a minute description of the small recent *Orbitolites marginalis* of LAMARCK (which, however, he designated as *O. complanata*); contrasted it with that of a large recent Orbitolite from Tonga, shown by his description to be identical with the *Marginopora* of QUOY and GAIMARD, to my previous account of which he added some important particulars; and compared both with the well-known *Orbiculina adunca* of the Bahamas. His investigations led him to the conclusion, that these three forms should rank under the same genus *Orbiculina*; their most important structural features being common to all, whilst their differences are only of specific value. His *Orbiculina complanata* (really *Orbitolites marginalis*) he characterizes by its spiral commencement, and by its possessing only one layer of cells; his *O. Tonga* (*Marginopora*) he characterizes by its cyclical commencement, and by its possession of two superficial layers of cells, with an intermediate stratum, as I had previously pointed out; whilst the *O. adunca* he shows to commence on the spiral type, and to carry it on much further than his *O. complanata*, but finally to assume the cyclical, and then to correspond very closely with his *O. Tonga*. The title of the genus *Orbitolites* to a place in the group of Foraminifera, in near proximity to, if not in union with, *Orbiculina* (which had been ranked as such by M. D'ORBIGNY from an early period of his investigations), and the entire absence of any ground for ranking it among the Bryozoa (Polyzoa), were clearly established by Professor WILLIAMSON in this valuable memoir; and though I shall hereafter have occasion to show that some of his conclusions were erroneous, yet I regard them as fully justified at the time, by the information which the materials at his command afforded; my own means of correcting them being only supplied by the comparison I have been enabled to institute through a much wider range of specimens. And it is with great satisfaction that I am enabled to add, that, after a careful inspection of my preparations and drawings, Professor WILLIAMSON authorises me to express his full accordance in the results which I shall now proceed to detail.

8. As the value of such details cannot be truly estimated without some knowledge of the range of the observations from which they are derived, I think it right to state

in *limine* what are the opportunities I have enjoyed. The first and most important of these was afforded me by the great abundance of Orbitolites of various sizes, from o to , besides a vast multitude of fragments, in Mr. JUKES's Australian

dredgings; besides which, Professor E. FORBES kindly put into my hands several specimens which had been taken in their living state by Mr. JUKES, from the marine plants to which they were attached. All these I have carefully examined under the microscope, so as to be able to make an exact determination of their external characters; and of a large proportion I have made microscopic sections in various directions, that I might assure myself of every particular respecting their internal structure. When I had nearly exhausted these sources of information, I found a new and most interesting series of specimens in Mr. CUMING's Philippine collection; and by the study of these I was enabled to test the validity of the conclusions, to which I had been led by the examination of the Australian forms. The kindness of various friends has further enabled me to examine specimens obtained from other widely-distant localities, such as different parts of the Indian, Southern, and Pacific Oceans, the Red Sea and the Ægean. And finally, I have had placed at my disposal, through the instrumentality of Professor QUEKETT, several Orbitolites of various sizes and ages, obtained on the shores of the Feejee Islands by the late Sir EVERARD HOME, in which the animal substance occupying the interior had been preserved by the immersion of the fresh specimens in spirits.

9. Besides the existing forms, I have examined a large number of specimens of *Fossil Orbitolites*, both from the Paris basin and from other localities; and I have instituted the same kind of minute comparison of these specimens, both with each other and with the recent types, that I had previously made among the diversified forms of the latter.

10. Postponing, until adequate means shall have been supplied by the details of their organization, to be presently given, the inquiry into the relationship of these different forms (Sect. VI.), we shall proceed in the first place to consider the general plan of organization of the Orbitolite, and then to study the variations to which this is subject.

II. *General Plan of Organization.*

11. In studying the organization of the Orbitolite, we shall have recourse, on the one hand, to the structural characters presented by the *Animal*, as displayed by the fleshy residuum left after the decalcification of specimens in which it has been preserved; and on the other, to the structural characters presented by the *Shell*, of which some are visible on its surface, and without any preparation, whilst others may be seen in thin specimens by transmitted light, but of which the greater part can only be brought into view by thin sections taken in various directions, especially *horizontal* or parallel to the surface, and *vertical* or perpendicular to the surface.

12. The state of preservation of the animal body of the Orbitolite, in the spirit-specimens which I have examined, is so complete, as to leave me no room for hesitation in affirming that it corresponds in every particular with the 'sarcode' which we have seen to have been first described by M. DUJARDIN, as constituting the bodies of many of the lowest organisms, and especially as the component of those of the Rhizopoda. A small portion of this substance, sufficiently magnified to exhibit its nearly homogeneous jelly-like aspect, with minute granules and somewhat larger particles scattered through it, is shown in Plate IV. fig. 2. Although it is so far decolorized in spirit-specimens as to present only a brownish hue, yet as specimens that have been gathered fresh and have been then dried, possess a reddish aspect, and as this is not due to the shelly substance, it may be presumed that the sarcode of the living Orbitolite has the same bright red colour as that of *Rotalia* and many other Foraminifera. The entire animal body (Plate IV. fig. 1) is composed of a numerous assemblage of minute segments, arranged at tolerably regular intervals in concentric zones around a sort of central 'nucleus;' the segments composing each zone being united with each other by a continuous annular 'stolon' or band of sarcode, and being connected with those of the adjoining zones by peduncles of the same material. I have not met with the least indication that the sarcode is contained within any *proper membrane*; and the absence of any such indication, notwithstanding the various manipulations to which I have subjected its segments, may be taken, I think, as strong negative evidence that it has no more existence in this animal, than it has in the species of Foraminifera which have been so well studied by M. DUJARDIN and Professor SCHULTZE. Nor is there the slightest trace of distinct *organs*, either in the mass of sarcode which forms the central nucleus, or in that which constitutes each one of the surrounding segments; and he would, I think, be a mere speculator, who should maintain the presence of a digestive cavity in any of these parts, or the existence of an intestinal canal in the peduncular threads which connect them together. The homogeneity of the component substance of the central nucleus, and of the entire assemblage of multiple segments, seems, indeed, to be conclusively established by the following facts:—In all the spirit-specimens which I have examined, the cavities of the outer zones are completely void, whilst those of the nucleus and of the inner zones are quite filled with their animal contents. This drawing-together of the soft body towards the centre, is evidenced also in many of the larger specimens which have been dried when collected in the living state, by the limitation of the red colour that indicates the presence of the sarcode, to the inner portion of the disk. In both cases it may be presumed that the animal matter has shrunk together, in the former through the corrugating action of the spirit, in the latter through desiccation. Now if the polypidom of a zoophyte be similarly treated, there is no such drawing together of the entire body, but each cell is found to contain the shrunk contents of its own polype-segment; and this difference seems to me to indicate a complete dissimilarity in the characters of the two organisms. For it is obvious that the sub-

stance of the peripheral segments of the Orbitolite-body can only be brought together towards the centre, through being completely unattached to the walls of the cavities which it occupies, and through having a form so alterable, as to be capable of being drawn in threads through the narrow connecting passages, and of then coalescing together again so perfectly, that the masses they form do not present the least trace of having been thus spun out. There is no known kind of animal texture, except *sarcode*, that is susceptible of this kind of alteration; and the evidence of it which I have adduced seems to me extremely valuable, not only as establishing the general nature of the animal body of the Orbitolite, but also as fully justifying the assumption, that, in the living state, the sarcode is projected in pseudopodia through the marginal apertures, and that alimentary particles are introduced by their instrumentality, as in other Foraminifera.

13. Turning from the animal body to the calcareous disks which enclose it, we find that, whether large or small, these are almost invariably circular, or nearly so; that they are usually nearly flat, any difference in thickness being generally in favour of the marginal portion; and that if, as sometimes happens, there is a slight central projection, this is formed by the nucleus alone. By these characters we may distinguish *Orbitolites* from *Orbiculina*; for although the discoidal forms of the latter so strongly resemble Orbitolites, that by the structure and arrangement of their marginal portion they could not be distinguished, yet they may always be discriminated by the knobby protuberance of their centre, which is occasioned by the mutual investment of the earlier whorls of the spiral in which they commence. The same entire absence, or very small size, of the central elevation, together with the uniformity or even slight increase of thickness towards the circumference, also helps us to separate *Orbitolites* from *Orbitoides*; the centre of the latter being always considerably elevated, and the thickness of its disk ordinarily diminishing gradually towards its margin*. Around the 'nucleus' which occupies the centre of the disk (Plate V. figs. 1, 6), are seen an indeterminate number of concentric zones of cells (*c, c, c*), the shape of which differs in different individuals (see Sect. IV.); these, although completely closed (unless laid open by abrasion), have their form

* I wish this statement to be understood with reference to the genus *Orbitoides*, as characterized by the structure which I have shown it to possess (Quart. Journ. of Geol. Soc., Feb. 1850), and not to the genus as defined by M. D'ORBIGNY (Cours Élémentaire de Paléontologie, tome ii. p. 194), who, notwithstanding that he has shown himself to be acquainted with my Memoir (by copying from it a figure of Nummulite), has not profited in any degree by my investigations, but has left the generic characters of *Orbitolites*, *Orbitolina* and *Orbitoides* in the state in which they might have been, and probably were, before that Memoir was published. The true distinction, however, has been fully recognized by M. D'ARCHIAC, who, in his 'Description des Animaux Fossiles du Groupe Nummulitique de l'Inde,' p. 349, has designated as *Orbitoides dispansa* and *Orbitoides Fortisi*, the bodies which, in the account of them he had previously given in the 'Mém. Soc. Géol. de France,' 2nd ser., vol. iii., he had designated as Orbitolites; thus correcting the error into which Mr. CARTER has fallen in his description of the same fossils, through reliance on M. D'ORBIGNY's insufficient and indeed erroneous characters of these genera.

distinctly indicated by the surface-markings. The only external orifices which communicate with these cells, are the minute pores (*d, d, d*) forming one or more ranges at the margin of the disk, each pore lying in a vertical furrow, between the projecting walls of two contiguous cells. In the smallest and thinnest disks (Plate V. fig. 1) we find but a single row, or sometimes two rows, of such pores; in disks somewhat thicker, there are three or four rows; and in the largest and thickest *Orbitolites* (Plate V. fig. 6), no fewer than ten or twelve such rows. This multiplication in the number of ranges of marginal orifices, indicates a like multiplication in the number of floors (so to speak), of which the disk is composed; and just as the total number of chambers in a building may be increased, either by extending its base over a larger area, or by additions to its number of storeys, so may an increase in the number of segments of which this animal is composed be provided for, either by the marginal addition of a new zone resembling the last, so that the diameter of the disk is alone augmented, or by an increase in the thickness of the newly-forming zone, so that it contains a larger number of superposed layers. The new zones, however, *never invest* or cover those which they surround, each being simply a continuation of the margin of the preceding; and in this respect the mode of growth of *Orbitolites* at every stage is pointedly distinguished from the early mode of growth of *Orbiculina*, just now specified as the cause of the protuberance of its centre.

14. The shelly *substance* of the calcareous disk, although firm, is by no means so dense and bony as that of the shells of many other Foraminifera of higher organization. It is apparently quite homogeneous, rarely presenting the least appearance of 'structure,' and this being probably fallacious; I refer to the punctated marking sometimes seen on the outer surface of the nucleus, which shows itself under the aspect represented in Plate VI. fig. 5, when the thin layer of shell which presents it is viewed by transmitted light. Although this appearance might be considered to indicate the existence of a cellular structure in the shell, yet I believe that such an inference would be fallacious; since I have not been able to detect the least trace of such a structure in the decalcified residuum, which, on the other hand, seems to me to be a substance as structureless as sarcode itself. Coupling these appearances with those which I have found to exist more distinctly in *Orbiculina*, I am disposed to interpret them as proceeding from minute *depressions* on the surface; and these are perhaps to be regarded as the rudiments of those minute closely-set apertures, which, in many Foraminifera, give passage to pseudopodial extensions of the sarcode from every part of their bodies.

15. In all the forms of *Orbitolite* that I have examined, the central *Nucleus* presents the same essential characters. When the interior of any disk, whether large or small, is laid open by a horizontal section passing through the central plane, the nucleus is seen to be occupied by a large cavity (Plate V. fig. 1) somewhat irregularly divided by a sinuous partition, which always, however, marks out a central

cell (*a*) of a somewhat pyriform shape, as distinct from the space (*b, b*) which surrounds it. The meaning of this feature is at once made apparent, by reference to the disposition of the sarcode which occupies the cavity of the nucleus ; for we then see (Plate IV. fig. 5) that the large central pear-shaped cell is occupied by a mass (*a*) of corresponding shape, from the small extremity of which a peduncular process extends, that dilates again into a still larger mass (*b, b*) completely surrounding that from which it springs ; the former may be conveniently designated as the 'central,' the latter as the 'circumambient' segment. In a *vertical* section of the disk, passing through the centre, such as that seen in Plate V. fig. 4, the nucleus seems to present *three* chambers ; but this is simply due to the fact that such a section will traverse the circumambient cell twice, that is, will cut it through on both sides of the central cell. In the section represented in Plate V. fig. 9, there are but *two* central chambers ; in this case the plane of division seems to have traversed the nucleus just where the neck of the central cell touches its margin, so that the circumambient cell is only on one side of it. If, on the other hand, the plane of division should happen not to pass through the central cell at all, so as to traverse the circumambient cell alone, a *single* broad cavity will present itself in the vertical section, as shown in Plate V. fig. 7. Frequently, however, it happens that the circumambient segment is partially subdivided on one side by an interposed partition (Plate VII. fig. 4) ; and then a vertical section will show *four* chambers, as is seen in Plate V. fig. 10, the central segment having a single portion of the circumambient segment on one side of it, and a double portion on the other. Some remarkable varieties in the size of the nucleus, and in the mode of its connexion with the surrounding parts, will be noticed hereafter (§§ 44–46, and 54, 55).

16. In describing the structure of the *Concentric Zones* which successively surround the nucleus, it will be requisite to make a distinction between the *simple* and *complex* types according to which the Orbitolite-disks may be generated ; the former being characterized by the existence of only one layer or 'floor' of segments, the latter by the presence of *two or more* such layers. For although, as will subsequently appear, I can show, by a series of transitional gradations between these two types of structure, and by their occasional coexistence in the same *individual*, that they are not to be held to characterize distinct *genera* (as Professor EHRENBURG supposed), or even distinct *species* (as Professor WILLIAMSON has urged with more apparent reason), yet, when most characteristically displayed, they differ so much from one another, and each is so remarkably distinguished by features of its own, that it seems more advantageous to describe them separately in the first instance, and then to discuss their relationship to each other.

17. The *Simple* type is found to prevail in those minute Orbitolite-disks, which occur in greater or less abundance in sands and dredgings from almost every part of the globe, but which are particularly numerous in those of the Philippine shores. Their ordinary diameter is about .05 of an inch, and they usually contain from ten

to fifteen concentric zones. The arrangement and connexions of these zones may be made out in the thinnest and most translucent specimens, by examining them by transmitted light, after mounting them in Canada balsam; this, however, gives such transparence to the thin shelly layer which is continuous over both surfaces, that it may escape notice (if not carefully looked for), so as to lead to the conclusion that the cells are open. Most specimens require to be somewhat reduced in thickness, by slightly grinding down one surface, to enable the arrangement of their interior to be distinctly made out; and this may be examined either by transmitted or by reflected light. Each zone thus seen in horizontal section (Plate V. fig. 1, c, c), consists of a circular set of small ovate cells, excavated, as it were, in the shelly substance of the disk, and communicating with each other laterally by passages which unite them together into a continuous annulus. The zone which immediately surrounds the nucleus is connected with it by passages which extend from the outer margin of the large circumambient segment to the several cells of which it is itself composed; and each zone communicates with the one on its exterior by similar passages, which usually extend, however, not from the *cells* of the inner zone to those of the outer, but from the *connecting passages* of the inner zone to the cells of the outer (Plate IV. figs. 8, 9); and thus it comes to pass, that the cells of each zone usually *alternate* with those of the zones that are internal and external to it. A vertical section of the disk, such as is shown in Plate V. figs. 4, 5, exhibits the same arrangement under a different aspect. The cells of the concentric zones are seen to be much higher than they are broad, so that they present a somewhat columnar form; the proportion of their height to their breadth, however, may vary greatly in different parts of the same disk, the former often increasing from the centre towards the periphery (fig. 4), whilst the latter remains constant, or nearly so; and the columns, instead of being straight, are generally more or less curved, and are sometimes bent in the middle at an obtuse angle (Plate V. fig. 7, a, b). The gradation which presents itself from one of these forms to the other, and their coexistence even in the same specimens, clearly proves that no value can be attached to the form and proportions of the cells, thus seen in a vertical section, as furnishing specific characters. In every perfect specimen, the columnar cells are seen to be closed at their two extremities by a thin shelly wall; and this is sometimes flat, sometimes more or less convex *.—The meaning of these arrangements is clearly seen, when we turn our attention to the structure of the animal (Plate IV. fig. 1). For the outer margin of

* In a large proportion of the specimens obtained from sands or dredging, the cells have been laid open by attrition; either throughout the surface of the disk, if it should be flat, or at its margin only, if it should be at all saucer-shaped. The constancy of this last character in a certain set of forms, resembling that represented in Plate VII. figs. 8, 10, might at first sight lead to the idea that they constitute a distinct specific type; but, as will hereafter appear, these plate-shaped disks cannot be separated by any definite line of demarcation from such as are quite plane; and in specimens of them which have not suffered attrition, the marginal cells are closed, like all the rest.

the circumambient segment of the nucleus is seen to give off a number of slender prolongations or 'stolons' of sarcode, which radiate from it to a short distance and then enlarge into columnar segments having a circular or ovoidal base, which are united with each other laterally by an annular 'stolon'; and from the portions of this 'stolon' which intervene between the segments of each annulus of sarcode, are given off the radiating 'stolons' that go to originate the next zone, the arrangement of whose parts is precisely similar to that just described.

18. In this manner, any number of concentric zones may be formed, which are exact repetitions of each other, except that the number of segments in the outer zones is greater than that of which the inner zones are composed. It does not increase, however, in the regular ratio of the respective diameters of the zones; for the cells of the outer zones, being usually both larger and more widely separated from each other than are those of the inner, are less numerous in proportion; thus in a specimen before me, there are twenty-eight cells in the innermost row and only forty-nine in the outermost, though the latter is more than twice the diameter of the former. The increase in the number of the segments is accomplished by the occasional *interpolation* of an additional segment, communicating directly with the one immediately interior to it, between the two segments which spring from the annular stolon on either side of the latter, as is shown in Plate IV. figs. 8, 9, *a*. Hence it is obvious that prolongations of sarcode giving origin to new segments, although ordinarily put forth rather by the connecting 'stolons' than by the segments themselves, may originate from any part of the annulus. This is shown still more forcibly by the occasional occurrence of irregularities, such as that represented in Plate VI. fig. 6.

19. The cells of the last-formed zone communicate with the exterior by the very same kind of radial passages, as in other instances communicate with the next zone; and the external orifices of these form the pores which present themselves at the margin of the disk (Plate V. fig. 1). Thus it is seen, on the one hand, how it happens that these pores are intermediate between the cells, instead of opening directly into them; and on the other, how each pore leads, by the divarication of its passage, into two cells, one on either side of it. When a new zone is formed, each pore opens into one of its cells; and this zone in its turn communicates with the exterior, through a new set of pores at its own margin. Each pore is often surrounded by a rather prominent annulus of shell (Plate V. fig. 1, *d*); and it is obvious that when the section passes through this, it will be indicated by a little 'beak' on either side of the entrance to the passage; such 'beaks' (which are of course repeated through the entire disk) are shown in their ordinary aspect in Plate IV. fig. 9, but they are frequently more prominent, as is shown in Plate VI. fig. 1.

20. In all cases in which the growth of the disk takes place with normal regularity, a *complete circular zone* is added at once. Exceptions to this regularity are rare, and they can be generally traced with probability to some accidental interruption. It can scarcely be doubted, I think, that when a new ring of cells is about to

be formed, the prolongations of sarcode issuing from the several pores of the preceding zone coalesce, so as to form a complete zone of segments and connecting stolons around the margin of the previously-formed disk; and that the deposit of calcareous matter forming the shelly walls of the cells and passages, takes place *upon*, or rather *in*, the superficial portion of this zone of sarcode. But I cannot find any evidence in the ordinary growth of the disk, that the sarcode extends itself over the surface of the portion previously formed; although occasional appearances will be hereafter described (§ 53), that seem to indicate that it *may* do so.

21. It is a fact of much importance in the due appreciation of the relations of *Orbitolite* and its allied forms to other tribes of Foraminifera, that the calcareous partition which separates each cell of any one zone from its neighbours on either side, is not double, but *single*. And this is in great part the case, even with regard to the partitions that separate the cells of successive zones; the inner or central boundary of one being chiefly formed by the peripheral wall of the other. It is not easy even in thin *sections* to distinguish the boundary between the walls of one zone and those of another, so absolutely continuous do they appear to be. But it not unfrequently happens, that in *fracturing* these disks, their component zones come apart from each other, along their natural lines of junction, so as to disclose the real inner (or central) margin of the outer segment, which then presents a set of wide apertures, through which we look at once into its cells; thus proving their incomplete enclosure by proper walls on that side (Plate V. fig. 1, *ff*). Thus in the formation of each new zone, the calcareous envelope seems to be only generated where the sarcode is not already in contact with a solid wall.

22. There cannot be any reasonable doubt, that the number of concentric zones which any disk may present, is entirely determined by its stage of growth, and that it affords no basis whatever for specific distinction. Just as in the case of the concentric layers of wood in the stem of a tree, a minute nucleus, surrounded by only a single annulus of cells, may come in time to be the centre of a large disk consisting of many scores of concentric zones. Although, as already stated (§ 17), most of the *Orbitolites* formed upon this simple type are of comparatively small size, yet there does not seem to be any definite limit to the multiplication of zones; for I possess specimens attaining .15 of an inch in diameter, and consisting of about forty zones (much larger, therefore, than the younger zones of the complex type), in which there is no appearance of any departure from the original mode of growth. That comparatively few specimens, however, attain so large a size upon this simple type of structure, is due, I believe, to the circumstance that they early tend to develop themselves upon the more complex plan which I shall presently describe.

