REPORT

ON THE

SCIENTIFIC RESULTS

OF THE

VOYAGE OF H.M.S. CHALLENGER

DURING THE YEARS 1873-76

UNDER THE COMMAND OF

CAPTAIN GEORGE S. NARES, R.N., F.R.S.

AND

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THE

VOYAGE OF H.M.S. CHALLENGER.

ZOOLOGY.

REPORT on the specimens of the Genus ORBITOLITES collected by H.M.S. Challenger during the years 1873-1876. By WILLIAM B. CARPENTER, C.B., M.D., LL.D., F.R.S., F.L.S., F.G.S.; Corresponding Member of the Institute of France, of the Königl. Baier. Akademie der Wissenschaften zu München, of the American Philosophical Society, &c., &c.

INTRODUCTION.

THIRTY-SIX years ago, when engaged in the study of the Microscopic structure of the calcareous skeletons of the lower Invertebrata, I received from my friend Prof. Edward Forbes some small discoidal bodies, which had been dredged-up in considerable abundance on the coast of Australia by Mr. J. Beete Jukes, whilst holding the post of Naturalist in H. M. surveying ship "Fly," between 1842 and 1846, with the information that these disks were probably identical with those which had been collected by MM. Quoy and Gaimard in the same locality during the voyage of the "Astrolabe," and described by them in the "Zoology" of that voyage, under the generic designation *Marginopora*. I could not, however, find any mention of this genus, either in the text or in the plates of their great work; but on consulting the Manuel de l'Actinologie of M. de Blainville, I found it there described (p. 412), on information received from MM. Quoy and Gaimard, in immediate sequence to the genus *Orbitolites*,—both genera being placed by De Blainville, though with hesitation, among his "Polypiers." Having examined, in the Paris Museum, the original specimens on which the genus was founded, I at once saw that Mr. Jukes's disks belonged to the same type, though with some modifications of detail; and I saw also their very close alliance to the fossil genus *Orbitolites*, originally established by Lamarck in his Système des Animaux sans Vertèbres (1801), on the basis of a well-known fossil of the Calcaire Grossier, which he placed among his "Polypiers Foraminés," between *Lunulites* and *Millepora*, giving the following as its diagnostic characters :—"Polypiarium lapideum, liberum, orbiculare, planum seu concavum, utrinque vel margine porosum, nummulitem referens. Pori minimi, adamussim 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 any spiral arrangement in their minute chambers or cells. In his Histoire Naturelle des Animaux sans Vertèbres (1816–1822), which ranks as a second edition of the preceding, Lamarck altered the name of this type from *Orbitolites* to *Orbulites* ; but as the latter designation had been previously applied to a Molluscan genus, the original one was restored by M. Milne-Edwards, in the posthumous edition of Lamarck's great work which he edited in conjunction with M. Deshayes. Under one or the other of these names, the genus was accepted by almost every systematist of repute as a Zoologist or a Palæontologist; but no one gave any account either of the internal structure of the calcareous disk, or of the animal that forms it ; or made any essential modification in Lamarck's definition of the genus, which all left in the place he had assigned to it :—even Dujardin, who first recognised the true zoological position of the FORAMINIFERA (which had been ranked, up to his time, as a peculiar group of Cephalopod Mollusks), speaking unhesitatingly of the Orbitolite-disk as a polypary, and of the animals which formed it as polypes. It seems to have been by Defrance (Dict. des Sci. Nat., tom. xxxvi., 1825, pp. 294, 295) that the existence, on the coast of New Holland, of a recent type closely resembling the fossil *Orbitolites* of the Paris basin, was first publicly stated, probably on information obtained from MM. Quoy and Gaimard.

The existence of a *recent* form of *Orbitolites* of far smaller size and much simpler structure than the fossil *Orbitolites complanata* had, however, been previously indicated by Lamarck in his second edition ; where he defines it under the specific name *marginalis*, as *Orbitolites utrinque plana, margine poroso*, speaking of it as found attached to fuci, corallines, &c., in the Mediterranean. This type was carefully studied by M. de Blainville, who expressed himself (*op. cit.*, p. 412) as almost convinced that these small calcareous disks are not true polyparies, but internal pieces, increasing at their circumference. It is evident, he says, that there are no true polype-cells ; but he speaks of "deux plans de locules qui occupent le bord," and says that "tout le reste est couvert d'une légère croûte crétacée, qui ferme les anciens pores." Being well acquainted with the Mediterranean specimens to which these remarks apply, I can well understand how M. de Blainville came to overlook the single row of true *marginal* pores, and to regard as genuine "les deux plans de locules" which they very frequently present, but which are the result of the abrasion of their edges. That Lamarck's little *Orbitolites marginalis* is a humble representative of the type of structure which attains its full development in the *Marginopora* of Quoy and Gaimard, does not seem to have occurred to him; and it is evident, from his description of the latter, that in that type also he failed to recognise the true marginal pores,—what he supposed to be such being incomplete chamberlets left open in the frilled edges of the abnormal specimens (resembling those figured in Pl. VII.) which represent this genus in the Paris Museum.