23. Although I have spoken of these disks as typically plane or nearly so (there being usually no great difference between the thickness of their central and that of their peripheral parts), yet it not unfrequently happens that the successive zones gradually increase in thickness from within outwards (as is shown in Plate V. fig. 5),

so that the height of the columnar segments progressively increases, and the entire disk becomes somewhat biconcave. Sometimes, again, without any alteration in the thickness of the several parts, the disk comes to assume, by the depression of its central portion, the shape of a plate, or that of a watch-glass, or (by the more complete upturning of its edges) that of a saucer. In any case in which either surface of the marginal zone is more exposed by its projection than those of the zones which it encloses, there will be a special liability to a laying-open of its cells (as shown in Plate VII. figs. 8, 10) if the disk should be subjected to attrition; and I believe that not only the recent species *O. marginalis*, but the fossil *O. macropora*, are nothing else than examples of this type, the figure of the latter given by GOLDFUSS* corresponding exactly with a form of it which I have frequently encountered. I have not met with any examples in this simple type, of that marginal thinning away as age increases, which is observable in many other Foraminifera.

24. From the simplest, it will be convenient to pass at once to the *most complex* type of structure presented by the Orbitolite, the existence of which is marked (as already noticed, ¶ 13) by a multiplication of the horizontal ranges of marginal pores. I have met with this form in specimens obtained by dredging, from the coast of Australia, from various parts of the Polynesian Archipelago, from the neighbourhood of the Philippine Islands, from the Red Sea, and from the Ægean; and as the sands of all these localities present the simpler type in great abundance, I am disposed to believe that the former is really not the less widely diffused than the latter, and would be discovered wherever it abounds, if properly searched for. The largest specimen in my possession, measuring seven-tenths of an inch in diameter, is from the coast of Australia, where these Orbitolites are so abundant at certain spots (as I learn from Mr. JUKES), that their entire disks and fragments, with fragments of Corallines (chiefly, I believe, the *Corallina palmata* of ELLIS), constitute the great mass of the dredgings. Among the Australian specimens, several attain a diameter of $\cdot 45$ inch, and a considerable proportion as much as $\cdot 30$ of an inch. Hence the Orbitolites of this type are among the largest forms of existing Foraminifera, being only surpassed, as far as I am aware, by the *Cycloclypeus* hereafter to be described. Of two specimens in my possession from the Feejee Islands, one measures $\cdot 63$ inch, and the other $\cdot 53$ inch in diameter; but the average of the Polynesian specimens, like that of the Philippine, Red Sea, and Ægean, seems to be considerably lower than that of the Australian, as their diameter seldom exceeds $\cdot 25$ of an inch, and is usually not more than $\cdot 10$ or $\cdot 12$.

25. The disks formed on this plan, like the preceding, may be considered as typically circular, although they are seldom or never exactly so in reality. They may be considered, too, as typically flat, with a slight concavity in the central part, from which, however, the nucleus often projects; but, as will hereafter appear, there is no constant relation either between the thickness and the diameter of different specimens,

* Petrefacta, pl. 12. fig. 8.

or between the thickness of different parts of the same specimen, and the distance of these parts from its centre. The only remarkable departure from the ordinary form which I have met with, presents itself in certain Orbitolites from the Feejee Islands, of which several specimens in the Museum of the Royal College of Surgeons, and two in my own possession, exhibit a curious plication towards their margins; the degree of this departure varies so much, however, in different individuals, the plication being almost obsolete in some (see Plate V. figs. 2, 3), that it cannot be admitted to mark a specific diversity; and considering that these disks always grow on the surfaces of other bodies, it can scarcely, I think, be considered improbable, that the plications originate in the inflections of those surfaces*. These same specimens, moreover, also exhibit another curious abnormality; namely, the projection of the upper and lower edges of the margin, so that a groove is left between them, the projecting laminae being thin and foliaceous, and their cells very irregularly arranged. This peculiarity, again, being far from uniform in its degree, and being altogether wanting in specimens which in other respects precisely resemble those with plicated and foliated margins, must be considered merely in the light of an accidental variety; but I cannot suggest any explanation of its occurrence, or of its limitation (so far as I am aware) to this particular locality.

26. The surface of the disk (Plate V. fig. 6) is marked out, as in the simpler type, by concentric zones of cells, the number of which bears a general (though not a constant) ratio to its diameter; these cells are usually somewhat rectangular in shape and sometimes approach a square, but are more commonly nearly twice as long in the line of the radius of the disk as they are in the transverse direction, their long sides being parallel to each other. We shall hereafter see, however, that the form of the superficial cells is very subject to variation, and that it may be very dissimilar even in different zones of the same disk (§§ 48-52). The pores at the margin of the disk are disposed, as in the simpler type, between the projections formed by the convexities of the cells; and each is usually surrounded by the projecting annulus formerly noticed (§ 19). The disposition of these pores, however, is far from regular, as they seldom form rows that seem exactly continuous with each other, either horizontally or vertically; and the number of pores in each vertical row is by no means constant, even in different parts of the margin of the same disk †.

* I have elsewhere noticed the fact, that various species of *Orbitoides* are disposed to exhibit a like contortion; and that the well-marked *ephippial* shape which some specimens present, is nothing else than an accidental variety (see Quart. Journ. of Geol. Soc., vol. vi. pp. 34, 35).

† In following the description of the internal structure of this type of Orbitolite, it will be convenient for the reader to make frequent reference to the ideal representation which has been built up in Plate V. fig. 6, by the combination of materials furnished by a great number of preparations which are represented in separate figures accompanying the original Memoir in the Archives of the Royal Society; these last of course furnish the real authority for every point in the description, the ideal figure, however, serving to display the relation of different parts to each other in a manner that no single preparation would possibly admit.

27. The disks of this complex type are not distinguished from those of the simple type already described, by any difference in the structure of the Nucleus; and there is frequently nothing specially characteristic in the structure of the zones that immediately surround it. Each of the peripheral zones, however, consists of two *superficial* layers, an upper and a lower, and of an *intermediate* stratum;—these will now be described *seriatim*.

28. The *superficial* layers are formed of the (usually) oblong cells, whose contour is indicated by the surface-markings; when they are laid open horizontally, by rubbing away the thin shell which covers them in (Plate VI. fig. 3), it is seen that the floor of each cell has an aperture at either end; but no communication can be traced, either through the side-walls between the contiguous cells of the same zone, or through the end-walls, between the cells of successive zones. Moreover, there is no such alternating arrangement of the cells of successive zones, as we have seen to prevail in the simpler type (§ 17); and they altogether seem to be quite independent one of another. When this superficial layer is examined in a vertical section having a radial direction (Plate VI. fig. 7), it is seen that the floors of its cells (a, a) are formed by the expanded summits (d, d', d'') of the irregular septa, which separate from each other the columnar cells of the intermediate stratum ($c c c c$); and that the apertures at the two ends of the floor are the entrances to passages (e, e', e''), which lead obliquely downwards (the passages on either side of the partition between two successive cells of the *superficial* layer inclining towards each other) towards these cavities. It is observable, moreover, that just at the point at which the contiguous passages meet each other, there is always a round aperture (f, f', f'') in the partition (g, g) which divides the contiguous cells of each zone; and when, in a horizontal section, the superficial cells have been entirely ground away, so as to lay open the most superficial part of the intermediate stratum, this part is found to be traversed in each zone by a continuous circular canal (Plate VIII. fig. 3), with large rounded openings that lead into the columnar cells beneath. The meaning of this arrangement becomes obvious, when we examine the disposition of the animal substance which occupies these cavities; for we find, as might have been anticipated, that the superficial cells are filled with segments of sarcode of corresponding shape (Plate IV. figs. 4, 7, aa); and that whilst these have no direct connexion with one another, each of them is connected by means of fleshy peduncles with the annular stolons bb that run along its extremities; whilst from the under side of these annular stolons (fig. 4) descend the thick columns of sarcode ($cc, c'c'$), which occupy the columnar cells of the intermediate stratum. The absence of any essential dependence of the segments of the *superficial*, and of those of the *intermediate* strata upon each other, seems indicated by the fact that there is no constant numerical relation between them,—a circumstance which extremely perplexed me, until I had ascertained, by examination of the animal, that the passages (Plate VI. fig. 7, e, e', e'') debouch, not (as I had at first supposed) into the columnar cavities, but into the annular canal;

which serves to bring the superficial and columnar segments of each zone into mutual communication.

29. As the description now given of the superficial layer applies equally to both surfaces, we may now proceed to the *intermediate* layer. When this is laid open by a horizontal section (Plate V. fig. 6), it is seen to consist of a series of concentric zones, the cells of which *alternate* with each other, like those of the simpler type (§ 17.). The cells are usually circular (or nearly so) in form; but seem to differ considerably in size, even in different parts of the same zone. Their borders, however, very commonly present a funnel-like aspect; and thus we perceive that the diameter of the cavity is liable to vary, according to the part of it which the section happens to traverse,—a fact which becomes more obvious when *vertical* sections are examined; for it is then seen (Plate VI. figs. 7, 8, 9) that each columnar cell is narrowed by constrictions at intervals, so as to divide it imperfectly into a series of segments vertically superposed one upon another. The number of these segments varies according to the thickness of the disk; so that it is anything but constant, either in different individuals, or in different parts of the same. Moreover, it may be often observed that the columns neither always pass from end to end in a straight line, nor maintain a complete isolation from each other (Plate VIII. figs. 1, 2); an inosculation of two columns not being unfrequent, and more rarely a fusion of two columns into one. All these features of structure presented by the shell, are beautifully displayed by the animal (Plate IV. fig. 4); the columns of sarcode (*cc*, *c'c'*) exhibiting the imperfect transverse segmental division, the not unfrequent inosculation, and the occasional fusion, which we have seen to exist in the cavities which they occupy. At their upper and lower extremities, they unite with the horizontal bands (*bb'*, *bb'*), which pass continuously round, in each zone, between the intermediate and the superficial layers.

30. Save in the case of such accidental inosculations as those just noticed (which are indicated in vertical sections like that represented in Plate VI. fig. 7, by the irregularly disposed apertures *h*, *h*), no other lateral communication seems to exist between the contiguous cells of the same zone, than that which is established by the annular stolons just mentioned. The cells of the successive zones communicate with each other, however, as in the simple type previously described (§ 17.); but with a curious modification; for whereas a horizontal section of the latter shows that each cell communicates with the *two* cells alternating with it in the interior zone (Plate V. fig. 1), a like section of the Orbitolite of complex type seems to show that such a connexion exists with only *one* cell of the interior zone, by a passage running obliquely from one to the other, and extending continuously through several successive zones (Plate V. fig. 6, *i*, *k*). I was long perplexed by the want of constancy in the direction of these passages; the very same section exhibiting opposite obliquities in contiguous parts (Plate VI. fig. 2). By the study of vertical sections, however, made tangentially instead of radially, so as to cross these connecting passages, I arrived at the explanation of this

apparent anomaly, which is simply as follows. Each columnar cell really communicates with the *two* alternating columnar cells in the next interior zone; but by two distinct passages, instead of by the divarication of one; and these passages are not upon the same plane, but those of different planes turn alternately to one side and to the other. This is well seen in the two tangential sections represented in Plate VI. figs. 8 & 9; of which 8 shows the back or central side of four contiguous columnar cells *aa'*, *bb'*, *cc'*, *dd'*, of the same zone, each of them perforated by a series of apertures, in which some degree of alternation is perceptible; whilst 9 shows the front or peripheral side of four other columnar cells, in which it is seen that, by the sinuosity of the partition, the apertures of any vertical row, even when in a line with each other, open alternately into the cells on the *right* and on the *left* of the septum; so that (*e.g.*) the passages extending backwards from the row of apertures in the columnar cell *bb'*, fig. 8, will debouch alternately in cells *aa'* and *bb'*, fig. 9, of the zone within. The same will of course be true of the pores which open on the margin, these being nothing else than the orifices of the inter-zonular passages just described, which, when another annulus is added, lead into its cells. This idea of the alternating direction of the inter-zonular passages, seemed to furnish the solution of the appearances presented in Plate VI. fig. 2; for, as the disks are seldom perfectly flat, the section which traverses, at one part of the disk, the set of passages running in one direction, will traverse the other set of passages, where, by the flexure of the disk, the plane of section is slightly altered in regard to it. All doubt, however, as to the validity of this explanation, was removed by the examination of the animal substance filling the vertical columns; for, as is shown in Plate IV. fig. 4, each column of sarcode in one zone (*cc*) does communicate with the two columns alternating with it in the next zone (*c'c'*) by two rows of peduncular stolons; and the peduncles which pass from each pair of contiguous columns, to the single column of the next zone, incline towards one another, so as to enter it nearly in the same vertical line, though in different horizontal planes.

31. That which has been already stated in regard to the partial deficiency of the inner wall in each of the concentric zones of the simple type (§ 21.), holds good also in regard to the septa which divide the successive zones of the intermediate stratum in this more complex type; for the walls of the columnar cells close-in around them very imperfectly on their inner or central side, leaving large irregular vertical fissures (Plate VIII. fig. 1) which are applied to the vertical rows of orifices (Plate VIII. fig. 2) on the outer margin of the included zone.

32. The thickness of this intermediate stratum, and the number of vertical segments of which it consists, are found to vary considerably in different parts of the same disk; being usually least near the nucleus, and gradually augmenting in successive zones as their distance from the centre increases (Plate VI. fig. 7); or ceasing to augment at a certain point, so that the outer part of the disk is flat; or even diminishing again, so that the disk thins away towards its margin. It is specially worthy

of note, that whatever differences of this kind may exist, they are entirely due to the variable length of the columns of the *intermediate* stratum; the depth of the cells of the superficial layers being nearly constant, and no vertical multiplication of these ever taking place. The intermediate stratum, where it abuts on the nucleus, is often very thin; the annular stolons that run beneath the superficial layers being in such near proximity to each other, that the intervening column of sarcode is very short, and consists of only a single vertical segment, Plate V. fig. 12.

33. The foregoing description applies in every particular to those specimens only, which present the structure of this type of Orbitolite in its most regular and characteristic development; and the differences between this more complex form, and the simple form previously described, are such as at first sight to preclude the idea of their specific identity. Hence I am not in the least degree surprised, that Professor WILLIAMSON, by whom their respective plans of organization were first compared (*loc. cit.*), should have unhesitatingly regarded these two forms as specifically distinct. But when a large number of specimens of the more complex type are carefully examined and compared with each other, it becomes obvious that a vast amount of diversity in the arrangement of the cells of the shell, and of the segments of the animal, may present itself; and that one after another of the characters which at first seem most clearly marked and therefore most distinctive, may be shaded off (so to speak) in such a manner that a *complete transition is established*, sometimes even in a single disk, between the simple and complex types. Such a transition is exhibited by the specimen of which a vertical section is figured in Plate V. fig. 7; for it is obvious that the central portion of this disk (*a—b*) is so exactly conformable to the simpler type, that if this growth had stopped at the twenty-third zone, it would have undoubtedly been regarded as an unusually large example of that form. So many variations present themselves in the development of the different parts of the more complex type, that it will be desirable to describe them under a distinct head (Sect. IV.); and when these shall have been duly considered, I think that all doubt as to the specific identity of the simpler and more complex forms will be done away.

III. *Physiology.*

34. *Growth.*—Of the mode in which the *Nutritive* process is carried on in Orbitolites, our imperfect acquaintance with their living habits leaves us much in the dark; nevertheless it is fair to reason by analogy from a comparison of their structure with that of other Foraminifera whose habits of life are known; especially as this analogy is sufficiently complete in the present instance, to justify a tolerably firm reliance upon it, and as the results to which it would lead are in harmony with the facts of observation. All the Orbitolites, whether of the simple or complex type, which have been collected in the living state, have been found growing on the surface of Seaweeds or other marine plants (as *Zostera*), or of Zoophytes; it may therefore be fairly presumed, that such is their ordinary habitat; and hence it is scarcely conceivable

that their *attached* surface should ever be invested by sarcode. Moreover, several of the spirit-specimens which I have submitted to decalcification, have proved to be so closely invested by a covering of *vegetation*, chiefly composed of *Diatomaceæ*, *Desmidiæ*, and other minute Algæ, that I cannot suppose even the free surface of their disk to be ordinarily covered by sarcode*. The analogy of other Rhizopods, however, would lead us to suppose that the sarcode projects from the marginal pores under the form of *pseudopodia*, and that it is by the introduction of alimentary particles (chiefly minute forms of vegetation) through their means into the mass of sarcode from which they are put forth, that the fleshy body pervading the entire disk is nourished. For although there is nothing like a digestive cavity in any part of it, or an alimentary tube passing from one portion to another, still less any vascular communication between the segments, yet as the sarcode forms one soft homogeneous mass continuous throughout, the body as a whole will receive the benefit of any incorporation of new matter with its substance, in whatever situation this may be made. That organic particles small enough to pass through the marginal pores, are thus introduced into the chambers of the disk, is proved by the curious fact, that the residuum left after the decalcification of large and therefore aged disks, whose animal contents have not been preserved, consists almost entirely of an assemblage of remains of minute *Diatomaceæ*, *Desmidiæ*, &c., which have obviously been retained in the interior of their cavities, after the assimilation of the nutriment they were competent to afford.

35. The sarcode-body of the animal, growing at the expense of the nutriment thus appropriated, will gradually, it is probable, project itself through the marginal orifices, not merely in filamentous pseudopodia, but in quantity sufficient to form new segments on the outside of each pore; and these segments, extending themselves laterally, will come into mutual connexion, and will thus form a complete annulus. It may be presumed to be by the calcification of the surface of this beaded ring of sarcode, that the formation of the shelly zone is accomplished; and if the calcifying process commence on the segments, and extend from these along the surface of their connecting stolons, we can understand why the passages that are left for communication with the exterior, should arise from the intermediate divisions of the annular canal, instead of from the segments themselves.

36. The addition of new zones usually takes place with the same regularity in the complex as in the simple type of structure; but departures from this regularity, occasioned by a want of completeness of particular zones, are more frequent; and this is perhaps to be accounted for by the larger size of the disk, which will tend to produce a less intimate dependence of each part of the animal body upon every

* I have found such an investment also on several dried specimens; and until I had detached and examined this, I should have supposed from its aspect that it was the desiccated flesh of the animal. I have little doubt that the "greenish cuticle" described by Mr. CARTER as covering his *Operculina arabica* (Ann. of Nat. Hist. ser. 2. vol. x. pp. 168, 172) and supposed by MM. D'ARCHIAC and HAIME (*op. cit.* p. 52) to be specially concerned in the formation of the shell, is of the same nature.

other, and will thus favour the partial action of any cause (*e. g.* an excess of nutrient materials) which promotes a more rapid growth on one side than on the other. And this view is most remarkably borne out by the fact, which I shall more fully illustrate in a subsequent memoir, that in another example of this group*, which, though normally growing upon the cyclical type, possesses a greater degree of segmental independence, such irregularities occur far more frequently; so that, in fact, it is rare to meet with a disk whose increase has taken place with uniformity throughout.

37. *Reparation of Injuries*.—Looking at that vegetative repetition of parts which pre-eminently characterizes the body of the Orbitolite,—every one of the segments first budded-off from the nucleus, and subsequently from the margin of the pre-formed zones, being the precise repetition of every other,—it may be expected from the analogy of similar organisms, that every one of these parts should be equally capable, both of repairing injuries done to itself, and of maintaining an independent existence when detached from the mass to which it originally belonged. And although no opportunity has yet presented itself, of subjecting such a conclusion to the test of experiments devised for the purpose, yet *accident* has furnished the means of verifying it, to a degree that could scarcely have been anticipated. For in the course of my examination of the large collections which have been placed at my disposal, I have met with several specimens, in which it is evident that, after larger or smaller portions of the disk had been broken away, a new growth has taken place along the fractured edge. Various examples of this are shown in Plate VIII. In the first that I happened to meet with, which is represented in fig. 6, the injury is evidently very slight, being confined to the loss of a few rows near the edge of the disk, for something less than half its circumference (*a—b*). This injury had obviously been sustained previously to the formation of the last two zones; for these, whilst added to the uninjured part of the margin in the usual way, have followed the irregular contour of the broken edge; and whilst in the former case the cells present their normal conformity to those of the margin they invest, in the latter, the cells, while obviously continuous with the preceding, are quite unconformable to those of the fractured margin, as is shown on a larger scale in fig. 7. Hence it seems to me probable, that the growth of these two rows along the *fractured* edge, has taken place, not from that edge itself, but by an extension of the sarcode about to form the new circle of the *entire* edge, from the points *a* and *b*. In fig. 9 is seen an example of a similar kind, in which a much larger portion of the disk has been broken away, so as to leave only an irregular fragment, including its centre and about an eighth of its margin. Here seven rows of cells have been formed since the injury; and these, whilst produced conformably to those of the uninjured margin, present the most marked want of conformity to those of the fractured margin, which, nevertheless, they completely surround. A careful examination of this specimen, indeed, seems to me to leave little room for doubt, that the growth of the innermost, or what I may call the *reparative* zone of

* I refer to a genus hitherto undescribed, which I shall designate *Cycloclypeus*.

cells, took place, not from the broken edge, but from the margin of the unbroken; just as, to use a professional simile, an ulcerated surface 'skins-over' by an extension of the integument from its edges, not by the direct formation of skin upon the granulation-surface itself. All the six rows subsequently produced, are conformable to each other, and to the first or reparative row, from which they have obviously extended themselves after the normal manner. It is observable, however, that the breadth of these rows varies in different parts, being least where they invest the projecting portions of the fractured edge, and greatest where they sink into its hollows. And thus it comes to pass, that the irregularities left in the shape of the disk, by the loss of a large part of its substance, are gradually compensated, so as to restore it to a form much more nearly corresponding to its typical symmetry.

38. Even a very small fragment appears thus to serve as the nucleus for a new disk. In fig. 8 is shown an example of this kind, in which the tendency to the reproduction of the typical form, by the compensative reparation just described, is very curiously marked. This specimen also presents the following very curious feature,—that the new growth has taken place from the *inner* margin of the original fragment (*aa*), and not from its *outer* or growing margin, as in the cases previously noticed. Having carefully examined it in various modes, I cannot entertain the slightest doubt that such has been the case; for the cells of the first new zone, as well as those of all the zones subsequently produced, are so manifestly conformable to those of the thinner and older portion of the fragment, and are so unconformable to those of the thicker and newer margin, that it seems obvious that the sarcode must have extended itself from the former part, along the fractured edge on each side, and have then enveloped the margin which had been left entire. This may have more readily taken place in the present instance, because at the part (*aa*) the fracture seems to have followed the course of one of the zones, instead of passing, as at the sides of this fragment, and in the instances previously cited, in such a direction as to cut the zones transversely.

39. The preceding instance clearly proves, that connexion with the central nucleus is not in the least degree requisite for the continued growth of the peripheral parts; since these may be entirely detached from it, without any loss of vital activity. The same inference may be deduced from the examination of specimens, in which, the central portion of the disk having been broken-out, a growth of new zones seems to have taken place from without inwards, so as to fill up the void space thus left. In no other way can I account for the appearances presented by a specimen in my possession, in which the included portion is as evidently unconformable to that which surrounds it, as it is in the preceding case, but in which there is also an unfilled void, the shape of one part of which clearly indicates that it occupies the site of the original centre. The *included* portion, and not the peripheral, must therefore be the after-growth in this instance; and if a little more time had elapsed, the whole of the central vacuity would probably have been filled up by it.

40. In the specimen represented in fig. 5, the central portion appears to have been lost, with about a third of the peripheral; and the new growth seems to have taken place at the same time, from the inner margin *aaa* of the fragment, and from its outer margin *bbb*, the two growths becoming continuous with each other along the broken edges *ab*, *ab*. For although the zones that lie internally to *aaa* are conformable to those which surround them, yet there is a peculiar character about them (more apparent in the specimen than in the drawing) which indicates them to have been formed at a later period, and to have been contemporaneous with those which surround the zone *bbb*. Their actual continuity at the angles *aa* is unfortunately interrupted by an injury which the specimen seems subsequently to have received; yet its traces are sufficiently perceptible on one side, to justify the belief in its former existence.—The specimen of which fig. 4 is a delineation, seems to have been the subject of several minor fractures and reparations; but the course of its zones marks out an obvious separation between an earlier- and a later-formed portion, one having sprung from the other along the line *ab*. The incompleteness of the specimen, however, prevents me from coming to any certain conclusion, whether the small inner portion is here the older, the large outer portion having grown in the first instance from its margin *ab*, and having gradually extended itself around it; or whether the outer portion is the residue of an unusually excentric disk, which, having lost its nucleus and the zones immediately surrounding it, has filled up the central space with an extension from its innermost zone, which is consequently the newest portion of the whole.—It is interesting to find evidence in *fossil* specimens, that the same kind of reparation has taken place. Among the Orbitolites which I have examined from the Calcaire grossier of Paris, is a disk of which a large part had obviously been lost by fracture, but of which the original symmetry had been in great degree restored by a similar outgrowth from the zones formed from the uninjured margin, along the fractured edge.

41. This series of abnormal phenomena, then, not only confirms the conclusion that seemed fairly deducible from our previous examination of the normal mode of growth, with regard to the independent endowments of the component segments of the Orbitolite body, but also affords some additional information of much interest. For we see, in the first place, that the growth of the sarcode, and the addition of new parts, may take place in the direction of the centre, where a free edge is exposed at the inner margin of any zone, as well as in the peripheral direction from the normal outer margin. Secondly, the reparative *nisus* seems always to tend towards the production of a disk, whose shape shall approach the circular, whatever may be the form of the fragment which serves as its foundation; thus showing that, notwithstanding the repetition and independence of the separate parts of these organisms, each cluster, whether large or small, is an integer, having an archetypal symmetry to which it tends to conform,—thus strongly reminding us of the laws of crystallization. And thirdly, the plan by which this recurrence to the discoidal form is provided for,

seems partly to consist in the limitation of the new growth to the natural margins of the zones; no such growth taking place from the edge of a fracture which has crossed the zones transversely, although it may proceed from the remains of a zone which has been broken off by a fracture that partly follows its course.

42. *Question of Individuality*.—It has been frequently discussed, whether each of the composite forms of Foraminifera, such as Orbitolite or Nummulite, is to be regarded as a *single individual*, or as a *colony* or *cluster of individuals*. All occasion for this discussion would, I think, be removed by the adoption of philosophical views as to what really constitutes an individual, and as to the relationship between the parts which, having a common origin in one generative act, are multiplied by a process of gemmation. As I have elsewhere endeavoured to show*, the entire product of every generative act, whether developing itself into a body of high organization, distinguished by the structural differentiation of its parts, or evolving itself as an almost homogeneous aggregate of equal and similar segments, must be regarded as homologically the same; and the essential difference between the two, as living beings, lies in the *functional* relations of their respective parts. For whilst in the former there is so close an *interdependence* amongst them all, that no one can exist without the rest, and the life of the whole is (as it were) the *product* of the lives of the component parts, there may be in the latter such a mutual *independence*, that each part can continue to live, grow, and reproduce itself when separated from the rest, so that the life of the whole is (so to speak) but the *sum* of that of its components. Now the term 'individual,' being commonly applied to the entire organism in the first case, and to only a small segment of it, perhaps, in the second, is obviously inappropriate either to one or to the other, except in so far as it expresses the fact of independent existence. But the limits of such individuality as this cannot be strictly defined, and they even differ widely in animals whose general plan of structure is the same†. Hence in regard to the Foraminifera, as in regard to Zoophytes, Composite Acalephæ, &c., we are to regard the entire mass originating in a generative act, as a *single organism*; and the question in regard to the *functional independence* of its multiple segments, is one of degree in each particular type. Thus, as we have seen, this independence exists in the case of the *Orbitolite* to such a degree as to make each part entirely self-sustaining, and to prevent the existence of any definite limit to the growth of the whole; yet it is quite possible that in a form so much more elevated as *Nummulite*, there may be, as maintained by MM. D'ARCHIAC and HAIME (*op. cit.* p. 69), such a degree of mutual dependence among the segments, and of unity in their aggregate life, that the latter predominates sufficiently to limit the growth of the organism to a tolerably determinate size‡.

* Principles of Comparative Physiology, chap. xi. sect. 1.

† See also Mr. HUXLEY's observations on this subject, in Philosophical Transactions, 1851, pp. 578, 580.

‡ Whilst admitting the possibility of this view, I shall hereafter have occasion to question its correctness; since the evidence on which it is based appears to me by no means satisfactory. In fact, when I come to

43. *Reproduction*.—The mode of *Reproduction* of the Foraminifera generally, is at present involved in the deepest obscurity; and there is little probability that it will be fully elucidated by any other means, than continued observation of the animals in their living state, such as may probably be best carried out with regard to the species of our own seas by keeping them in Vivaria. In default of such observations, and as a guide to further inquiry, I think it as well to state what has fallen under my own notice. In many parts of the body of spirit-specimens of *Orbitolite*,—especially, but not solely, in the superficial cells,—I have found the sarcode broken-up as it were into little spherules, as represented in Plate IV. fig. 3; these spherules, however, do not seem to possess any peculiar investment, nor does their sarcode appear to have undergone any special change. Similar spherules are figured by Professor EHRENBURG (*op. cit.*) in several of the cells of his *Sorites orbiculus*; and Professor SCHULTZE has recently (*op. cit.* pp. 26, 27) described bodies which seem to be of the same kind, though more opaque (probably through having a denser envelope), as frequently presenting themselves in certain chambers of *Rotaliæ*, or even throughout the entire series. I feel much inclined to believe that these bodies are *gemmules*, which, like the zoospores of the Algæ, are produced by a resolution of certain portions of the substance of the organism into independent particles, which, spontaneously detaching themselves, and escaping through the marginal pores of the disk, will go forth to lay the foundation for new disks elsewhere.

Besides these, however, I have more rarely met with certain other bodies, apparently imbedded in the sarcode, which may be either *gemmules* in a later stage, or may possibly be true *ova*; these, represented in Plate IV. fig. 11, seem to exhibit various stages of binary subdivision; and they present a deep-red colour, even in spirit-specimens. I can scarcely imagine that these can be vegetable organisms that have been introduced through the marginal pores; since they are much too large to pass through these, without a great alteration in form; and this would seem to be incompatible with the firmness of their envelope. At *g*, fig. 11, is represented, under the same magnifying power with the foregoing, an object which I have detected in one of my vertical sections of the shell, where it occupies one of the superficial cells, the cover of which is deficient. Now it is quite possible that this cell may have been accidentally abraded, and that the object in question may have found its way into it *ab externo*; its position and aspect, however, seem to me much more conformable to the idea, that it has been developed in the disk itself, and that it has burst through the lid of the cell by its own enlargement, in preparation for its final escape. And this view seems borne out by the fact, that I have frequently found a few cells open on different parts of the surface of disks which did not appear to have suffered any abrasion; as if the rupture of their lids had taken place as an ordinary

describe (in a future memoir) the structure and varieties of *Nonionina*, the nearest existing type to Nummulite, and in my belief generically identical with it, I shall have occasion to show, that there is not only no proof of the existence of such a limitation to its growth, but that there is strong evidence to the contrary.

phenomenon of their development, instead of being the result of accident.—I do not wish to attach any weight to the interpretations I have here offered; but I simply state the facts, and the explanations of them which have suggested themselves to my own mind; merely adding, what I hope to present in more detail at a future opportunity, that bodies resembling the first or primordial cell, in which Foraminifera of all forms originate, are not unfrequently met-with in the chambers of many other species.

IV. *Variations.*

44. *Variations in Size.*—We have already seen that diversities both in the *diameter* and in the *thickness* of the disk, arise directly from the degree in which the animal substance (whereon the skeleton is modelled) has extended itself either *horizontally* or *vertically*, so as to multiply either the number of concentric rings, or the number of the superposed segments of which each ring consists. This, however, is not the only source of variation in size; for a most extraordinary diversity presents itself in the dimensions of the individual components, by whose repetition the entire disk is made up. It is in the *nucleus* that I find this diversity most strongly marked, as will appear from a comparison of Plate VII. figs. 1—4, which exhibit parts of a gradational series of twelve, from the smallest to the largest forms I have met with, all of them accurately drawn, under the same magnifying power, from specimens in my possession*. The length of the entire nucleus of fig. 4 is about *seven* times that of the nucleus of fig. 1, and its breadth about *four* times as great; the area of the former is therefore about twenty-eight times that of the latter; and as it is also several times as thick, the whole of the cavity, which was occupied in the living state by animal substance, could scarcely have been less than a *hundred times as large* in the one as in the other. (Compare also figs. 5, 6, 10, 12, 13 of Plate IV.) There is not by any means the same amount of difference between the dimensions of the ordinary cells which are formed by concentric extensions of the nucleus; nevertheless, it will be seen by a glance at the figures just referred-to, that these also exhibit marked diversities in size, the largest cells being usually found to spring from the largest nuclei, and *vice versâ*. Moreover, the individual cells of the very same disk are occasionally found to differ amongst each other, as widely as do the cells of fig. 1 from those of fig. 4.

45. Similar differences present themselves in the *thickness* of individual cells; as is of course best seen in the simple type of Orbitolite, in which the augmentation of thickness is not produced by the vertical superposition of multiple segments. A remarkable example of this kind is presented in the comparison of figs. 4 and 5 of Plate V.; these being, like the figures in Plate VII., drawn under the same magnifying power. I possess a series of vertical sections of different individuals, in which the same gradual transition is seen from the thin to the thick, as I have just stated

* The entire series of figures is in the possession of the Royal Society.

to exist in regard to superficial area; and which also proves that the relative thickness of the central and of the peripheral portions is equally liable to variation.

46. It seems obvious, from the foregoing considerations, that neither the absolute nor the relative dimensions of the individual parts of these composite fabrics, can, any more than the dimensions of the entire disks, be taken as affording valid characters for the discrimination of species; and that such a wide range of variation exists among individuals, as would, if the extreme cases alone were known, seem fully to justify their separation under distinct specific designations. Thus, if the two extreme forms, figs. 1 and 4 (Plate VII.), had been the sole objects of comparison, most naturalists would undoubtedly have considered the strongly-marked difference in the size of their respective nuclei to entitle them to rank as separate species; and even if fig. 2 or fig. 3 had been brought into comparison with them, it might have been a question whether it should be associated with fig. 1 or with fig. 4, or should rank as a third species intermediate between them, or should be considered as a connecting link specifically identical with both, and therefore establishing their specific identity with each other. The comparison of the entire series must be felt to remove all ground for hesitation on this point, since it is manifestly impossible to draw a line across any part of it, which should divide it into two or any larger number of groups, respectively characterized by constant and well-marked differences in size. And here again, therefore, we have evidence of the great importance of bringing into comparison a sufficiently large number of forms, to enable us to determine in some degree the measure of individual variation.

47. *Variations in Shape.*—The very strong tendency which we have seen to prevail in the Orbitolite, not only to the maintenance of the circular type in the regular growth of the disk, but to its reproduction after accidental injuries, seems to prevent the occurrence of any considerable variation in its general form, except such as may be directly produced by external agencies. The circular sometimes gives place to an elliptical shape (Plate VII. fig. 4), especially in young specimens, whose form is more determined by that of the nucleus than is that of older individuals. And the occurrence of such a variety in the recent type, makes me indisposed to admit that ellipticity of shape can be in itself a sufficient basis for the specific differentiation of any fossil form of this genus. Of the marked differences in the general aspect of the disks, which may arise from differences in the relative proportions between their thickness and their diameter, and in the relative thickness of their central and peripheral portions, mention has been already made (§§ 17 and 32.). And the only other important departure from the typical shape which I have met with, either in the simple or in the more complex form, has been described under a former head (§ 25.).

48. *Variations in the Form of the Superficial Cells, and in the Markings of the Surface.*—The appearances presented on minute observation by the surface of the Orbitolite, are so far from being uniform, that to any one whose eye had not become

familiarised with their variety by the examination of a considerable number of specimens, they would become sources of great perplexity. We have already seen that the cellular markings present two very distinct forms, the *rounded* (Plate V. fig. 1) and the *oblong* (Plate V. fig. 6); the first of these being specially characteristic of that simpler type of structure in which there is only a single layer of cells, but not being confined to it; whilst the second is peculiar to the complex type, in which there are two superficial layers, distinct from the intermediate stratum. Now the occasional coexistence of both these plans of structure in a single individual (§ 33.), sufficiently proves that the diversity of the surface-markings to which they respectively give rise, cannot be regarded as a basis for specific distinction; and when these extremes of diversity are kept in view, it must be felt to be highly improbable that any modifications of either form should possess greater importance. That such modifications are mere individual varieties, is further evidenced by their *gradational* character, and by the fact that two or more of them may present themselves in the same disk. In my description of them, I shall limit myself to an account of those more remarkable and frequently-recurring varieties, which will serve, I think, as a key to any others that are likely to be met with.

49. Although each surface, in either of the two principal types, ordinarily shows a division into concentric zones, which are again transversely subdivided so as to mark the separation of the cells, yet sometimes the concentric zones are alone visible, and no transverse subdivision is indicated, save by the alternation of lights and shadows proceeding from a like alternation of solid substance and of hollow spaces beneath (Plate VII. fig. 7). This predominance of the concentric divisions, which gives a very distinctive aspect to the disks which exhibit it, is usually most apparent in individuals whose vertical section exhibits two planes of cells; and it has seemed to me to depend on the unusual freedom between the *lateral* communications, which I have noticed in certain individuals thus formed, so that the animal portion of each zone might be described as an annulus of sarcode, merely constricted at intervals. This peculiarly cyclical aspect of the surface (on whose occurrence in fossil specimens I believe the genus *Cyclolina* to have been founded, § 5.) may pass into either of the principal types previously noticed; thus in fig. 14 we observe the concentric zones, though still very strongly marked, breaking up (so to speak) into bands of rounded cells with slightly convex covers; whilst in figs. 5, 6 they are subdivided by very definite transverse lines into cells of remarkable squareness, which still retain the original flatness of their surfaces.

50. On the other hand, the appearance of concentric division is sometimes almost entirely wanting; the surface of the disk exhibiting excentric circular markings, which resemble those of an engine-turned watch-case (Plate VII. fig. 8), and the boundaries of the cells being formed by the intersection of these with each other. This aspect, however, which seems due to an unusual freedom in the *oblique* communications between the cells in each zone and those alternating with them in the

contiguous zones on either side, insensibly passes into the ordinary type; and it is not uncommon to meet with disks, especially fossil, which exhibit in one part the engine-turned aspect (Plate VII. fig. 8), and in another (fig. 14) that of concentric zones transversely subdivided. Indeed I have sometimes found that the very same disk might be made to present either of these aspects, according to the manner in which the light is made to impinge upon it and is reflected from it.

51. Although the rounded or ovoidal form of the superficial divisions is specially characteristic of the simple type of Orbitolites, yet it is by no means restricted to this; being frequently met-with in the thicker disks of the more complex type, and being almost constant in the fossil forms that abound in the early Tertiaries. Its occurrence, however, may always (I believe) be considered as indicating an incomplete separation between the superficial cells and the columnar cells of the intermediate stratum (§ 58.); so that the former present the shape of the latter, in place of the form which properly characterises them. The shape of the cell is sometimes marked out in unusual strength by the convexity of its lid or cover, as shown in Plate VII. fig. 15; and this feature is often so pronounced in the large fossil Orbitolites of the Paris basin, as to become visible to the naked eye. A very marked diversity in its degree, however, as well as in the size of the cells, is to be noticed in the contiguous zones of another specimen (Plate VII. fig. 16); whence it is obvious that the convexity is a mere accidental variation, and is a character of no value whatever as regards the differentiation of species. The relation of the rounded to the square or oblong cells is made evident by the occurrence of intermediate links of transition. Thus, from such *circular* cells as are delineated in Plate VII. fig. 9, the passage is easy, through those shown in figs. 8 and 14, to those of fig. 6 (which are drawn under about twice the magnifying power), and thence to the *square* cells of the inner part of the portion of the disk figured in Plate VII. fig. 13. This last figure illustrates the important fact, that while the cells in one part of the surface of the disk are *square*, others in close proximity with them may be *oblong*; thus conducting us to the extreme form of this type, represented in Plate VII. fig. 12.

52. The foregoing considerations seem to render it obvious, that the diversities in the *form* of the superficial cells do not afford any ground whatever for the establishment of a corresponding multiplicity of specific types, but that they must rank as individual variations to which there is scarcely any definite limit. If the originals of Plate VII. figs. 5, 7, 9, 12 and 15, had happened to have presented themselves to the Systematist without any of the connecting forms, he might have been pardoned for describing them as distinct species characterised by well-marked differences in the form and arrangement of their cells; but no such differentiation can be admitted in the face of the fact, that these are only extreme examples of variations, which show themselves in a minor degree between almost every two specimens brought into comparison, and even between the different parts of the same disk. Moreover, when it is borne in mind, that the animal basis on which the calcareous skeleton is moulded

is not a body of constant shape, provided with organs having a fixed relation one to another, but is a mass of almost homogeneous sarcode, which in the living state is continually undergoing changes of form, one part extending itself into pseudopodia, whilst another undergoes a corresponding contraction, a strong *à priori* improbability is seen to exist, that, in animals of such organization, the form of the component segments should possess that value as a specific character, which it can only derive from *constancy*.

53. Besides those regular markings of the surface, which correspond to the division of the interior into cells, a peculiar aspect is frequently given to it by the deposit of calcareous thickenings, which are sometimes irregular, but which occasionally present an approach to symmetry. The most remarkable example I have met with, of this kind of addition, is delineated in Plate VII. fig. 11, in which it will be seen that the deposit has taken place in radial lines disposed with a certain degree of regularity. But in fig. 10, which represents a specimen whose surface is far less altered by these deposits, no such symmetry presents itself; and other specimens in my possession exhibit the means between these extremes. Hence we are justified in pronouncing this peculiarity to result from an accidental outgrowth, which is so variable in its degree as not to afford the least basis for specific differentiation. It is worthy of note, however, that it presents itself far more frequently, and also in a far more characteristic manner, in the Orbitolites of the Philippine Seas, than in those of the Australian or of any other provinces; and this circumstance seems to render it probable, that the outgrowth is directly due to the influence of some external conditions, probably to an excess in the proportion of carbonate of lime in the waters inhabited by these particular specimens.