Notwithstanding the special attention which M. d'Orbigny was giving to the minute shells now ranked as FORAMINIFERA, he does not seem, when he presented in 1825 to the Académie des Sciences his Tableau Méthodique of that group (which he then ranked as a sub-class of CEPHALOPODA), to have had the least idea that *Orbitolites* and *Marginopora* should have a place in it; and no mention is made of either in the systematic arrangements published by him in 1844 (Dict. Univ. d'Hist. Nat., tom. v.) and in 1846 (Foram. Foss. de Vienne), in both of which he fully accepted the view of the Rhizopodal character of the animals that form Foraminiferal shells, which had been promulgated by M. Dujardin in 1835.

Dujardin's doctrine, however, was strongly opposed by Prof. Ehrenberg; who, in 1838, announced to the Berlin Academy[1] his conclusion—avowedly based on observation of certain forms of these animals in the living state—that the true place of the Foraminifera in the animal kingdom is in the class BRYOZOA, first constituted by him on the basis of what were then known as "Ciliobrachiate Polypes," viz., *Flustræ*, *Halcyonellæ*, &c. In this group he correctly assigned a place to the genus *Lunulites;* and it seems to have been from the superficial resemblance which (as both Lamarck and De Blainville had noticed) is borne to the calcareous disk of *Lunulites* by *Orbitolites*, that he associated the latter with the former in his Order *Polythalamia*, Family *Asterodiscina*. Having some years previously visited the Red Sea, for the purpose of zoological exploration, Prof. Ehrenberg had brought thence two kinds of small calcareous disks, which he saw to possess similar general characters; upon one of these he conferred the generic name *Sorites*, and upon the other *Amphisorus;* and he erected these into the Family *Soritidæ*, which he placed next to the *Asterodiscina*. It is perfectly clear, from his descriptions and figures of these disks, that Ehrenberg's *Sorites* is identical with Lamarck's *Orbitolites marginalis*, the small recent type inhabiting the Mediterranean; and that his *Amphisorus* is so closely allied to this, that its difference is not more than specific. But he was so completely carried away by his preconceived ideas, as not only to describe the entirely closed cells of the surface of these disks (which are only open in dead and abraded specimens) as covered with a moveable operculum, which shuts their orifices when their animals are retracted, but actually to figure an eight-armed Bryozoon as issuing from one of them.

[1] Ueber noch jetzt lebende Thierarten der Kreidebildung, und den Organismus der Polythalamien. *Abhandungen der königl. Akad. der Wissenschaften zu Berlin*, 1839, p. 81.

Such was the general state of knowledge, or rather of ignorance, in regard to the zoological characters of *Orbitolites* and *Marginopora*, at the date (1848) when I undertook a careful microscopic examination of Mr. Jukes's specimens of the latter, the results of which led me to compare their structure with that of the fossil *Orbitolites complanatus.* These results I communicated to the Geological Society in May 1849, and they were published in its Quarterly Journal for Feb. 1850. The place universally assigned to these genera by zoologists and palæontologists being in immediate proximity to *Lunulites* (whose Bryozoic nature could not be reasonably doubted),—and the living *Soritidæ* of Prof. Ehrenberg having been described and figured as Bryozoic, on the basis of personal observation, by the microscopic autocrat of the time, whose dicta it was heresy to question,—I entered upon the investigation without the least suspicion that this organism was to be regarded in any other light; and that I was not at once undeceived, was mainly due to the fact that among the small number of specimens first placed in my hands by Prof. E. Forbes, there was not one by any means perfect,—all being more or less abraded, and not one possessing that central "nucleus" which is the portion most indicative of their Foraminiferal affinities. Nevertheless, the marked dissimilarity in structure which I found to exist between the calcareous disk of *Orbitolites*, and the skeleton of *Lunulites* or any other undoubted BRYOZOA, made me even then express myself doubtfully as to its title to be closely associated with them. I found that between the recent *Marginopora vertebralis* of Quoy and Gaimard, and the fossil *Orbitolites complanata* of Lamarck, the differences are so trivial as to amount at most to a specific distinction; so that the later genus must be abolished, and the Australian disk be ranked as the recent type of the fossil so abundant in the Calcaire Grossier. And I showed that, in the one as in the other, the "cells" (which I now designate as "chamberlets") are normally closed-in over the whole surface; that the two surfaces are separated from each other by an intervening stratum, traversed by a set of round columnar cavities of its own, with inter-communicating passages; that each superficial cell communicates with this intermediate cavitary system by two small apertures; and that the only real external orifices are the minute pores at the margin of the disk, which do not communicate directly with the cells of the superficial layers, but are the openings of passages leading to the outermost series of columnar cavities in the intermediate stratum. To this complicated arrangement I could find no parallel in the Class BRYOZOA, but I was equally unable to indicate any parallel to it elsewhere.