54. *Variations in Mode of Growth*.—Although the cyclical mode of growth, when once established, is subsequently maintained with great regularity, and although in what may be considered the typical form, it commences from the 'nucleus' itself, yet there are numerous instances in which the typical regularity is more or less widely departed-from, so that the early increase seems to take place after an altogether different plan. The most marked antithesis to that regularly concentric type of growth, in which a complete annulus of cells is formed around the large circumambient segment of the 'nucleus' (see ¶ 17, also Plate IV. fig. 5, and Plate VII. fig. 2), is presented by those forms in which this circumambient mass only gives origin to new cells at its extremity; these in their turn bud-forth others, which extend and multiply themselves laterally as well as in advance; and thus a kind of spiral is produced, which opens-out very rapidly, the lateral portions of its mouth tending to grow-round and embrace the nucleus. Thus, starting from the central globular mass, 1, of Plate IX. fig. 4, we see that the circumambient mass 2 2, which nearly surrounds it, gives origin at one of its extremities to a smaller mass, 3, from which bud-off two cells, 4 4, which again give origin to four cells, constituting the row 5 5. The cells of the next row, 6 6, are more numerous, but are themselves exceeded by

those of the zone 7 7, which not only surrounds it, but extends further backwards upon the nucleus. So the cells of the zones 8 8, 9 9, 10 10, 11 11, and 12 12, progressively increase in number, and each zone extends itself further back upon the nucleus, until those of the last of these zones nearly meet upon its yet unenclosed margin. The cells of zone 13 13 do actually meet there, so as to form a complete circle; and zones 14 14 and 15 15 are formed with cyclical regularity, as would be any other zones subsequently produced. A still more complete spiral, in which twenty-two zones (commencing with the central segment) succeed one another before the first complete annulus is formed, is shown in Plate IX. fig. 2. Both figs. 2 and 4 (the latter of which is diagrammatized) represent the central portions of large disks, whose peripheral portions grow on the regular cyclical plan.

55. Now if these two plans of growth—the one cyclical from the beginning, the other cyclical only after having been at first spiral—were constantly presented in well-marked contrast with each other, there would be good ground for considering them (as Professor WILLIAMSON has done*) to be characteristic of distinct specific types. But this idea cannot be entertained, when a large number of individuals are examined. For it then becomes apparent, that the number of cases in which the nucleus is surrounded on all sides by the same number of zones, indicating that the concentric mode of growth has prevailed from the very first, are very few; but that in by far the larger proportion of specimens, there is a slight excentricity of the nucleus, with a larger number of zones on one side than on the other, as in Plate IX. figs. 1, 3; indicating that the first-formed zones have been incomplete circles, owing to a restriction of the gemmation of the nucleus to one part of its periphery. This is shown extremely well by decalcified specimens of the animal, no two of which, in fact, precisely resemble one another as to the mode in which the first zone of segments originates in the nucleus. Thus in the specimen represented in Plate IV. fig. 1, of which the nucleus is represented on a larger scale in fig. 12, the circumambient segment of the nucleus gives off only *three* stolons, at the end most remote from its connexion with the central mass; and the first zone of segments is far from being entire, the cyclical type not being completely attained until two or three successive additions have been made. In fig. 13, *eight* stolons are given off from the nucleus; and from the half-zone which they form, an entire circle is next produced; thus affording a remarkable confirmation to the idea I have already suggested (§ 37.), as to the capacity of a portion of a zone to give origin to a complete annulus, by the lateral extension of its bands of sarcodæ. In fig. 10, the nucleus gives off *eleven* stolons on one side, and there are indications of *three* or *four* on the other. In fig. 6, the stolons come forth from a still larger proportion of the periphery of the nucleus; the zone which first surrounds it, however, is still incomplete in some parts, though the succeeding zone forms an entire circle. Finally, in the specimen represented in fig. 5, which is almost the exact counterpart of the disk represented in Plate VII. fig. 2,

* Transactions of the Microscopical Society, 1st series, vol. iii. pp. 116, 119.

the stolons pullulate from the entire circumference of the nucleus, and the annular zones of segments are complete from the first. The greater the limitation of the power of gemmation to one side of the nucleus, and the larger the number of incomplete zones, the more will the early plan of growth approximate to the spiral type, such as is represented in Plate IX. figs. 2, 4. It is obvious that the existence of these intermediate gradations breaks-down that barrier between the extreme forms, which Professor WILLIAMSON had proposed to erect; and shows that in this, as in many other particulars, differential characters, which at first sight appeared to be perfectly satisfactory, lose all their force when carefully traced through a sufficiently extended series of specimens.

56. It is desirable to note, as bearing on the relations between *Orbitolites* and *Orbiculina*, that even in those forms of the first-named type, in which the *spiral* mode of early growth is most characteristically displayed, it never seems to proceed far beyond a single turn; and further, that the later portion of this whorl merely surrounds the earlier, and does not cover it; so that unless (as sometimes happens, Plate V. fig. 5) the nucleus should itself be thicker than the zones of cells which immediately surround it, there is no central protuberance. In *Orbiculina*, on the other hand, the early growth invariably takes place according to the spiral type; this type is always maintained, until several turns have been made; and the later whorls not only surround but cover-in the earlier, so as to give rise to the central knob or protuberance. Some general remarks, which I have to make on the combination of the helical and cyclical types of growth, bearing upon certain fundamental questions of classification, will be more appropriately introduced in a subsequent Memoir, after the structure of *Orbiculina* shall have been compared with that of *Orbitolites*.

57. It is not, however, in the early mode of development alone, that striking diversities present themselves; for numerous variations, some of them quite as remarkable, are seen in the course of the evolution of the several parts which are characteristic of the 'complex' type. Thus, in the first place, the intermediate stratum is sometimes entirely deficient in the zones immediately surrounding the nucleus; so that the upper and lower annuli of sarcode are represented by only a single band, as is indicated by the singleness of the aperture through which it passes. In the specimen figured in Plate V. fig. 9, we see this to be the case only with the *three* zones nearest the centre; in that represented in Plate V. fig. 10, the canal is single in the *five* inner zones; whilst in that represented in Plate V. fig. 7, the canal is single for the first *twenty-three* zones. Whenever the annular canal is single, the upper and lower superficial cells also become continuous, and form a series of columnar cells in every respect similar to those of the simpler type (compare Plate V. fig. 5 with the portion *a—b* of Plate V. fig. 7). If, then, the growth of either of these disks had been checked within the first zone in which its annular canal becomes double, it would have been accounted as belonging to the simpler type; and the wide variation which here shows itself, in regard to the distance from the nucleus at which the more com-

plex type begins to be assumed, sufficiently explains the fact already noticed (§ 22.), that although the disks of the 'simple' type are for the most part of minute size, yet that the diameter of many of them exceeds that of the smaller disks of the complex type.

58. Even when an intermediate stratum is formed by the separation of the annular canals, the superficial cells are not always clearly marked-off from its columnar cavities; for instead of being separated by floors formed by the expanded summits of the zonal septa (§ 28.), they sometimes open at once into the columnar cells of the intermediate substance, so as to be quite continuous with them. Of this we have an example in the three zones 6—8 of the specimen represented in Plate V. fig. 10, *b—c*. This continuity of the superficial cells with the intermediate columns, is sometimes maintained throughout the disk, so that in no part of it are the former clearly marked off from the latter; as is seen in the portion *b—d* of fig. 7, Plate V.; in which, however, the intermediate layer is much less regular than usual. This method of growth is so remarkably constant in the *Fossil Orbitolites* of the Eocene strata, whose intermediate layer is fully and very regularly developed (see Plate VI. figs. 10, 11, and Plate VIII. fig. 2), that it might be considered to be specifically characteristic of them, did we not occasionally find it to occur in certain zones of recent disks, which are elsewhere exactly conformable to what I have described as the regular type. Thus in the vertical section represented in Plate V. fig. 10, we see that whilst the superficial cells of the three zones *b—c* are continuous with the columns of the intermediate stratum, a change then occurs in the relative places of their zonal septa, so that the cells of the former come to be, as it were, detached from the columns of the latter, and to have floors formed by the summits of the partitions by which these are divided. It is, as already remarked (§ 51.), where the superficial cells are continuous with the columnar cells of the intermediate substance, that they present the rounded or ovoidal shape, instead of the elongated straight-sided figure which is their characteristic form. And the former seems to give place to the latter, whenever the cells of the superficial layers are perfectly separated from those of the intermediate stratum, and are connected only with the annular passages.

59. The intermediate stratum, again, may be altogether wanting, notwithstanding that the two superficial layers are separated from each other by a horizontal partition. In this case, each layer has its own annular canal; and its cells have sometimes such an arrangement as regards those of the other layer, that one of the connecting stolons from which each segment arises, will pass into the alternating cell of the upper layer, and the other into that of the lower. This arrangement may present itself as one of the modes of transition from the simpler to the more complex type, as is shown in Plate V. fig. 9; the columns being disposed to subdivide transversely when they attain a considerable length, and the annular canal becoming double; whilst in zones more distant from the centre, the two layers are separated by the interposition of the intermediate stratum. Sometimes, however, the disk continues to increase and attains

a considerable size on this duplex type; and its edge then presents two rows of rounded prominences with pores between them, those of the upper and lower rows alternating with each other, as is well seen in the vertical plate of the monstrosity represented in Plate IX. fig. 10. It is on a disk of this type that Professor EHRENBURG has founded his genus *Amphisorus*, which I cannot regard as even specifically distinct from the ordinary Orbitolite.

60. The next variety to be noticed, consists in a complete absence of regularity in the disposition of the columnar cells of the intermediate stratum, so that they present an assemblage of indefinitely-shaped passages, communicating with each other in various directions. This variety is chiefly interesting, as showing how little importance is to be attached to smaller deviations of the same kind. The most remarkable example of it which I have met-with, is represented in Plate V. fig. 7, *c—d*. In Plate V. figs. 11, 12 are represented two examples of irregularity in the disposition of the superficial and intermediate cells in the zones immediately surrounding the centre.

61. Lastly, I have to mention, that the septa dividing the contiguous cells of the same zone are occasionally deficient, so that the interior of the zone is a continuous circular passage, with only slight indications of the normal divisions. In such a case, it is obvious that the ring of sarcode must have been everywhere of nearly uniform thickness, showing no division either into horizontal or into vertical segments; and it may not be thought improbable that this is its first condition in every case, and that its segmental division is a subsequent process, so that the shelly investment, if formed previously to the segmentation, will have the character of incompleteness just described. I cannot help suspecting, that the peculiar groove around the margin of the Feejee specimens formerly noticed (§ 25.), is referable to a still greater incompleteness of the production of the calcareous investment around the newly-forming zone.

62. *Monstrosities*.—Besides those departures from the normal type of growth, which have been described as variations or irregularities, there are certain others of rarer occurrence, which can only be regarded as '*monstrosities by excess*;' consisting in the production of one or more incomplete secondary disks by outgrowth from the first. In the specimen represented in Plate IX. fig. 8, the secondary disk forms a half-circle BD, of about the same diameter with the primary AC, and is superposed vertically upon the latter, the plane of junction passing through its centre. In the specimens represented in figs. 7 and 9, the secondary disk is relatively smaller, extending only from the centre to the margin of the primary, but still meeting it nearly at right angles.—In the specimen of which two different aspects are shown in figs. 5, 6, it would seem difficult to say which is the primary and which the secondary disk, and it would be more correct to describe the entire structure as consisting of a single half-disk AB and of two half-disks BC and BD, meeting each other at an acute angle CBD, neither of them being in the same plane with the single half-disk, but both of them meeting it at similarly obtuse angles ABC and ABD. The opening of one of the

obtuse angles is shown in fig. 6, and that of the acute in fig. 5; and in each view it is seen, that the divergence takes place in a plane which passes through the common centre of all three.—The specimen delineated in fig. 10 exhibits a multiple outgrowth of a nature resembling that shown in figs. 8 and 9. For from the surface of the disk there rises a triradiate crest, formed by three vertical plates meeting one another at nearly equal angles, but all of them nearly perpendicular to the plane on which they rest. It is a very remarkable feature in this specimen, however, that the line in which the three vertical planes meet, is traceable at its base to the nucleus of the horizontal disk; so that they all bear the same relation to it, as does the single outgrowth in the instances previously cited. Hence we may attribute all these monstrosities to an excess of productive power in the sarcode of the original nucleus, which has put forth its first extension, not merely in the horizontal, but also in the perpendicular direction; the whole subsequent development of these outgrowths taking place after the normal plan, from the foundation thus laid.—It is interesting to remark, that the presence of such outgrowths as those now described, is far more frequent in certain localities than it is in others. Among some hundreds of specimens which I have examined from the coast of Australia, I have only met with those represented in figs. 7, 8, 9, and two or three others; the remarkable specimen delineated in figs. 5, 6, occurred with another less peculiar among a comparatively small number of Orbitolites collected by Mr. CUMING in the Philippine Seas; but in a small collection which I have inspected from the Ægean Sea, the monstrosities of this kind (of which fig. 10 was the most remarkable) were so numerous, that I think I am scarcely wrong in asserting that one specimen out of every three or four presented some excess*. Among the fossil Orbitolites of the Paris basin, the presence of a completely-semicircular vertical plate is not at all uncommon.

63. There may be some doubt in the first instance, as to the light in which we are to regard the specimen represented in Plate VIII. fig. 10; whether as a 'monstrosity by excess,' or as the product of the fusion of two individuals: but I think this will be removed by a closer examination. For it is obvious, that the smaller disk, which is surrounded by the outer zones of the larger one, has been developed from a nucleus of its own; and this nucleus does not appear to have any direct connexion with the periphery, still less with the centre, of the larger disk: on the other hand, when we consider the circumstances under which Orbitolites grow (§ 34.), it is very easy to understand, that the smaller and younger individual, having attached itself in too near proximity to the larger and older one, should become imbedded therein (so to speak) by the extension of the newly-forming zones of the latter around its margin.

* This is by no means a solitary case of the prevalence of monstrosities in particular localities. The collection of Mr. BEAN of Scarborough contains a number of curiously-distorted specimens of the common *Planorbis marginatus*, which have all been collected in one brook. Their peculiarities are by no means repetitions of each other; and I am disposed, therefore, to regard them rather as resulting from the influence of external conditions, than as accidental varieties hereditarily propagated.

In fact, the manner in which the outer zones of the larger disk envelope the smaller, precisely corresponds with that in which we have seen the new zones originating from the uninjured margin of a mutilated specimen, to extend themselves along its fractured edges (§ 37.).

V. *Of the Essential Characters of Orbitolites, and of its relations to other Types of Structure.*

64. If, now, we seek to determine the essential characters of that type of organization which is known under the designation *Orbitolites*, we find them to lie in the presence of a *series of annuli of sarcode* (and of corresponding *passages* in the shelly disk) arranged concentrically round a nucleus; each zone in the simpler type containing but a *single* annulus, so constricted at intervals as to form a series of somewhat columnar segments (occupying the cells of the shelly disk), connected with each other by narrow bands of sarcode; whilst in the more complex type each zone contains two such annuli, including between them a portion of its series of columnar segments, so as to constitute an *intermediate* stratum, distinct from the *superficial* portions. In either case, the segments of successive zones freely communicate with each other by *radiating bands of sarcode* (also leaving *passages* in the shelly disk), whose normal direction is such as to connect each segment with the two segments that alternate with it in each of the adjacent zones.

65. Now the addition of new zones, each similar to the last, is a simple matter of *growth*; but the passage from the simpler to the more complex plan marks an advance in *development*; and this advance essentially consists (here as elsewhere) in a progressive *differentiation of parts*. When, with the vertical extension of the columnar segments, the annular canal subdivides itself into two, the communications between the successive zones no longer come-off, as before, from the annular canal, but from the intermediate portions of the columnar cells; and instead of the two diverging passages from each cell being in the same plane, they lie in different planes, alternating with each other vertically. Up to this point, we observe little else than a multiplication of parts vertically, as well as horizontally, and a separation of connexions that were previously confluent. But in the highest stage of development, we find a marked alteration in plan; for those portions of the columnar segments, which lie between the two annular canals of each zone and the two surfaces of the disk, become completely differentiated from the portions that occupy the intermediate stratum, so as to form a peculiar set of *superficial cells*; and these are so equally connected with *two* zones, as to make it impossible to say that they belong specially to either.

66. Now we have seen that *development* may be checked, while *growth* continues, at any period of its progress; so that we find *Orbitolites* growing to a considerable size upon the very simplest plan,—others still larger formed upon the duplex plan,—the largest yet known (fossilized in the Paris basin) developed upon the multiple plan

without separation of the superficial cells,—while the most complete, in regard alike to multiplication and to differentiation of parts, are only found among the disks at present existing; and it is interesting to observe, that some of them present this highest grade of development, while as yet of comparatively minute size. I am not acquainted with any other Animal body, in which so wide a range of developmental variation normally exists. The lower classes of the Vegetable Kingdom, however, especially the group of Fungi, afford abundant examples of it*.

67. The extreme freedom with which all the cavities of the shell mutually communicate, is a very marked feature in the structure of this type; and shows that the several parts of the animal body are far more closely connected into one whole, than they are in most of the other Foraminifera whose general plan of conformation is more or less analogous. Indeed, if we were to imagine a discoidal mass of sarcode to be traversed by a reticulated calcareous skeleton, somewhat resembling that open areolar texture which forms the *shell* of the Echinida, and this network to possess something of that regularity of the disposition of its successively formed parts, which is presented to us in the *spines* of the Echinida, we should have no unapt representation of the relation of the shelly disk of the Orbitolite to the animal which it envelopes. There are certain Sponges which have a reticulated skeleton composed of mineral matter disposed in a mode not altogether dissimilar, whilst the constitution of their soft bodies is essentially the same. And a remarkable connecting link between Orbitolites and Sponges, seems to be presented to us in the curious *Thalassicolla* discovered by Mr. HUXLEY†. The relations of Orbitolite to other Foraminifera have already been partly touched-on, and will become more clear hereafter, when the types which most approximate to it shall have been themselves described.

VI. Of the Species of Orbitolites.

68. It only remains to inquire, whether the diversities which have been described as existing among Orbitolites, afford any ground for assuming the existence of more than a single species. With regard to the *recent* forms, with which, so far as they are at present known, I have made myself fully acquainted, I can speak confidently; since, as I have demonstrated, the Orbitolite with a *single* stratum of cells (*O. marginalis* of LAMARCK, *Sorites* of EHRENBERG), that with a *double* stratum (*Amphisorus* of EHRENBERG), and that with *multiple* strata (*Marginopora* of QUOY and GAIMARD, *Orbiculina Tonga* of Professor WILLIAMSON), are fundamentally the same forms, developed in three different modes.

69. Of the identity of all the *fossil* species with the foregoing, I cannot speak with the same confidence; since there are some of which I can only judge from figures. Into the structure of that which is best known, however, and which has been commonly accounted the type of the genus, viz. the *Orbitolites complanata* of the Paris

* See especially the recent Memoirs of M. TULASNE, in the 'Annales des Sciences Naturelles.'

† Annals of Natural History, 2nd series, vol. viii. p. 433.

basin, I have made investigations scarcely less minute and extended than into that of the recent forms; and I have come to the conclusion, that it cannot be specially distinguished from the large Australian Orbitolite, to which it bears a very obvious general conformity. It is true that it differs from the typical forms of the latter in two important features of structure, which are, however, mutually connected;—namely, the direct continuity of the cells of the superficial layers with the columnar cells of the intermediate layers; and the rounded or ovoidal form of the superficial cells, which (as already stated) these always possess, as in the simpler type, unless they are disconnected with the columnar cells, and communicate only with the annular stolons (see ¶ 58.). But since this very peculiarity does present itself in certain existing individuals, whose development seems to have taken place upon a lower type, and since it occasionally shows itself in the course of the passage from the simplest to the most complex type, in such as ultimately attain the latter, there appears to me no room for questioning the specific identity of the *O. complanatu* with the Australian forms, notwithstanding that I have never met, among the numerous specimens which I have examined of the former, with those elongated parallel-walled superficial cells, which constitute the most distinctive feature in the latter. It may be well, moreover, to bear in mind the remark I have already made, respecting the local prevalence of particular varieties of form; since there is nothing more strange in the incompleteness of the type of development presented by the Paris-basin Orbitolite, than in that tendency to excessive development, which gives rise to the numerous monstrosities that are presented by the Ægean specimens (¶ 62.), or in those radial deposits on the surface, which are so common among the Philippine forms (¶ 53.). My belief in the specific identity of this fossil with the recent types has been strongly confirmed by the circumstance, that among the Paris-basin forms I have found a minute specimen, which corresponds in every respect with the simple type of the existing species.

70. Of the other fossil species cited by LAMARCK, the *O. macropora* of the Maestricht beds, judging from the figure given of it by GOLDFUSS, is nothing else than an Orbitolite of simple type, whose marginal cells have been laid open by attrition both above and below, as in Plate VII. figs. 8, 10. The *O. concava* and *O. pileolus* of LAMARCK are not distinguished in his definition by any other character than that drawn from *form*, which we have seen to be so variable as to be quite insufficient as a distinctive feature. It is quite possible, moreover, that they may belong to another type, nothing being said in the description of them, either of concentric lines, or of pores. If, as I believe, the *O. concava* of LAMARCK (figured by MICHELIN in his 'Icon. Zoophyt.,' pl. 7. fig. 9) be identical with the *O. conica* of M. d'ARCHIAC, I feel certain (from careful examination of its imperfectly-preserved internal structure) that, whatever it may prove to be, it is *not* an Orbitolite. So again, the *O. lenticulata* of LAMARCK, judging by the figure given of it by LAMOUROUX*, is *not* an Orbitolite,

* Polypiers, pl. 72. figs. 13, 16.

but probably a Lunulite. Of the species subsequently described by other authors, I entertain no doubt that the *O. disculus* of M. LEYMERIE*, as well as in all probability the *O. plana* of M. D'ARCHIAC, is nothing else than a variety of *O. complanata*, more especially as its young is said to be like the *O. macropora* of Maestricht. The *O. gensacica*, *O. secans*, and *O. socialis* of M. LEYMERIE, are all undoubtedly *Orbitoides*, and all belong, I believe, to the same species; though on this point I could not speak positively, without an examination of their internal structure. So, again, the *O. mamillata*, *O. Fortisii* (*O. gigantea* of D'ORBIGNY), *O. papyracea*, *O. stellata*, *O. sella* and *O. radians* (*O. radiata* of D'ORBIGNY) of M. D'ARCHIAC† are all probably *Orbitoides*, as he has himself subsequently recognized in regard at least to some of them‡. The *O. elliptica* of MICHELIN, so far as I can judge from the figure he gives of it (pl. 71, fig. 11), is certainly not entitled to rank as a distinct species, its elliptic form being utterly insufficient to separate it (§ 47.). And as I have already pointed out (§ 49.), unless some distinctive character be furnished by the internal conformation of the bodies which have been ranked in the genus *Cyclolina* by M. D'ORBIGNY, this also should take rank merely as a variety of *Orbitolites* §.

VII. Concluding Remarks.

71. It might be asked with some show of reason, what good purpose can possibly be answered by such a minute and prolix description of a type of animal structure, so mean and insignificant as that which has been occupying our attention. To such a question I would reply—First, that I hold it to be a worthy labour to learn, and to place within reach of others, *everything* that *can* be learned respecting *any* form of Organized Being; that such a complete acquaintance is the great desideratum in every department of Biological Science; and that no works have ever exercised so beneficial an influence on its progress, as those admirable Monographs of single species, which, by thoroughly elucidating their structure and physiological history, have served as a basis for all subsequent inquiry into the nature of the Plants or Animals formed on a like plan:—Secondly, that such an inquiry can scarcely be otherwise than of peculiar utility, as relating to a tribe of Animals whose nature and history are almost as unknown to us now, as those of Polypes were to the Naturalists of a century ago, when TREMBLEY wrote his immortal ‘*Mémoires pour servir à l'Histoire d'un Genre de Polypes d'eau douce*,’ what little *is* known respecting them, being of a nature to mark them as distinct from every other type of living beings

* Mém. Géol. Soc. de France, 2 sér., tom. v. pp. 190, 191.

† *Ibid.* tom. ii. p. 178, and 2 sér., tom. iii. p. 4.

‡ Description des Animaux Fossiles du groupe Nummulitique de l'Inde, p. 350.

§ For a recent description of a form of this reputed genus, which occurs in contiguity with typical *Orbitolites*, and which seems to me to correspond in every respect with those recent specimens of which Plate VII. fig. 14 exhibits the external aspect, see Mr. CARTER's Memoir on the Fossil Foraminifera of Scinde, in ‘*Ann. of Nat. Hist.*,’ 2nd ser., vol. xi. p. 174.

with which we have a tolerable acquaintance:—and Thirdly, that certain *general principles* evolve themselves as results of these investigations, which are quite as applicable to every other department of Biological Science, as they are to the single case of the *Orbitolite*.

72. It has been shown that a very wide range of variation exists among *Orbitolites*, not merely as regards *external form*, but also as to *plan of development*; and not merely as to the shape and aspect of the *entire organism*, but also with respect to the size and configuration of its *component parts*. It would have been easy, by selecting only *the most divergent types*, from amongst the whole series of specimens which I have examined, to prefer an apparently substantial claim on behalf of these to be accounted as so many *distinct species*; and I could thus have easily created an almost indefinite number of such species. But after having classified the specimens which could be arranged around these types, a large proportion would yet have remained, either presenting characters *intermediate* between those of two or more of them, or actually *combining* those characters in different parts of their fabric; thus showing that no lines of demarcation can be drawn across any part of the series, that shall definitely separate it into any number of groups, each characterized by features entirely peculiar to itself. Thus, then, we see that the real relationship of the different types to each other, can only be determined by *the careful comparison of a very large number of individuals obtained from as many different sources as possible*;—a process which is too frequently neglected by Systematists, many of whom erect species, and even genera, without the least care to determine, by any such process, the real value of the distinctions by which they characterize them.

73. The right mode of proceeding in every other department of Natural History, must be that which has thus been proved to be the only reliable method in this; and I venture, therefore, to lay down the following general Canons, deduced from the results of the preceding investigation; which will, I think, be found accordant with the experience of all soundly-judging Naturalists, although they have not yet, so far as I am aware, received a formal expression.

74. To become fully acquainted with the Natural History of any Species, it is requisite;—(1) to study not only its external conformation, but also its *internal organization*; by which alone can the value of superficial resemblances or differences be duly estimated; (2) to trace out its entire *developmental history*, so that the true relationship of individuals in different stages of evolution may be appreciated; (3) to compare together a *large number of specimens* taken from any one locality, in order to ascertain what is the range of its variation under nearly identical conditions; (4) to search out its whole *Geographical distribution*, and to bring into mutual comparison large numbers of specimens from the remotest regions, as well as from all the intermediate areas over which it spreads, in order to determine the range of its variation under the most diverse conditions; and (5) to follow the same course of comparison throughout its *Geological distribution*, still relying only on the informa-

tion afforded by large numbers of specimens, collected (so far as may be possible) from different formations, and from different geographical areas. Until the whole of this process shall have been carefully and systematically gone through, no limitation of a species by a definition of any kind, can be regarded in any other light than as *a provisional means of marking-out the existence of a particular type of structure*, whose relationship to other types must be a matter of further investigation.

75. Let me subjoin such "pregnant instances," as shall prove the importance of each of the foregoing principles, from the result of the violation or neglect of it:— (1) so long as external conformation was alone regarded, and no account was taken of *internal organization*, the Nautiloid Foraminifera were placed among Cephalopods, and the Coralloid forms among Polypifera; to neither of which classes have they any kind of relationship; (2) so long as *developmental history* was unstudied, the Hydroid Zoophytes and the Medusoid Acalephæ were considered as entirely disconnected groups, belonging to two different Zoological classes, instead of (as in reality) different states of the very same organisms; (3) so long as reliance is placed on the comparison of a *few individual specimens* only, without any account being taken of the intermediate forms by which the more divergent types may be connected, so long are species multiplied to a most unwarrantable excess, as is found to be the case in almost every department of Zoology and Botany by those who devote themselves to a more extended comparison; thus, nineteen species have been made from the common *Potatoe*, and many more from the *Solanum nigrum*; so, multitudes of species have been instituted in various genera of Californian shells, by the late Mr. C. B. ADAMS, whose identity is established by a more extended comparison of individuals (as will be shown in a Report which is being prepared at the request of the British Association, by my brother, the Rev. P. P. CARPENTER); in fact, wherever this test is conscientiously applied, its effect is to *reduce* the number of reputed species, sometimes in a most remarkable degree*. (4) In like manner it has been by comparing only a small number of specimens from remote geographical provinces, and by neglecting the intermediate varieties that present themselves even among sufficiently large collections from these, still more among specimens collected from intervening regions, that not only numerous errors of detail have been committed, but general doctrines have been propounded, which the advance of Science has proved to be utterly untenable. As an example of the former kind, may be cited the facts mentioned by Dr. J. D. HOOKER (*op. cit.*), that of the New Zealand varieties of *Oxalis corniculata*, one of the most widely-diffused and most variable Flowering plants in the world, no less than seven or eight species have been made, neither of them supposed to be identical with any belonging to the European Flora; whilst *Pteris*

* I am most glad to find my views on this point in accordance with those of Dr. JOSEPH D. HOOKER (see his 'Introductory Essay on the Flora of New Zealand,' § 2), who has been led to the conviction, that instead of affirming the existence of 100,000 species of known Plants, we ought not to reckon more than half that number.

aquilina has a different name in almost every country in the world. It has been through reliance on such ignorant determinations, most of them proceeding on the notion that "the plants (or animals) of newly-discovered, isolated, or little-visited localities must necessarily be new," that the doctrine of the universal distinctness of the species of the New World from those of the Old, and of those of the Southern from those of the Northern Hemisphere, has attained a very wide currency amongst Naturalists, and is still obstinately persisted-in by some, in defiance of ample evidence to the contrary*. (5) Lastly, not only has the limitation of the comparison among Fossil types, to a small number of individuals, led to the excessive multiplication of species in the forms that are furnished by the same strata; but the same habit of relying on minute differences, without attention to osculant characters, has given rise to that disposition to regard the species of successive formations as necessarily different, which is introducing the greatest confusion into geological and palæontological determinations of every kind. How an extended comparison of individual forms tends not only to reduce the number of reputed species, but to establish the continuity of the same specific types from one stratum to another, will be remarkably seen when the laborious researches of Dr. WRIGHT of Cheltenham on the *Cidarites* of the Liassic and Oolitic formations shall have been made public.

76. Another general consideration of some interest, appears to me naturally to connect itself with the foregoing history,—namely, that the lower the general plan of organization of any being (that is, the greater the prevalence of 'vegetative' or 'irrelative' repetition in its different parts), the more is that plan liable to be modified by slight differences in external conditions, and the wider, therefore, may we expect its range of variation to be, if it be disposed to vary at all. In some instances, it is true, there appears (as in many higher forms of organization) to be an absolute incapacity for any such variation; and a limitation of the geographical and geological distribution of the species results from its want of power to exist under any great diversity of external conditions. But when the same general type of organization is found to prevail extensively both in space and in time, it may, I think, be safely regarded as probable, that that type has within itself the power of accommodation to a considerable diversity of external conditions; and hence that in the comparison of individuals, differences of conformation should be considered as of less account towards the establishment of specific distinctions, than they are when there is an obvious restriction of the type to a limited Geographical area or a particular Geological epoch.

77. In the foregoing communication, I have thought it right not only to make known the *results* of my researches, but so to develop my *plan of investigation*, that the value of those results may be duly estimated. In the memoirs which I trust to be

* "Thus as long ago as 1814, Mr. ROBERT BROWN gave a list of 150 European plants common to Australia and Europe. The identity of many of these has repeatedly been called in question, but almost invariably erroneously; added to which, more modern collectors have greatly increased the list."—HOOKER, *op. cit.* p. 18.

enabled to forward from time to time, regarding those other typical forms of Foraminifera of which I have made a special study, it is not my intention to do more than state the *results*; hoping that they may be understood to have been attained by a method of inquiry as closely resembling that which I have here followed through its details, as the circumstances of each case may have admitted. I would have it borne in mind throughout, that, as has been admirably remarked by one of the most accomplished Botanists of our time, "the Naturalist who has the true interest of science at heart, not only feels that the thrusting of an uncalled-for synonym into the nomenclature of science is an exposure of his own ignorance, and deserves censure, but that a wider range of knowledge and a greater depth of study are required, to prove those dissimilar forms to be identical, which any superficial observer can separate by words and a name" (Dr. J. D. HOOKER, *op. cit.* p. 14, note).

EXPLANATION OF THE PLATES.

PLATE IV.

Structure of the Animal of Orbitolite.

- Fig. 1. Entire Animal, from a small and simple disk, the shell having been removed by maceration in acid; in the peripheral portion the segments of sarcode are wanting, and the structureless residuum of the shell is alone seen:—magnified 40 diameters.
- Fig. 2. Appearance of a portion of Sarcodæ, highly magnified:—180 diam.
- Fig. 3. Portion of the body of one of the more complex forms (resembling fig. 4), in which the sarcodæ has broken up into little spheres (gemmules?);—*a, a*, superficial segments; *b, b*, annular band:—180 diam.
- Fig. 4. Portion of the body of one of the more complex forms, as seen in *vertical* section;—*aa, a'a'*, upper and lower rows of superficial cells, each cell connected, at its two extremities, with the annular bands *bb* and *b'b'* of *two* zones; from these annular bands spring the columnar segments *cc, c'c'*, those of the same zone occasionally passing into each other, and communicating with those of the next zone by oblique peduncles alternately passing towards one side and the other:—150 diam. (N.B. This figure is somewhat *ideal*, being made-up from several preparations; but for every point which it represents, these preparations give warranty.)
- Fig. 5. Nucleus and first two annular zones, exhibiting the typical conformation;—*a*, the central segment; *bb*, the circumambient segment, from the entire margin of which are given off peduncles of sarcodæ, which give origin to the first annular zone:—84 diam.

- Fig. 6. Nucleus and first two annular zones of another disk, showing a deficiency in the connexions of the first annular zone with the circumambient segment *bb*, for about a third of the circumference of the latter, between the points *cc*:—84 diam.
- Fig. 7. Portion of one of the *surfaces* of an animal of complex type (as in fig. 4):—*aa, aa*, rows of superficial cells, connected at their two extremities with the annular bands *bb, bb*:—150 diam.
- Fig. 8. Portion of fig. 1, enlarged, to show the ordinary mode in which the segments of each zone are connected by peduncles with the *annular band* of the preceding zone, so as to alternate with its segments; showing also the occasional interpolation of additional segments, *a, a*, whose peduncles come off from the *segments* of the preceding zone:—90 diam.
- Fig. 9. Portion of a section of the shelly disk enlarged, to show the corresponding appearances it presents; each cell being ordinarily connected by a radial passage with the *annular canal* of the preceding zone, and thus with the two cells alternating with itself; but cells *a, a*, being sometimes interpolated, which open directly into the *cells* of the preceding zone:—90 diam.
- Fig. 10. Central and circumambient segments (*a* and *bb*) of a large disk, showing the origin of the segments of the first annular zone, *c, c*, from less than half the circumference of the nucleus:—84 diam.
- Fig. 11. Peculiar bodies (ova?) found in the substance of the sarcode in different parts, showing successive stages, *a, b, c, d, e, f*, of binary subdivision; *g*, other bodies of somewhat larger size, found in one of the superficial cells of a vertical section:—130 diam.
- Fig. 12. Central portion of fig. 1, enlarged to the same scale as figs. 5, 6, 10; showing the central segment *a*, the circumambient segment *bb*, and the origin of the first annular zone in *three* peduncles proceeding from the end of the latter:—84 diam.
- Fig. 13. Central portion of another disk, showing the origin of the first annular zone by *eight* peduncles from the circumambient cell:—84 diam.

PLATE V.

Structure of the Calcareous Disks of Orbitolite.

- Fig. 1. Ideal Representation of a Disk of the Simple Type, the details of the different parts made-up from actual specimens; showing the natural surface, with the markings of the cells; the natural margin, with the single row of pores between the protuberances of the cells;—a portion of the interior, as displayed by a *horizontal* section, showing the central cell *a*, the circumambient cell *b, b*, the concentric zones of cells *c, c*, with the annular passages which connect together the cells of the same zone, and the radiating passages

which extend from the annular passages of each zone to the cells of the next, and, in the outermost zone, to the pores d, d ;—another portion as displayed by a *vertical* section e, e , in a *radial* direction, which lays open the columnar cells, but passes through the intercellular partitions, in alternate zones;—and another portion ff , as displayed by a fracture in the course of one of the zones, laying open the entrances to the cells from its inner or central side.

Figs. 2, 3. Two large recent disks from the Feejee islands, plicated towards the margin, but one much more so than the other, and with a projection of the upper and lower edges, so as to leave a deep marginal furrow:—enlarged 2 diam.

Figs. 4, 5. Vertical sections of two disks, drawn under the same magnifying power, showing the marked difference in the size and proportions of their parts. In each disk we see the central cell, with the circumambient cell laid open on either side of it; and the cells of successive zones, with their communications:—30 diam.

Fig. 6. Ideal Representation of a Disk of the Complex Type; the details of the different parts made-up from actual specimens:— a , central cell; b , circumambient cell; c, c , concentric zones of oblong superficial cells, some of them laid open; d, d , marginal pores, forming several rows; d'', d''' , corresponding pores of inner zones, once marginal, but now connecting them with surrounding zones; e, e , vertical section in a radial direction, showing the zones nearest the centre to be made up of simple columnar cells, but those of the remainder of the disk to be composed of two superficial layers and of an intermediate stratum; f, f , floors of the superficial cells, with an aperture at each end of every one; g, g , annular canals, running beneath these floors, with the large apertures leading to the columnar cells of the intermediate stratum; g' , the same canals near the other surface of the disk; g'' , the same canals laid open through the plane at which they give off the two passages into the superficial cells; g''' , the same canals, as cut transversely by a vertical section; h , passage of the horizontal section through the intermediate stratum, showing the summits of its columnar cells about to enter the annular canals; i, i, i , and k, k, k , passage of the horizontal section through two different planes of the intermediate stratum, showing the connexion between the columnar cells of successive zones, by oblique passages running in different directions; l , portion immediately surrounding the nucleus, formed upon the simple type, as in fig. 1.

Fig. 7. Vertical section, taken in a radial direction, of a recent disk incompletely developed on the complex type; showing at a , a single chamber of the cavity of the nucleus, the section having traversed the circumambient cell; from a to b , including twenty-three zones, the disk developed upon the simple

type; from *b* to *c* the annular canal double, and an irregular intermediate stratum interposed, from which, however, the superficial cells are not completely differentiated; and from *c* to *d* the imperfect separation of the superficial cells from the intermediate layer, and the extreme irregularity of the latter :—50 diam.

Fig. 8. Tangential section, near the margin of the same disk, showing the same peculiarities :—50 diam.

Fig. 9. Central portion of a disk, showing the nuclear cavity divided into two (the section having traversed the central cell and one side of the circumambient); the formation of the first three zones (*a—b*) on the simple type; the imperfect separation of the superficial cells from the intermediate stratum in the next two zones (*b—c*); and the regular development of the remainder (*c—d*) on the complex type :—50 diam.

Fig. 10. Vertical section of the central portion of a disk of complex type; showing four cavities in the nucleus; the first five zones (*a—b*) constructed upon the simple type, with a single annular canal, but an incipient separation manifesting itself between the superficial cells and the intermediate stratum; in the next three zones (*b—c*) the annular canal double, but the superficial cells still partly continuous with the columnar; the outer part (*c—d*) framed according to the regular complex type :—48 diam.

Fig. 11. Vertical section of a disk of complex type, showing an unusual development of vertically superposed cells immediately around, and even partly covering, the nucleus, from which they arise by four layers of passages; a progressive diminution in the thickness of the disk, as far as the fifth zone (*b*), with a gradual approximation towards the regular type, on which the remainder (*b—c*) is developed :—48 diam.

Fig. 12. Vertical section of a disk of complex type, showing commencement of its first zone by a single layer of passages (*a*) from the nucleus; the presence of two annular canals, with the absence of separation of the superficial cells, in the first zone (*b*); the incomplete separation of the superficial cells from the intermediate columnar portion in the second zone (*c*); and the normal conformation of the remainder (*c—d*) :—48 diam.

PLATE VI.

Fig. 1. Portion of a disk of simple type, from the immediate neighbourhood of the nucleus, showing the beak-like projections at the sides of the passages very remarkably developed :—100 diam.

Fig. 2. Horizontal section of the intermediate layer, passing (in consequence of the flexure of the disk) through two different planes, and thus showing the two different directions of the oblique passages which connect the colum-

nar cells of different zones; also showing a marked difference in the size of adjacent cells:—100 diam.

Fig. 3. Horizontal section through one of the superficial layers, showing the elongated form of its cells, and the aperture at each end of their floor:—100 diam.

Fig. 4. Nucleus and surrounding zones of the excentrically-developed disk shown in Plate IX. fig. 3; the beak-like projections at each side of the pores opening into the new zones (shown in fig. 1) are here generally deficient:—100 diam.

Fig. 5. Appearance of the thin wall covering-in the central cell of a large nucleus, as seen under a high magnifying power, showing the quasi-cellular markings:—100 diam.

Fig. 6. Horizontal section through the intermediate layer of a disk of complex type, showing an unusual irregularity in the communications of the cells:—100 diam.

Fig. 7. Radial section of a recent disk, showing the complex development on the normal type; *aa, bb*, upper and lower superficial layers; *c, c, c, c*, intermediate stratum; *dd, d'd', d''d''*, summits of partitions between successive zones, forming the floors of the superficial cells; *e, e', e''*, oblique passages through the floors of the cells of the superficial layer, leading towards the annular canals; *f, f', f'', f'''*, annular canals of four zones, near the lower surface of the disk; *gg*, partitions between the adjacent cells of the same zones; *hh*, perforations in these, through which the columnar cells inosculate with each other:—100 diam.

Fig. 8. Tangential section of a fossil disk of complex type, showing four columnar cells, *aa', bb', cc', dd'*, of the same zone, divided by sinuous partitions, with the orifices leading into the columnar cells of the next interior zone:—100 diam.

Fig. 9. Similar tangential section, showing four cells of the next interior zone, *aa', bb', cc', dd'*, alternating with the preceding, and the entrance of the passages of the same vertical row, alternately into one and the other of the cells on the two sides of each of the sinuous vertical partitions:—100 diam.

Fig. 10. Radial section of a fossil disk, showing the incompleteness of the separation of the superficial cells from the intermediate layer, and the irregularity in the arrangement of its cells, with their numerous lateral inoscultations (compare Plate V. fig. 7, *b—d*):—48 diam.

Fig. 11. Radial section of a thicker fossil disk, showing a more regular arrangement of the columnar cells of the intermediate layer (still, however, with numerous passages for lateral inoscultation), and the complete continuity of the superficial cells with these:—48 diam.

PLATE VII.

Figs. 1—4. A series of specimens, drawn under the same magnifying power (35 diam.), illustrating the variations which present themselves in regard to the *Size* of the nucleus.

The remaining figures represent various appearances exhibited by the *Surfaces* of Disks, simple and complex:—all magnified 35 diam., except fig. 6, which is magnified 70 diam.

Figs. 5—7. Portions of surfaces of simple disks, in which the concentric circles are strongly marked, and the transverse divisions of the cells are comparatively obscure.

Fig. 8. Simple disk, slightly concave, the marginal cells laid open by abrasion, the surface marked rather by 'engine-turned' or excentric, than by concentric circles.

Fig. 9. Portion of the surface of a complex disk, having small, round, and flattened superficial cells.

Fig. 10. Simple disk (from Australia), slightly concave, the marginal cells laid open by abrasion, the surface irregularly thickened by calcareous deposits.

Fig. 11. Flattened simple disk (from the Philippines), with abundant superficial deposits, arranged with considerable regularity in a radiating direction.

Fig. 12. Portion of the surface of a large complex disk, with very narrow oblong superficial cells.

Fig. 13. Portion of the surface of a complex disk, showing a marked difference in the proportions of the straight-sided cells, even in adjacent zones.

Fig. 14. Surface of simple disk (*Cyclolina*? of D'Orbigny), with an excentric nucleus, surrounded by strongly-marked concentric circles.

Fig. 15. Portion of the surface of a simple disk, showing unusually large and protuberant ovoidal cells.

Fig. 16. Portion of the surface of a large fossil disk of complex type, showing varieties in the size and form of the superficial cells.

PLATE VIII.

Fig. 1. Inner surface of a zone of a thick fossil disk, showing a tolerably regular arrangement of the columnar cells, the segmental constrictions of these, and the fissures leading into those of the next row:—35 diam.

Fig. 2. Outer surface of a similar zone, showing the continuity of the cells of the superficial layer with the vertical columns of the intermediate (the latter not unfrequently dividing, however, at their extremities, so as to form two cells at the end of each column), and the pores leading to the oblique

passages, directed alternately to one side and to the other, which lead to the cavities of the columnar cells:—35 diam.

Fig. 3. Horizontal section of the intermediate layer, immediately beneath the floors of the superficial cells, laying open the annular canals, with the summits of the columnar cells:—100 diam.

Figs. 4—9. Various examples of the *Reparation* of disks after fracture, and of the growth of new disks from detached fragments. For description, see ¶ 37—40 of Memoir. Fig. 6 is magnified 6 diam.; the rest 35 diam.

Fig. 10. Monstrosity formed by the inclusion of a young disk within the outer zones of an older one, that seems to have been brought into contact with it by the progressive increase of its own diameter:—25 diam.

PLATE IX.

Figs. 1—4. Various departures from the typical mode of concentric development, presented in their early state, both by simple and complex disks; some of them even passing towards a spiral mode of evolution. Figs. 1 and 3 are magnified 35 diam.; Figs. 2 and 4 are enlarged 90 diam.

The remaining figures show various forms of *Monstrosity*, produced by excess of growth from the nucleus.

Fig. 5, 6. Two views of a disk from the Philippine shores, having a single plane on one side, and two planes, meeting at an acute angle, on the other:—6 diam.

Figs. 7, 8, 9. Small Australian disks, with vertical crests:—35 diam.

Fig. 10. Disk from the Ægean Sea, with a tri-radiate crest:—35 diam.

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XIV. *Researches on the Foraminifera—Supplemental Memoir.**On an Abyssal type of the Genus Orbitolites;—a Study in the Theory of Descent.**By WILLIAM B. CARPENTER, C.B., M.D., LL.D., F.R.S.*

Received May 31,—Read June 14, 1883.

[PLATES 37, 38.]

INTRODUCTION.

THE subject of this communication is a type of the genus *Orbitolites*—first obtained in the deep-sea dredgings of H.M. Surveying Ship “Porcupine,” off the north-west of Ireland, in 1869,* and subsequently brought up from various depths in other parts of the North Atlantic and also in the Mediterranean,—which presents many points of general scientific interest; the first of these being the completeness of the transition which it establishes between the *Milioline* and the *Orbitoline* plans of growth, and the full confirmation it thus affords of the validity of the principles on which my Classification of the FORAMINIFERA is founded.

In the Monograph of the genus *Orbitolites* (1855), which constituted the First Series of my “Researches on the Foraminifera,”† I embodied the results of a careful and thorough investigation of the structure and relations of all the forms under which that type was then known to me: and I showed that while the most highly developed and most specialized of these forms exhibit the *cyclical* plan of growth almost from the very commencement,—a complete zone of sub-segments being formed by gemmation from the entire periphery of the “circumambient segment” of the central “nuclear mass,”‡ and the whole disk being made up of a succession of similar concentric zones,—there are other forms in which the primary gemmation takes place from only one side of that mass, so as to impart to the early extension of the composite structure a more or less *spiral* direction,§ which only gives place to the cyclical after repeated gemmations. The transition from the one plan of growth to the other I showed to be made by the progressive widening-out of the spire, and the increase in the number of the

* See Proc. Roy. Soc., vol. 18, p. 397.

† Phil. Trans., 1856, pp. 181–236.

‡ Ibid., Plate IV., figs. 5 and 6.

§ Ibid., Plate IX., figs. 1 to 4.

sub-segments (formed by the division of the principal segments) at every new stage of gemmation; so that at last the *alæ* of the spire, extending themselves on either side round the nuclear mass, meet and complete the circlet, around which new zones are then successively budded forth, as in the forms that are cyclical from their commencement.

I did not at that time feel justified in calling in question the validity of the order *Cyclostègues*, which had been instituted by M. D'ORBIGNY, for the reception of this and other types characterised by the cyclical plan of growth; but in my Second Series (presented in the following year), which contained the results of a similar investigation of the genus *Orbiculina*, I showed that the latter *always* begins life on the spiral plan of growth, which may or may not give place subsequently to the cyclical, and that the marginal portions of a full-grown cyclical *Orbiculina* cannot be distinguished from similar portions of an *Orbitolite*. From this fact I drew the conclusion* that although *Orbitolites* and *Orbiculina* had been placed by M. D'ORBIGNY in two distinct orders, *Cyclostègues*, and *Helicostègues*, "the relationship between them must be extremely close;" and ventured further to affirm that no Classification can have any claim to be considered as *natural*, in which they shall be widely separated."

To this point I reverted in the Concluding Summary appended to my Fourth Memoir,† in which I showed how completely the results of my researches were opposed to the principles on which the Classification of M. D'ORBIGNY had been framed, indicated the line of "descent with modification" by which a division of the primary segments that form the simply-chambered shell of a *Peneroplis* into sub-segments would give origin to the chamberlets of the spiral *Orbiculina*, and pointed out how gradational the transition is from the latter to the cyclical *Orbitolites*.

When I subsequently undertook, in conjunction with my friends, W. K. PARKER and T. RUPERT JONES, to frame an entirely new Classification of FORAMINIFERA on the basis of the principles I had laid down, I felt no difficulty in assenting to their view that the pedigree of this series might be traced yet further back, viz.: to those simplest forms of the *Milioline* type, whose shell is a flattened nautiloid spire altogether destitute of partitions—thus belonging to that *monothalamous* section which all previous Systematists had ranked as fundamentally distinct from the *polythalamous*. "From the undivided spiral of *Cornuspira*," I pointed out ("Introduction to the Study of the Foraminifera," p. 67), "to the regular scarcely-divided spiral of certain 'spiroloculine' forms of *Miliola*, the transition is almost insensible; and from the 'spiroloculine' we pass by easy steps to all the other forms of the *Milioline* type." Again, a subdivision of the widely-expanded spire of *Cornuspira* into segmental chambers gives us *Peneroplis*, with its septal planes perforated by a row of separate pores; while from this, it was again pointed out, the spiral *Orbiculina* might

* Phil. Trans., 1856, p. 552.

† Ibid., 1860, p. 571.

be derived by a further division of the segments of the sarcodic body into sub-segments, with a corresponding division of the primary chambers of the shell into chamberlets.

In the new specific type of *Orbitolites* I have now to describe, the whole transition which I thus hypothetically indicated, is actually presented during the successive stages of its growth. For it begins life as a *Cornuspira*, taking-on that 'spiroloculine' condition which marks the passage towards the *Milioline* type: its shell forming a continuous spiral tube, with slight interruptions at the points at which its successive extensions commence; while its sarcodic body consists of a continuous coil, with slight constrictions at intervals. The *second* stage consists in the opening-out of its spiræ, and in the division of its cavity at regular intervals by transverse septa, traversed by separate pores, exactly as in *Peneroplis*. The *third* stage is marked by the subdivision of the 'peneropline' chambers into chamberlets, as in the early forms of *Orbiculina*. And the *fourth* consists in the exchange of the spiral for the cyclical plan of growth, which is characteristic of *Orbitolites*; a circular disk of progressively increasing diameter being formed by the addition of successive annular zones around the entire periphery. This increase in diameter is not here accompanied (as it is in most of the other forms of the *Orbitoline* type) by a corresponding augmentation in thickness; and as the extraordinary tenuity of these disks affords an easily recognisable and (as I believe) a constant differential character of the species, I proposed in 1870* to designate it *Orbitolites tenuissima*.

ORBITOLITES TENUISSIMA. *Carpenter*, 1870.

The disks of *O. tenuissima* are usually almost perfectly flat (Plate 37, fig. 1), and exhibit a remarkable regularity of structure. The diameter of the largest complete specimen I have seen is not above 0.25 inch; but it is obvious from the size and curvature of the fragments which the dredges frequently contained, that they must have belonged to disks whose diameter was at least 0.6 inch, these larger specimens having come to pieces in their rough removal from the soft and tranquil ooze on which they had previously lain. This fragility depends in part upon the extreme tenuity of the disks, their thickness rarely exceeding *one three-hundredth* of an inch; and in part on the slightness of the connexion which (as I shall presently show) exists between the successive zones.†

When either surface of the disk of *O. tenuissima* is viewed by reflected light under a low magnifying power, its concentric zones are seen to be crossed by radial lines (Plate 37, figs. 1, 2) resembling those which pass between the septal bands

* Proc. Roy. Soc., vol. 19, p. 176.

† In *Cycloclypeus*, the marginal portions of the disk, though of even greater tenuity, have not by any means the same fragility; partly because its *vitreous* shell-substance is much firmer than the *porcellanous* shell-substance of *Orbitolites*, and partly because a layer of it is usually continued from each new zone over the whole surface of the previously formed disk. See Phil. Trans., 1856, p. 558.

of *Peneroplis*. But when a portion of the disk is viewed under a higher power by transmitted light,—which, through the extreme tenuity of its superficial lamellæ, brings its internal structure into distinct view (Plate 38, fig. 5),—these lines are seen not to be mere surface-markings, as in *Peneroplis*, but to be the indications of internal shelly partitions, which divide each flattened annular chamber into a series of narrow chamberlets, resembling those which I formerly described as constituting the two superficial layers of the “complex” type of *Orbitolites*.* Here, however, these chamberlets form but a single plane, as in the “simple” type formerly described; and the pores by which the last-formed annulus opens at the margin of the disk are arranged in single series (Plate 37, figs. 4, 5). It is worthy of note that these pores are not round, like those of ordinary *Orbitolites*, whether of the “simple” or of the “complex” type;† but are more or less elongated in the plane of the disk—a peculiarity obviously related to its extreme compression. Similar pores are seen upon the edge of any zone from which the zone external to it has been detached by fracture; and it is obvious that they constitute the channels of communication between the cavitory system of each zone and that of the zones internal and external to it; while the marginal series brings the cavitory system of the peripheral zone (and, through it, that of every interior zone backwards to the spiroloculine “nucleus”) into relation with the surrounding medium.

When a portion of the thin shelly lamella forming either surface of the disk has been removed by dilute acid, so as to lay open the cavity beneath (Plate 37, fig. 2), it is seen that each zone of chamberlets lies between two concentric rings of shell, *a, a, b, b*; and that the radiating partitions, *c*, while springing from the inner shell-ring, do not extend to the outer, so that a continuous gallery is there left, into which all the chamberlets open at their peripheral extremities. And when we examine the disk by transmitted light (Plate 38, fig. 5), we see it to be from this gallery—not from the chamberlets—that the pores of the shell-ring which incloses it proceed.

Whilst the structure of the concentric zones forming the peripheral portion of the disk thus corresponds in all its essential characters with that of the ordinary “simple” type described in my former Memoir, the structure of the central portion of the disk is altogether different. The spheroidal “primordial chamber” (Plate 38, fig. 3, *a*) is extremely minute, not exceeding 1-1000th inch in diameter, and from this proceeds a compressed shelly tube, which forms a nautiloid spiral around it (Plate 38, figs. 3, 5) each successive turn slightly increasing in breadth, so as closely to resemble the first-formed part of the spire of *Cornuspira*. The continuity of its cavity, however, is interrupted, usually at about every two-thirds of a turn, by a thickening of its wall (Plate 38, fig. 3, *b*), which seems to have been formed as a sort of foreshadowing of a septum at each addition to its length; and thus, as long as the growth of the shell proceeds upon the same plan, it is a ‘spiroloculine’ *Mitiola*.

* Phil. Trans., 1856, p. 202, Plate V., fig. 6, *c, c*; Plate VII., fig. 12.

† Ibid., Plate V., figs. 1 and 6, *d, d*.

But after making from six to eight turns (the number varying in different individuals) the spire begins to open out in the horizontal plane (Plate 38, fig. 5, *a*) without any vertical enlargement, and a complete septum is formed at the next break, marking off the first principal chamber from the previously-formed spiral tube. This septum is traversed, as in *Peneroplis*, by a variable number (*four* in the specimen here figured) of passages, which would show themselves as pores upon its external surface; but these, instead of opening into another single undivided chamber, lead into as many chamberlets, which are formed by the subdivision of the next principal chamber, *b*, by radial partitions, exactly as in *Orbiculina*. This chamber, in the individual here figured, is not separated by a completely-formed septum from the succeeding chamber, *c*, and the latter is undivided save by a single radial partition; but this is a mere individual variation,—which is of interest, however, as showing that the subdivision of the chambers into chamberlets is a secondary, not a primitive formation. The septum which closes-in the chamber *c* is traversed by 13 pores, which open into as many chamberlets formed by the subdivision of the next principal chamber; the separation of these chamberlets by radial partitions being complete for about four-fifths of the length of the chamber (that is, of the distance between its inner and its outer septum), but deficient for the outer fifth, so as to leave the continuous gallery *d*, *d*, into which all the chamberlets open at their outer ends. This chamber, it will be observed, extends itself on either side at *d'*, *d'*, so as to enclose a portion of the spiroloculine “nucleus;” and this extension is still more marked in the next chamber, whose two alæ, *e'*, *e'*, reach the ends of the transverse diameter of the original spire. The septum which separates this chamber from the preceding has the number of its pores increased to 30; and these open outwards into as many chamberlets in the next-formed chamber. As new chambers are successively added, the backward extension of their alæ is carried further and further, until (in the individual here figured, Plate 37, fig. 1) those of the ninth chamber meet at the back of the spiroloculine “nucleus,” so as to enclose it all round, and the tenth chamber forms a complete ring of chamberlets, whose derivation from the undivided chamber of the ‘peneropline’ type is made obvious by the previous transition. With each increase in the length of the septal plane, there is a proportionate increase in the number of pores by which it is traversed, the distance between them having a very uniform average; and the number of these pores determines the number of chamberlets in the next annulus, which has thus no definite relation to that of the chamberlets in either of the last-formed or in the subsequently-formed annulus. The breadth of the zones (and, consequently, the length of their chamberlets) has a range of variation from 1-180th to 1-80th of an inch, its general average being 1-120th inch; so that a disk having a diameter of 0.6 inch (or a radius of 0.3) would be made up of about forty such concentric zones. A very narrow zone is occasionally seen to intervene between two zones of ordinary breadth; but, as I have always found this to originate

in a fractured portion of the preceding zone which then formed the margin of the disk, it would seem to have been a special reparative addition.

The whole cavitary system, from the primordial chamber to the marginal annular gallery, is occupied by a continuous sarcodic body of a dark olive-green hue (Plate 38, fig. 1). Although this body may be said to consist at any one moment of a multitude of sub-segments, connected together by annular and radiating stolon-processes, yet, from what we know of its semi-fluid condition in the living animal, we may pretty confidently surmise that this subdivision is by no means permanent, but that an interchange is continually taking place between the protoplasmic contents of the inner and the outer portions of the cavitary system, so that what occupies the central spire at any moment may be transferred in no long time to the marginal annulus, and *vice versa*.

The extreme tenuity of this sarcodic body, and the transparence of the shelly laminæ that invest it, have enabled me very distinctly to recognise, by light transmitted through the disk, the presence of nucleus-like bodies (Plate 38, fig. 2) of about 1-1750th of an inch in diameter, imbedded in its substance. As might be expected from the consideration just stated, these corpuscles are very irregularly distributed. In the specimen here figured (Plate 38, fig. 1), two of the outer half-whorls of the 'spiroloculine' centre (shown on a larger scale at *b, b', b', b'*, fig. 4), are crowded with them; while in a single chamberlet, *c*, of one of the interior annuli, there are as many as five. Elsewhere, on the other hand, they present themselves with less frequency, only one or two occurring in any single chamberlet (*d, d, d*), and a large proportion of the chamberlets being entirely destitute of them. The finding of these corpuscles in the highly composite sarcode-body of *Orbitolites* is an interesting extension of the discovery, of Dr. R. HERTWIG, of corpuscles regarded by him as nuclei, in what I long since characterised as the "reticularian" type of RHIZOPODA, of which the ordinary FORAMINIFERA are the testaceous forms. This discovery was first made in the fresh-water Monothalamous *Mikrogromia*,* and subsequently extended by him to various marine Polythalamia, such as *Spiroloculina*, *Globigerina*, and *Rotalia*,† and by F. E. SCHULTZE to *Quinqueloculina*, *Lagena*, *Polystomella*, and *Planorbulina*.‡ What is the function of these corpuscles in that indefinite extension of the protoplasmic body, and the multiplication of its segments, which is so remarkable a character of this type, is not yet apparent; but that they do *not* become the centres of distinct cells separated from each other by any limiting membrane, or even of permanent segments or sub-segments, may be regarded as certain. If the nuclear character of these corpuscles be admitted, the entire composite organism thus seems to present a most interesting link of connexion between the *unicellular* and *multicellular* types; the absolute continuity of its protoplasmic substance entitling it to rank with

* Archiv für Mikrosk. Anat., Bd. x., Supplementheft (1874) p. 1.

† Jenaische Zeitschrift, Bd. x., 1876, p. 41, &c.

‡ Archiv für Mikrosk. Anat., Bd. xiii., 1877, p. 9.

the former, whilst in the multiplication of its nuclei it obviously tends towards the latter.

The growth of this beautiful organism doubtless takes place after the completion of the first annulus, in the manner described in my former Memoir (§ 35). The sarcodic body, when enlarged by the nutriment it has appropriated, will project itself through the marginal pores, in quantity sufficient to form, by the coalescence of its separate protrusions, a continuous belt of sarcode; and in the substance of this a set of radial calcareous partitions will be deposited, commencing between the pores of the margin of the previous shell-ring, while two horizontal lamellæ are formed on the superficial planes, to constitute, as it were, the floor and ceiling of the new circle of chamberlets. These horizontal lamellæ overlap but very slightly the margin of the previous annulus (Plate 37, fig. 3, *a, a*); and their adhesion to it is generally so weak that the annuli readily come apart. As the subdivision of the annulus into chamberlets does not extend to its outer portion, a passage is left (seen in vertical section at *b, b, b*, fig. 3), which is occupied by a continuous ring of sarcode, as shown in Plate 38, fig. 1; and from this ring proceed the stolons which pass outwards through the pores of the septum that closes it in.

The homogeneousness of the protoplasmic substance by which the entire cavitary system is occupied, is shown (as in the types formerly described) by the completeness with which the effects of injuries are repaired, and the plan of the original fabric restored (see Phil. Trans., 1856, Plate VIII., figs. 4-9). Not only is the loss of any part of the disk repaired by the formation of a new and continuous annulus along the broken as well as the unbroken margin, so that the next and all succeeding zones follow the new contour (as shown in Plate 37, fig. 6); but a new and entire annulus of chamberlets may form itself around the whole circumference of a mere marginal fragment (fig. 7), by the enclosure of which in a subsequent succession of annuli, the discoidal form characteristic of the type is completely and characteristically restored. Owing to the transparence of these attenuated disks, I have been able to assure myself that *every part* of the margin of this fragment, whether broken or unbroken, peripheral, central, or lateral, has contributed to the formation of the first new complete annulus, by which the foundation was laid of the subsequent regular series of concentric zones; thus clearly indicating that a sarcodic extension took place from every chamberlet laid open by the fracture, as well as from the normal pores of the last-formed septal plane, and that these extensions coalesced to form a continuous ring, as in the formation of the ordinary succession of concentric annuli.

This perfect reproduction of a form of peculiar regularity, in a type of animal organisation so low that its body-substance does not show any advance upon the primitive protoplasmic condition, is, in itself, a matter of great interest. But the interest is much enhanced by the consideration that this organism begins life, and forms its first shelly envelope, upon a plan altogether different; exchanging this for its later mode of growth, by a transition so rapid as to manifest the almost sudden attainment of a

much more specialised character. And when this transition has been once made, there appears no disposition whatever, in the reparation of injuries, to a reversion to the earlier plan. Now, this is a "pregnant instance" of the following "law of formation," sagaciously laid down long since by Sir JAMES PAGET:—"When, in an adult animal, a part is reproduced after injury or removal, it is made in conformity, not with that condition which was proper to it when it was first formed, or in its infantile life, but with that which is proper according to the time of life in which it is reproduced; proper, because like that which the same part had, at the same time of life, in members of former generations." And the study of this humble *Orbitolite* will be found, not only in this, but in other particulars, to justify the profound remark made by the same philosophic Pathologist,* long before the promulgation of the doctrine of "evolution," that, "if we are ever to escape from the obscurities and uncertainties of our art, it must be through the study of those highest laws of our science which are expressed in the simplest terms in the lives of the lowest orders of creation."

Geographical, Bathymetrical, and Geological distribution.

So far as is at present known, *Orbitolites tenuissima* inhabits only the North Atlantic Ocean and the seas in communication with it. The first complete specimens were obtained in the "Porcupine" dredgings of 1869, at depths of from 630 to 1,443 fathoms, between the north-west of Ireland and Rockall Bank. In the "Porcupine" expedition of 1870, however, it was brought up from a bottom of only 64 fathoms in Setubal Bay, on the coast of Portugal, and afterwards from a shallow bottom within the Mediterranean, near Carthage. That it is an inhabitant of other parts of the Mediterranean I then inferred from the fact that I had detected fragments of it in the Foraminiferal dredgings, made at 250 fathoms by EDWARD FORBES and Lieut. (now Admiral) SPRATT in the *Ægean*, in 1842; and it is stated by Dr. J. GWYN JEFFREYS, in his "Report on the Biology of the 'Valorous' Cruise," that it has been dredged by the Marquis DU MONTEROSATO at from 100 to 200 fathoms' depth, off the coast of Sicily. That it might extend far to the north, would be expected from its capability of bearing the low temperature of 37° Fahr., which prevails over the deep bottom from which it was first brought up; and this expectation was verified by its presenting itself in one of the "Valorous" dredgings in Baffin's Bay (lat. 62° 6' N., depth 1,350 fathoms, temperature 34° 6' Fahr.), as well as at two stations in the North Atlantic, No. 12, depth 1,450 fathoms, and No. 13, depth 690 fathoms, both in the parallel of 56°. It has been only once brought up, however, in the "Challenger" expedition, viz., at Station 44, off Cape Hatteras, from a bottom of 1,700 fathoms' depth, over which creeps (there is strong reason to believe) an underflow of cold water from the Arctic basin. Several specimens have (I am informed) been since found in a

* "Lectures on Surgical Pathology," 1849;—Lect. VII. General Considerations on Repair and Reproduction.

dredging taken by the French exploring-ship "Travailleur" in the Bay of Biscay (Fosse de Cap Breton), at a depth of 1,200 fathoms.

It would seem, therefore, that *Orbitolites tenuissima* has its proper home on the sea-bottom of the deeper parts of the North Atlantic, where the temperature ranges from 37° to 35° Fahr.; but that it also is capable of living, not only in much shallower, but also in much warmer, waters. For the temperature of the Mediterranean and *Ægean*, even at depths below 100 fathoms, is never less than 54°, while on the shallow bottom of Setubal Bay, and on the shore-slope near Carthage, the summer temperature must be considerably higher.

Looking to the singular retention, in this beautiful *Orbitoline*, of the *Milioline* type from which its derivation may now be confidently affirmed, the probability seems strong that it was a very early form; and if identical with COSTA'S *Pavonina italica*,* as the imperfect account given by him of that type would seem to indicate, it probably inhabited the Mediterranean during the greater part of the Tertiary period. Its persistence in the abyssal depths of the North Atlantic harmonizes well with the idea of its antiquity; those depths having been found, by the recent exploration of them, to be inhabited by many "survivals" of the Cretaceous and even earlier Faunæ. It may be remarked, finally, that the considerable diameter attained by these very fragile discs, seems a proof of the extreme tranquillity of the deep-sea bottom; since they could not otherwise have gone on growing and extending themselves, without showing more frequent marks of injury and reparation than I have observed in them.

Relation to other Orbitoline Types.

Having been requested by the late Sir C. WYVILLE THOMSON to prepare a Report on the *Orbitolites* collected in the "Challenger" Expedition, I have carefully studied the remarkable gatherings made of them on and near the summit of the Fiji reef, and also at a depth of 18 fathoms on its slope. The result of that examination now enables me to indicate with great probability the successive stages of the evolution of that highly specialised "complex" type, the derivation of which from a *Milioline* ancestry would have seemed—but for the completeness of the series of intermediate forms—almost inconceivable. And I can now also mark out, with more distinctness than formerly, the types of this Genus, which, in virtue of their constancy and definiteness, are entitled to rank as distinct species.

The first of these is the *O. marginalis* of Lamarck, known to him only by small Mediterranean specimens of no more than two millims. (about 0·08 inch) in diameter, but attaining on the Fijian reef a diameter of 0·2 inch, and presenting a much more characteristic aspect than is discernible in the dwarfed Mediterranean form. The well-developed "cycloline" disks of this beautiful form of the "simple" type (fig. I., 1),

* See his "Paleontologia del Regno di Napoli," part ii., in 'Atti dell' Accad. Pontan,' vol. vii., p. 178, plate xvi., figs. 26-28.

which I formerly* differentiated only by the singleness of its row of marginal pores (fig. I., 3), I now find to be uniformly characterised by the marked eccentricity of their primordial chamber, and by the spiral direction of their early growth (fig. I., 2), which I formerly supposed to be only occasional variations. In fact, the first formed portion of these disks, like that of a young *Orbiculina adunca* (*loc. cit.*, Plate XXVIII., fig. 2), exactly resembles what a Peneropline shell would be, if its chambers, as they widen out, were to undergo division into chamberlets; thus corresponding in every essential particular with the "orbiculine" stage of *O. tenuissima*. But while we have seen that this stage, in the last-named species, is preceded by a spiroloculine coil, representing a true "milioline" stage, it has no other predecessor in *O. marginalis* than what I formerly designated as the "nucleus," consisting of a flask-shaped "primordial chamber," from the neck of which proceeds a "circumambient chamber" that passes

Fig. I.—*Orbitolites marginalis*.

almost completely round it (as in fig. II., 3). The morphological import of this arrangement becomes clearer when we compare the sarcodic bodies of the two types; for it is then obvious that the "circumambient segment," which springs from the "primordial segment," and then, after making a single coil around it, gives off the first "peneropline" segment, really represents the *multiple* spiroloculine coil of *O. tenuissima*; this early generalised "milioline" stage being (as it were) abbreviated with the advance towards specialisation, as we see in numberless cases elsewhere.

The "Challenger" collection—especially that of the 18 fathoms' dredging—includes a very large number of thin flat disks, attaining a diameter of about 0.32 inch, whose surface often presents rather an "engine-turned" than an annular aspect, and which are specially characterised by the possession of a complete *double* row of marginal

pores (fig. II., 2). Both these peculiarities were noticed in my former Memoir (pp. 215, 221), but were treated as merely varietal modifications. I now find, however, that they accompany one another very constantly; and that the type is so well differentiated by them as to be fully entitled to rank as a distinct species, which I designate *O. duplex*.* Notwithstanding the difference in the surface-aspect of its disks, and the doubling of their marginal pores, the sarcodic body of this species conforms in every essential particular to that of the preceding. For each of its concentric annuli consists of a single cord (fig. II., 4, *c c'*), that passes through a

Fig. II.—*Orbitolites duplex*.

continuous circular gallery in the median plane of the disk, and carries a double series of columnar sub-segments (*a a'*, *b b'*), which occupy chamberlets (fig. II., 1) that extend in vertical series to the two surfaces of the disk. But each annular cord, instead of giving off (as in *O. marginalis*) a single stolon-process to initiate a sub-segment of the succeeding annulus, gives off *two* such processes between each pair of its own sub-segments (fig. II., 4, *d d'*, *d' d'*); and these have separate passages through the septal plane—one above and the other below the annular canal, as shown in fig. II., 2,—

* This species, as intimated in my former Memoir, appears to be the type described by Prof. EHRENBURG (Abhandl. der König. Akad. der Wissenschaften zu Berlin, 1839) as a BRYOZOON, under the designation *Amphisorus Hemprichii*. As his conception of the generic characters of this type was fundamentally erroneous, and as he gave no diagnosis of the single species he created, I have not thought it necessary to preserve his specific designation,

opening on its external side in a double series. This arrangement, as will presently appear, is the first step in the evolution of the "complex" form of the Orbitoline type.

Another advance upon *O. marginalis* is seen in the more rapid approach of *O. duplex* to the cyclical plan, shown in the abbreviation of the early spiral stage. For the "nucleus" of *O. duplex* has but a slight eccentricity, and its circumambient segment (fig. II., 3, *b, b*), instead of putting forth but a single stolon-process, gives off several;* so that, as each of these originates a new sub-segment, a crescentic row of sub-segments is at once constituted. The row formed next in succession to this almost entirely encircles the milioline nucleus, and the third row generally completes the annulus, all further increase in the disk taking place on the cyclical plan. In *O. duplex*, therefore, we have such an abbreviation, not only of the "milioline" but also of the "orbiculine" stage, that the proper "orbitoline" type is attained at a relatively earlier period.

Fig. III.—*Orbitolites complanata*.

We come, lastly, to that "complex" form—the *O. complanata* of LAMARCK—in which the special peculiarities of the Orbitoline type are most fully displayed. Its disks (fig. III., 4) attain not only a much larger diameter, but a relatively greater thickness, than those of either of the "simple" species; the annulations which mark their surfaces are as complete in their central as in their peripheral portions; their superficial

* Phil. Trans., 1856, Plate IV., fig. 13.

chamberlets have an elongated form (fig. III., 3, *a*), and their margins exhibit, even in the smallest (or youngest) specimens, *multiple* series of pores (fig. III., 1), indicative of that complicated arrangement of the cavitary system which I described minutely in my former Memoir.

The meaning of that arrangement is best understood by an examination of the sarcodic body left after the decalcification of the disks, which are modelled, as it were, upon it. The accompanying representation (copied from Plate IV., fig. 4 of my

Fig. IV.

Portion of sarcodic body of *Orbitolites complanata*:—*a a'*, *b b'*, the upper and lower annuli of two concentric zones; *c c*, the upper layer of superficial sub-segments, and *d d*, the lower layer, connected with the annular cords of both zones; *e e* and *e'e'*, intermediate columnar sub-segments of the two zones.

former Memoir) shows two annular cords, *a a'*, *b b'*, in each annular zone, instead of the single cord of *O. duplex*; and between these two cords is interposed a series of columnar sub-segments, *e e*, *e' e'*, whose bases and summits (so to speak) are brought into continuity by them. It is of the interposed shell-substance that lodges these columnar sub-segments, that the thickness of the disk (fig. III., 2) is chiefly made up; and this is obviously in relation with the length of the columns. Between each annular cord and the nearest surface of the disk, is a series of sub-segments, *c c*, *d d*, which occupy the elongated chamberlets whose partitions are marked externally by radial lines that cross the several annuli (fig. III., 3, *a*), as in *O. tenuissima*. These partitions, however, being complete, the chamberlets have no lateral communication with each other; neither do they communicate by means of radial passages with those of the annuli internal and external to them. But each has a passage at either end through its own floor, which allows a stolon-process to pass from the sub-segment which it lodges to the annular cord beneath; each sub-segment being, therefore, in connexion with the two annular cords, and forming, as it were, a bridge between one and another, as shown in fig. IV. Except through the intermediation of these sub-segments, the annular cords of the successive zones have no connexion with each other; but the intermediate columnar sub-segments of each annulus communicate with those of the next by

oblique stolon-processes, that pass off alternately at regular intervals from the two sides of each column, traversing the annular septa; and the orifices of the passages in the last-formed septum, through which these stolon-processes extend themselves outwards, are seen as multiple series of pores on the margin of the disk (fig. III., 1).

The vertical section of the calcareous disk given in fig. III., 2, shows the separation of the two superficial planes of chamberlets by the interposition of the shelly fabric that gives lodgment to the intermediate sarcodic columns; while at 3 is shown diagrammatically, on a larger scale, the cavitary system of the disk, with the communication between its several parts. At *a* are seen the chamberlets of the superficial planes, which are completely closed in when not abraded; and these are shown in vertical section, above and below, at *b*, while at *c* are seen their floors, each having a pore at either end, which communicates with the annular canal beneath. The annular canals are seen at *d* in vertical section, and at *d'* and *d''* as laid open in horizontal section; the former showing how they cross the tops of the cylindrical chamberlets of the intermediate stratum, and the latter (taken a little nearer the surface) showing the manner in which they open into the pores leading to the superficial chamberlets. In the lower part of the figure, the intermediate stratum is traversed by two horizontal sections in slightly different planes, cutting across the cylindrical chamberlets, and showing the two series of oblique stolon-passages by which the chamberlets of successive annuli communicate with each other.

The nuclear mass which occupies the centre of the disk consists, as in *O. duplex*, of a "primordial segment," surrounded by a "circumambient segment," and this last (fig. V., *b, b*) puts forth a set of stolon-processes from its entire periphery, each of

Fig. V.

which gives origin to a columnar sub-segment; so that a complete annulus is at once constituted, thus establishing the *cyclical* plan of growth *from the very first*.

The collection of specimens of *O. complanata* made on the Fiji reef contains disks of all sizes ranging from 0.04 inch to nearly 1 inch; and even in the smallest of them, whose nucleus is surrounded by only two or three annuli, the immediate assumption of the completed plan is marked by the multiplicity of the series of marginal pores. But while this may, I think, be unquestionably regarded as the *typical* condition of the species, the collection also includes an abundance of disks whose peripheral portion is characteristically "complex," whilst their central portion is no less characteristically "simple;" the passage from the one plan of growth to the

other taking place at no fixed stage, but being made sometimes earlier, sometimes later, for the most part gradually, but sometimes abruptly, as I indicated in my former Memoir (§§ 57, 58).

I can now trace out more distinctly than before the successive phases of this transition; and can show how exactly the fundamental characters of *O. marginalis* and *O. duplex* are reproduced in what may be called the childhood and youth of those "sub-typical" examples of *O. complanata*, which, instead of beginning life on the "complex" plan, only attain the more elevated type in adult age. These phases are exhibited in the following vertical section (fig. VI.) taken in the radial direction,

Fig. VI.

which, though representing them somewhat diagrammatically, is true to nature in every essential particular. Of the successive zones traversed by the sectional plane between the circumambient chamber, *c c'*, which passes round the primordial chamber, *p*, the first five, *m*, *m'*, *m''*, *m'''*, *m''''*, are formed exactly on the type of those of *O. marginalis*; each chamberlet being connected laterally with the other chamberlets of its own zone by a single annular canal, *ac*, and with the chamberlets of the zones internal and external to it by the radial stolon-passages, *r r*. These are succeeded by three zones, *d*, *d'*, *d''*, formed upon the "duplex" plan; each chamberlet having, as in the preceding case, but a single annular canal, *ac*, but communicating with the chamberlet of the annulus external to it by two oblique radial stolon-passages, as shown at *r*. Thus, then, if the growth of this disk had been checked at the fifth zone, *m''''*, its margin would have presented the single row of pores characteristic of *O. marginalis*; and if at the eighth zone, *d''*, it would have shown the double row characteristic of *O. duplex*. But in the next zone, *e*, the annular canals *ac*, *a'c'*, are duplicated, each of them sending off a stolon-passage into the next annulus. In this and the succeeding zone, *e'*, however, there is no separation between the superficial portions, *s s'*, of the chamberlets, and their median portions, *m m*; and this continuity, here transitory, shows itself as the typical character of the chamberlets of the fossil *O. complanata* of the Paris basin. But in the existing *O. complanata*, a separation comes to be effected, as shown in the succeeding zones, *f*, *f'*, *f''*, *f'''*, by horizontal extensions of the septa *i i*, that are interposed between the median portions of the chamberlets, so as to form the floors of the superficial layers; while at the same time there is a shifting of their relative positions, so that the superficial chamberlets, *s s*, *s' s'*, instead of lying over or under the median portions, *m m*, alternate with them, and are entirely

cut off from any other communication with them than that which is afforded by the annular canals, with which each superficial chamberlet communicates at either end, by a passage which—thus traced out—is seen to be homologous with one of the double radial stolon-passages of *O. duplex*, and therefore with the single radial passage of *O. marginalis*. The septa, *i i*, which divide the median portions, *m m*, of the successive annuli, are traversed by numerous passages, which, from the lateral obliquity of their direction (fig. III., 3, *f, f*), scarcely show themselves in a radial section, although they debouch at the edge of the last annulus as marginal pores, *mp*.

Notwithstanding this progressive complication in the structure of the shelly disks, there is no appearance of any corresponding specialisation in the character of the sarcodic body: that of the typically "complex" form showing no other advance upon the very simplest, than is marked by the duplication of the sarcodic annuli, by the separation of the superficial from the intermediate columnar sub-segments, and by the multiplication of the oblique stolon-processes which connect these last with each other, this multiplication being obviously in relation with the increasing length of the interposed columns, which shows itself in the thickening of the disk. The most marked increase in the complication of the animal body obviously consists in the duplication of the sarcodic annuli; and this may be readily conceived as a longitudinal splitting of each cord into two, with a persistence of adhesion at intervals, so that the two semi-annuli, when carried apart from one another by the interposition of the intermediate stratum, remain connected by the vertical sarcodic columns which traverse that stratum. The sub-segments which occupy the upper and under layers of surface-chamberlets are clearly shown, by their relation to the sarcodic annuli, not to be new productions, but to be homologous with the upper and under halves of the sub-segments that occupy the columnar chamberlets of the "simple" type; that homology, however, being so masked in the typically "complex" form by the displacement they have undergone, that it could not have been certainly recognised, but for the occurrence of those sub-typical forms which enable the passage from the most "simple" to the most "complex" to be continuously traced-out.

I have been unable, after the most careful examination of the sarcodic bodies of *O. duplex* and *O. complanata*, to discover any indication that this progressive complication in the disposition of their parts, is accompanied by any such structural modification as might lead to the suspicion of differentiation of function. On the contrary, I find their substance to be everywhere of the same elementary character, consisting of a homogeneous protoplasm, that contains a large number of spherules of from $\frac{1}{6000}$ th to $\frac{1}{8000}$ th of an inch in diameter, sometimes crowded closely together, in other instances more dispersed, as shown in fig. 3, Plate IV. of my former Memoir (Phil. Trans., 1856). These spherules, when subjected to pressure, break up into a number of pellucid corpuscles, which are usually of from $\frac{1}{15000}$ th to $\frac{1}{20000}$ th of an inch in diameter. The absence of these spherules is a marked feature of difference in the protoplasmic

body of *O. tenuissima*; on the other hand, I have not met in the higher types with those nuclear (?) bodies which I have recognised in the abyssal species (see p. 556).

The homogeneousness of the entire sarcodic body, even in the largest and most complicated forms of *O. complanata*, appears to be further indicated by the fact, that in specimens taken alive and preserved in spirit, the peripheral portion of the cavitory system is invariably found empty; the sarcodic body, corrugated by the action of the spirit, being drawn together towards the central portion of the disk through very narrow passages of communication, which could only happen with a substance of which every part is free to move upon every other. Looking, also, to the manner in which the entire organism receives its nourishment through the marginal pores, and to the entire absence of any special means for the distribution of that nourishment, I think it may be fairly assumed that such a protoplasmic circulation goes on throughout life, as must produce a continual change in the substance of every individual sub-segment.

Additional evidence of this homogeneousness is afforded by the two following facts: first, that in specimens which live under conditions peculiarly favourable to their enlargement, out-growths of irregular shape, but always possessing a regular internal structure, are put forth from any part of the disk (see "Challenger" Report, Plate VII.); and second, that, as in *O. tenuissima*, every part seems equally capable of reproducing the entire disk on its characteristic plan.

Evolutionary History of the Orbitoline Type.

Thus by the combined study of *O. tenuissima* and of sub-typical examples of *O. complanata*, we are enabled to work out the whole evolutionary history of the Orbitoline type, from its simplest to its most complex form. For there can, I think, be no reasonable doubt, that the succession here presented to us in the consecutive phases of two lives, has been the genetic history of this type; which, originating in the simplest "jelly-speck" that could form a shelly chamber, first assumed the form of a spirally-coiled undivided tube (*Cornuspira*, fig. VII., 1); then of a spire interrupted at intervals by imperfect partitions (*Spiroloculina*, 2); then of a flattened spire crossed by complete septa traversed by stolon-passages (*Peneroplis*, 3); then of a progressively widening spire, whose chambers are divided into chamberlets (*Orbiculina*, 4); then of a chamberletted disk of one storey, commencing as an orbicoline spire, but subsequently increasing by annular additions (*Orbitolites tenuissima* and *O. marginalis*, 5); then of a chamberletted disk, whose origin still shows in its slight eccentricity a trace of the primordial spire, and whose single storey has, so to speak, two rows of windows (*Orbitolites duplex*, 6); and lastly, of a "complex" disk, whose growth is cyclical from the beginning, and whose upper and lower superficial planes are separated by the interposition of an intermediate columnar structure between the duplicated annular stolons (*Orbitolites complanata*, 7). This last would seem to be the culmination of the type, which, while attaining a considerable size, has never shown, so far

as is at present known, any tendency to pass into a higher form. Indeed, the typical forms of the existing *O. complanata* are in one small particular (as already shown, p. 565) more specialised than the fossil forms that were so remarkably abundant in the Middle Tertiary epoch.

It is a remarkable feature of this case, however, that all the forms through which the highest *Orbitoline* type is thus shown to have passed, continue to hold their ground at the present time, as the characteristic representatives of less specialised groups. There being every reason to regard *Cornuspiræ*, *Peneroplides*, and *Orbiculinæ* as distinct races, propagating themselves genetically without any essential modifi-

Fig. VII.

cation, it can scarcely be supposed that every one of them is a "potential" *O. tenuissima*. So, again, as we find *O. marginalis* and *O. duplex* living and propagating under the very same conditions as *O. complanata*, I cannot regard these "simple" forms of the Orbitoline type, each of which has its characteristic plan of structure and limit of growth, as potentially "complex;" notwithstanding the exact repetition of their plans in the early stages of certain examples of the higher type. For I have never observed in the largest and best developed examples of *O. marginalis* and *O. duplex* the least tendency to assume the "complex" form; on the other hand, I have frequently found their last formed annuli deficient in internal partitions, as if their productive power had exhausted itself. It would seem, therefore, more just to

regard those sub-typical examples of *O. complanata*, which exhibit the transition I have described from the "simple" to the "complex" plan of structure, not as advanced forms of either of the two "simple" species, but as retarded forms of the highest; and a clue to the conditions of that retardation can, I think, be found in the marked inferiority I have invariably observed in the size of the original nuclear mass of these individuals. I drew attention in my former Memoir (§ 44) to the remarkable range of dimension which this mass exhibits, when a considerable number of specimens are examined; and showed that the cavity of the "primordial" and "circumambient" chambers in one individual must have been more than a hundred times as large as that of another. Now the result of the far more extended comparison of specimens which the "Challenger" collection has enabled me to make, is, that while the "nucleus" of the typical *O. complanata* (in which the cyclical plan of growth, and the "complex" structure, show themselves from the very first) is always many times larger than that of either *O. marginalis* or *O. duplex*, the "nucleus" of its sub-typical forms always bears a very close accordance in size to that of *O. duplex*, which it resembles also in the one-sided pullulation of the first sub-segments from the circumambient segment, rendering the earlier zones more or less incomplete, and the position of the "nucleus" slightly eccentric. Whether these forms genetically propagate themselves as a *race*, perpetuating an earlier stage of the evolution of the perfected type, or are merely *individuals* which have begun life as "starvelings" that do not inherit the characteristic vigour of the type, I have no adequate ground for even surmising; being only able to affirm this, that as there is no kind of constancy in the stage of growth at which the "simple" plan gives place to the "complex," there is nothing to justify a specific differentiation of this sub-typical variety. That its peculiarity may depend upon conditions less favourable to the full development of the type, seems to be indicated by the fact that, whilst the largest and most typical specimens of *O. complanata* were found in the rock-pools on the summit of the Fiji reef, where they would have the highest temperature and the greatest abundance of food, the sub-typical specimens presented themselves chiefly in the collection made by the dredge at 18 fathoms' depth.

Theory of Descent.

I propose, in the last place, briefly to examine the bearing of the remarkable case of "descent with modification," which I have thus detailed, upon the general "Theory of Descent" and of the "Origin of Species."

Those who find in "natural selection" or the "survival of the fittest" an all-sufficient explanation of the "origin of species," seem to have entirely forgotten that before "natural selection" can operate, there must be a range of varietal forms to select from; and that the fundamental question is (as Mr. DARWIN himself clearly saw, at any rate in his later years), *what gives rise to variations?* No exercise of "natural selection" could *produce* the successive changes presented in the evolu-

tionary history of the typical *Orbitolites*, from *Cornuspira* to *Spiroloculina*, from *Spiroloculina* to *Peneroplis*, from *Peneroplis* to *Orbiculina*, from *Orbiculina* to the "simple" forms of *Orbitolites*, and from the "simple" to the "complex" forms of the last-named type. And as all these earlier forms still flourish under conditions which (so far as can be ascertained) are precisely the same, there is no ground to believe that any one of them is better fitted to survive than another. They all imbibe their nourishment in the same mode; and no one type has more power of going in search of it than another. That they are all dependent on essentially the same conditions of temperature and depth of water, is shown by their occurrence in the same marine areas. That they all equally serve as food to larger Marine Animals, can scarcely be doubted; and it is hardly conceivable that any of their devourers would discriminate (for example) between the disks of a large *O. marginalis*, a middle-sized *O. duplex*, and a small *O. complanata*, which even the trained eye of the Naturalist cannot distinguish without the assistance of a magnifying-glass.

To me, therefore, it appears that the doctrine of "natural selection" can give no account of either the origin or the perpetuation of those several types of Foraminiferal structure which form the ascending series that culminates in *Orbitolites complanata*. On the other hand, there seems traceable throughout that series a *plan* so definite and obvious, as to exclude the notion of "casual" or "aimless" variation. Between the simple spirally-coiled sarcodic cord of a young *Cornuspira*, and the discoidal body of an *Orbitolite*, with its thousands of sub-segments disposed with the most perfect symmetry, and connected together in most regular and uniform modes, who (in the absence of the intervening links) would have suspected any genetic relation—who would have ventured to construct a pedigree? And yet we find the gradations from the one to the other to be not only most complete, but often significant of further progress; many of the changes being such as seem to have no meaning except as anticipations of greater changes to come. Thus, the slight constrictions that show themselves in the first spiral coil of *O. tenuissima* (Plate 38, fig. 3) are what constitute the essential difference between the spire of *Cornuspira* and that of *Spiroloculina*; marking an imperfect septal division of the spire into chambers, which cannot be conceived to affect in any way the physiological condition of the contained animal, but which foreshadows the complete septal division that marks the assumption of the Peneropline stage. Again, the incipient widening-out of the body, previously to the formation of the first complete septum, prepares the way for that great lateral extension which characterises the next or Orbiculine stage; this extension being obviously related, on the one hand, to the division of the chamber-segments of the body into chamberletted sub-segments, and, on the other, to the extension of the zonal chambers round the "nucleus," so as to complete them into annuli, from which all subsequent increase shall take place on the cyclical plan.

In *O. marginalis*, the first spiral stage is abbreviated by the drawing-together

(as it were) of the "spiroloculine" coil into a single Milioline turn of greater thickness; but the Orbiculine or second spiral stage is fully retained.

In *O. duplex*, the abbreviated Milioline centre is still retained, but the succeeding Orbiculine spiral is almost entirely dropped out, quickly giving place to the cyclical plan.

And in the typical *O. complanata* the Milioline centre is immediately surrounded by a complete annulus, so that nothing remains of the original spire save the one turn of the circumambient segment.

So, in the passage from the "simple" to the "complex" type, we have a remarkable anticipatory step in *O. duplex*, which can scarcely be supposed itself to derive any advantage from the substitution of a double for a single row of communications between the annuli, since *O. marginalis* flourishes equally well with its single row; but which forms, so to speak, a stepping-stone to a higher grade.

Everything in this history, then, shows a well-marked progressive tendency along a definite line towards a highly specialised type of structure in the Calcareous fabric; and this without any corresponding departure from the original homogeneity of the Animal body which forms that fabric. And as being, so far as I know, altogether unique in these peculiarities, I venture to offer this study of a humble protoplasmic organism, brought up from an ocean-depth of nearly two miles, to the consideration of those who believe with Sir JAMES PAGET, that "the highest laws of our [biological] science are expressed in the simplest terms in the lives of the lowest orders of Creation."

EXPLANATIONS OF PLATES.

PLATE 37.

Structure of Calcareous Disk of *Orbitolites tenuissima*.

- Fig. 1. Surface of young disk, showing its eccentric spiroloculine "nucleus," giving origin to successive zones of orbiculine chamberlets, which gradually increase in breadth with the opening-out of the spire, until they extend completely round the nucleus; after which the successive additions are made on the cyclical plan, as concentric annuli. Magnified 25 diameters.
- Fig. 2. A portion of three peripheral annuli, enlarged to 64 diameters, and partially laid open by the removal of the superficial lamella, so as to show the two annular septa, *aa*, *bb*, the chamberlets, *c*, separated by radial partitions, and the annular gallery, *d*, into which all the chamberlets open at their peripheral extremities.
- Fig. 3. Vertical section of three annuli of the disk, taken in the radial direction, so as to traverse the chamberlets lengthways; *a, a*, junctions of two annuli, with

the annuli external to them ; *b, b, b*, annular galleries traversing the septa between the chamberlets. At *a, a*, are seen the openings through which the sarcodic cords that occupy the annular galleries send radial extensions into the chamberlets of the succeeding annuli. Magnified 64 diameters.

Fig. 4. Internal aspect of a small portion of an annulus detached by fracture ; showing the entrances to the chamberlets of that annulus through the septal plane. Magnified 64 diameters.

Fig. 5. External or peripheral aspect of a portion of a marginal annulus, showing the passages through its septal plane, as marginal pores elongated in the plane of the disk. Magnified 64 diameters.

Fig. 6. Portion of a disk, whose remainder, with the "nucleus," has been lost by injury previously to the formation of the last two annuli, which have extended themselves along the fractured margin, and into the nuclear space. Magnified 15 diameters.

Fig. 7. Incipient production of an entirely new disk, with regularly concentric annuli, from a fragment of the peripheral portion of an old one. Magnified 15 diameters.

PLATE 38.

Structure of Sarcodic Body and Calcareous Disk of *Orbitolites tenuissima*.

Fig. 1. Sarcodic body of the central portion of the disk ; showing the primordial segment giving off the spiroloculine coil, the sixth turn of which, *a*, begins to open out into a peneropline form, afterwards becoming divided into rows of orbiculine sub-segments, which are connected together laterally by the continuity of the sarcodic body through the gallery at the outer end of each row, and radially by the stolon-processes that pass through the septal passages, from the gallery of the inner row into the chamberlets of the outer. Nuclear (?) corpuscles are seen irregularly distributed through the sarcodic substance. Magnified 75 diameters.

Fig. 2. Nuclear (?) bodies, as seen under a power of 450 diameters.

Fig. 3. Section of first-formed portion of the disk, laying open the primordial chamber, *a*, and the spiroloculine chambers, partially divided as at *b*, which coil round it. Magnified 125 diameters.

Fig. 4. Portion of the sarcodic body shown in fig. 1, enlarged to 125 diameters, to show the distribution of the nuclear (?) corpuscles :—*a*, expanded extremity of the last spiroloculine coil ; *b, b, b', b'*, portions of preceding coils, crowded with nuclear (?) corpuscles ; *c*, orbiculine sub-segment, with five corpuscles ; *d, d, d, d*, orbiculine sub-segments, each with one or with two corpuscles.

Fig. 5. Central portion of the calcareous disk, as seen by transmitted light ;—*a*, expanded chamber formed by the termination of the spiroloculine coil, and

closed-in by a peneropline septum traversed by four passages; *b*, second chamber, divided by radial partition into orbiculine chamberlets; *c*, third chamber, not here separated from the second by a septum, and having only one radial partition; *d*, *d*, fourth chamber, having at *d'*, *d'*, lateral extensions which begin to enclose the spiroloculine coil; *e*, *e*, fifth chamber, with lateral extensions, *e'*, *e'*, proceeding still further backwards; these chambers, and those that succeed them, divided by radial partitions into orbiculine chamberlets. Magnified 75 diameters.

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ORBITOLITES TENUISSIMA.

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

By WILLIAM B. CARPENTER, M.D., F.R.S., F.G.S., F.L.S.

Received June 14,—Read June 14, 1860.

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. crista*, 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, FICHEL 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 crista* 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 FICHEL 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 $2\frac{1}{2}$ 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', a²*, whilst it traverses the septa *b, b¹, b², b³* 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 caecal 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 e, e' , 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, d¹, d²*) 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. crista*, 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 *hh'* 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. crista*, 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 FICHEL and MOLL, which Mr. PARKER considers to be the *Geoponus stella-borealis* of EHRENBURG, 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. crista* 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 FICHEL 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; FICHEL 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 *Siderolina* 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 *Helicostegæ* 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.

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 *Calcarina* (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 *Calcarina* 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 inosculation 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. FICHEL 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 *Rotalia*, 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 *Rotalia*, 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 *Rotalia* or *Polystomella*; 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 agglom-

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 sarcod-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 sarcod-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 sarcod-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. FICHEL 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 FICHEL 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 sillonnées 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 laevis* 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 lavis* 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. laevis* does (through *Planorbulina*) to the *Rotaline* type (§ 217). The essential difference between *T. baculatus* and *T. laevis* 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. laevis* 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 EHRENBURG, 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 *osculum*. 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 *spongy*. In communicating this result, however, to Dr. GRAY, I thought it right to suggest the possibility that this spongy 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', e''*) resemble the principal septa (*d, d', d''*) 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', f''*) 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 laminae (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 *Helicostège* 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 spongy 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 sarcod-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 sarcod 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 spongy 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 *spongy*.

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 deduced 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 *Alveolina*, 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 *porcellaneous*; presenting an opaque 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 *Helicostegues*, 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.

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 develop 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 *Cyclocypeus*, *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 develop themselves. As I have just pointed out, the relation of *Cyclocypeus* 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 transparency 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 laminae, 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 probable 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:—

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 laminae 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 sub-tropical 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. FICHEL 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 *Lagena* 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*, *Marginalina*, *Dimorphina*, *Flabellina*, and *Fronicularia*, 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 *Nodosariæ* 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 EHRENBURG 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 Alga* 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', a''*, through the cavity of the chambers, whilst in the alternate whorls *b, b', b''*, 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'*, and *d''*, 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 sarcodæ. 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', c''*, 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', a²*, chambers of three whorls which are laid open by the plane of section; *b, b¹, b², b³*, septa of four whorls alternating with the preceding, which are traversed by the plane of section; *c, c¹, c²*, 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', a'' , the furrows being deepest at the posterior margin for the reception of the retral processes; whilst at bb', bb'' , 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', d'' , three turns of one of the spiral canals; e, e', e'' , three of the meridional canals; f, f', f'' , 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 *Calcarina*, showing their ordinary aspect. Magnified 20 diameters.
- Figs. 8, 9. Hispid varieties of Philippine *Calcarina* (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 'turbinoïd' 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. laevis*, as seen laterally at *a*, and on its basal aspect at *b*. Magnified 25 diameters.
- Fig. 2. Section of *T. laevis* 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. lavis* 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. lavis*, 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 *Carpenteria* 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 spongy 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'*, and *d''* three of the complete septa dividing the principal chambers, and at *g* and *g'* 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', e''*, secondary septa partially dividing the principal chambers, but not extending to their central portion; *f, f', f''*, 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 *Carpenteria* 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 spongy tissue occupying the chambers of *Carpenteria*. Magnified 75 diameters.

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XXVI. *Researches on the Foraminifera.*

By WILLIAM B. CARPENTER, M.D., F.R.S., F.G.S. &c.

Received June 19,—Read June 19, 1856.

PART II.

ON THE GENERA ORBICULINA, ALVEOLINA, CYCLOCLYPEUS AND HETEROSTEGINA.

Genus ORBICULINA.

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

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

* Testacea Microscopica, Vindob. 1798.

† Système des Animaux sans Vertèbres. Paris, 1801.

‡ Conchyliologie Systematique. Paris, 1808.

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

|| Encyclopédie Méthodique, Zoophytes. Paris, 1824.

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

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

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

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

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

* Transactions of the Royal Academy of Berlin, 1839.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

GENUS ALVEOLINA.

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

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

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

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

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

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

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

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

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

Genus *CYCLOCYPEUS*.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

GENUS HETEROSTEGINA.

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

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

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

† Foram. Foss. de Vienne, p. 212.

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

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

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

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

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

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

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

Concluding Remarks.

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

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

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

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

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

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

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

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

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

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

EXPLANATION OF THE PLATES.

PLATE XXVIII.

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

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

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

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

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

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

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

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

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

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

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

- Fig. 20. Inner surface of one of the annuli of a similar fossil disk, showing the differentiation of the superficial from the intermediate layers of cells:—50 diam.
- Figs. 21, 22. Portions of the superficies from similar fossil disks, showing varieties in the surface-markings:—50 diam.
- Fig. 23. External aspect of *Alveolina Boscii* (recent); *a, a*, growing margin, showing multiple apertures resembling those at the margins of *Orbitolites* and *Orbiculina*:—40 diam.
- Fig. 24. Longitudinal section of *Alveolina Boscii*, showing its internal structure and the successive stages of its growth:—40 diam.

PLATE XXIX.

- Fig. 1. Section of disk of *Orbiculina adunca* parallel to the surface, showing the cells and their communications:—100 diam.
- Fig. 2. Surface-layer of disk of *Orbiculina adunca*, showing its punctuated appearance:—100 diam.
- Fig. 3. Vertical section of disk of *Orbiculina adunca*, passing through its central nucleus, and showing columnar arrangement of its cells, and the manner in which the earlier whorls of the spire are invested by the later:—100 diam.
- Figs. 4–7. Transverse sections of *Alveolina Boscii*, showing the increase in the number of turns of the spire from its terminal to its central portion:—40 diam.
- Fig. 8. Portion of a similar transverse section enlarged; showing—*a, a, a*, internal prolongations of the surface-layer; *b, b, b*, outer longitudinal canals; *c, c, c*, inner longitudinal canals:—80 diam.
- Fig. 9. Portion of a longitudinal section (Plate XXVIII. fig. 24) similarly enlarged; showing 1, 2, 3, 4 successive layers formed by the involution of the spire; and in each the passages *a a*, *b b*, and *c c*, between one band and the next. (N.B. The variation in the appearances presented by the other layers, depends upon the difference of relative direction in which the section traverses each of them respectively):—80 diam.
- Fig. 10. Thin section of *Cyclochypus*, taken parallel to the surface, and close to the covering of the chambers; showing part of the system of interseptal canals:—50 diam.
- Fig. 11. Diagram of a single chamber of *Cyclochypus*, showing its relations to other chambers, and to the interseptal system of canals: *a*, cavity of chamber; *b, b'*, adjacent chambers of the same annulus, each separated from *a* by a double septum; *c c'* and *d d'*, chambers of internal and external annuli, separated from *a* by the annular partitions *e e*, *e' e'*, but communicating with it by the passages *f, f, f, f*; in the septa between *a* and *b, b'* are seen the interseptal canals, each of which sends two oblique branches across the annular septa, to communicate with corresponding canals in the septa

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

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

PLATE XXX.

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

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

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

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

PLATE XXXI.

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

- Fig. 2. Vertical section of *Cycloclypeus*, taken in the direction of one of the annuli, showing the upper and under layers *ab*, *a'b'*, with the septa between the chambers, each of which is seen to be composed of two layers with an interposed lamella, pierced by two or more canals whose orifices are shown; on the left side of the figure, the chambers are seen to be closed by the inter-annular septum, which is pierced by several irregularly-disposed passages, *c*, *c*, that establish communications between each chamber and those of the annuli internal and external to it:—60 diam.
- Fig. 3. Section of *Cycloclypeus*, taken horizontally (or parallel to the surface of the disk) through the shelly covering of the chambers, showing its minutely tubular structure, and its junction with the two interannular non-tubular septa *ab*, *a'b'*, and with the intercameral septa *cc*, *c'c'*, along the course of which last are seen the divided ends, *d*, of vertical interseptal canals: the chamber thus inclosed is remarkable for its great length in comparison with its breadth:—100 diam.
- Figs. 4 & 5. Vertical sections of *Cycloclypeus*, corresponding with fig. 2, and showing irregularities in the division of the chambers: at *cc*, fig. 4, are seen the orifices of the interseptal canals laid open; and at *c*, fig. 5, is shown a part of the vertical canal-system, passing upwards and downwards towards the two surfaces of the shell, through its transparent portions:—60 diam.
- Fig. 6. Section of *Cycloclypeus*, taken in the same direction as fig. 3, but nearer to the surface, showing the relation of the tubular and non-tubular portions of the shell, and the orifices of the canals:—100 diam.
- Fig. 7. Vertical section of young specimen of *Heterostegina*, showing the investment of the first-formed whorls by those which succeed them, and (on the right) the commencement of the thinning-out: *a*, *a*, *a*, passages of communication between the successive bands of which each whorl is composed:—35 diam.
- Fig. 8. Vertical section of young disk of *Cycloclypeus*, showing at *a* an irregular subdivision into two or three layers of chambers:—22 diam.
- Fig. 9. Horizontal section of a portion of *Cycloclypeus*, corresponding with fig. 3, but more highly magnified:—150 diam.
- Fig. 10. Vertical section of the floor of one of the chambers, showing its lamellated arrangement, the minutely-tubular structure of one portion of it, *aa*, and one of the non-tubular cones, *bb*, which is continuous with the annular septum *c*:—150 diam.
- Fig. 11. Horizontal section of a portion of *Heterostegina*, taken near the margin, showing the disposition of the chambers, the communications *aa* between those of successive bands, the minutely-tubular structure of their roof, the interseptal canals, and the high development of the canal-system in the thickened non-tubular margin, *bb*:—150 diam.

Fig. 1. Vertical section of *Cyrtolophus*, taken in the direction of one of the annuli, showing the upper and under layers *a*, *b*, with the septa between the chambers, each of which is seen to be composed of two layers with an internal lamella, placed by two or more canals whose orifices are shown; on the left side of the figure, the chambers are seen to be closed by the inter-annular septum, which is pierced by several irregularly-disposed passages, *c*, *c'*, that establish communication between each chamber and those of the annuli internal and external to it.—100 diam.

Fig. 2. Section of *Cyrtolophus*, taken horizontally (or parallel to the surface of the disk) through the shell, covering of the chambers, showing its minute tubular structure, and its junction with the two intermediate non-tubular septa *a*, *a'*, and with the inter-annular septa *c*, *c'*, along the course of which are seen the divided ends, *b*, of vertical internal canals; the chamber thus included is remarkable for its great length in comparison with its breadth.—100 diam.

Fig. 3. Vertical section of *Cyrtolophus*, corresponding with fig. 2, and showing irregularities in the division of the chambers; at *c*, fig. 4, we see the orifice of the internal canals laid open; and at *c'*, fig. 5, is shown a part of the vertical canal system, passing upwards and downwards towards the two surfaces of the shell, through its transverse partitions.—60 diam.

Fig. 4. Section of *Cyrtolophus*, taken in the same direction as fig. 3, but nearer to the surface, showing the relation of the tubular and non-tubular portions of the shell, and the orifices of the canals.—100 diam.

Fig. 5. Vertical section of young specimen of *Cyrtolophus*, showing the investment of the first-formed whorls by those which enclose them, and (on the right) the commencement of the flaring-out; *a*, *a'*, passages of communication between the successive bands of which each whorl is composed.—50 diam.

Fig. 6. Vertical section of young disk of *Cyrtolophus*, showing at *a* an irregular sub-division into two or three layers of chambers.—55 diam.

Fig. 7. Horizontal section of a portion of *Cyrtolophus*, corresponding with fig. 3, but more highly magnified.—150 diam.

Fig. 8. Vertical section of the floor of one of the chambers, showing its lamellated structure, the minute tubular canals *b*, which are continuous with the annular canals of the non-tubular zones *a*, *a'*, which is continuous with the annular canals of the next zone.—150 diam.

Fig. 9. Horizontal section of a portion of *Cyrtolophus*, taken near the margin, showing the disposition of the chambers, the communication *a* between those of successive bands, the minute tubular structure of their roof, the thin inter-annular canals, and the high development of the canal system in the thickened non-tubular margin, *b*;—150 diam.

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