At what date the Foraminiferal nature of *Orbitolites* first came to be suspected by M. d'Orbigny there is no means of knowing; but in the year 1852 (Cours Elémentaire de Paléontologie) he assigned it a place in that group; creating for it, and for some other genera having a like discoidal form, the Order *Cyclostègues,* which he defined as follows :—"Animal composé de segments nombreux, placés en lignes circulaires. Coquille discoïdale, composée de loges concentriques, simple ou multiples; point de spirale."

He united Quoy and Gaimard's recent *Marginopora* (as I had myself previously done) with Lamarck's fossil *Orbitolites;* but so little did he know of the internal structure of this type, that he altogether failed to perceive its very close similarity to that of *Orbiculina*, which he ranked with *Peneroplis*, *Dendritina*, and other genera allied to these, among his "Hélicostègues."

This similarity had been already recognised (1850) by Prof. W. C. Williamson, whose previous studies of Foraminiferal structure had so far prepared him for the right appreciation of it, that, on coming into possession of specimens of *Orbitolites marginalis*[1] from the calcareous sands of Havannah, and of a small worn specimen of the recent *Orbitolites complanata* from Tonga, he made it perfectly clear, by a comparison of their internal structure with that of the proteiform *Orbiculina adunca*, that these three types closely accord in their general structure, differing only in their plan of growth (Transactions of Microscopical Society, vol. iii., 1852). And it is greatly to his credit, that at a time when the authority of M. d'Orbigny was generally accepted as the highest in regard to Foraminifera, Prof. Williamson should have ventured not merely to call in question the value of "plan of growth" as an *ordinal* character, but even to rank it as good only for *specific* differentiation. He clearly showed (1) that the well-known *Orbiculina adunca* of the Antilles, though always *beginning* life as a *Hélicostègue*, often ends it as a *Cyclostègue;* its first-formed arcuate rows of chamberlets, which represent the successive chambers of the flattened spire of *Peneroplis*, often sending backwards two alar extensions, which meet at the back of the first-formed spire, so as to form a complete annulus, after which every successive addition takes place on the *cyclical* plan; (2) that whilst in *Orbitolites marginalis* the first growth is spiral, yet this very early gives place to the *cyclical* plan; and (3) that in *Orbitolites complanata* the growth is *cyclical* from the beginning, the very first row of chamberlets forming a complete annulus, and all further additions being made on the same plan. He also showed that *Orbitolites marginalis* and *Orbitolites complanata* alike originate in a globular or pyriform primordial chamber, which opens by a flask-shaped neck into a second chamber; and that it is from the latter that the first row of chamberlets originates in each case. He fully recognised also the "simplicity" of the structure of *Orbitolites marginalis*, with its single tier of chamberlets, and the "complexity" of that of *Orbitolites complanata*, with its "multiplication of strictly analogous parts"; and he showed that the latter is further differentiated by its possession of concentric rows of superficial fossæ, distinct from the cavities of the intermediate stratum of the disk. And the only considerable error in his whole description, which arose from the abrasion of the surface of his single specimen of the "complex" type, was his treating the chamberlets of the superficial plane, which are closed-in by lamellæ of shell, as open fossæ. The great importance, then, of Prof. Williamson's memoir, lay in

[1] It is unfortunate that Prof. Williamson misnamed the specimens he so well described. His *Orbiculina complanata* is clearly the *Orbitolites marginalis* of Lamarck; while his *Orbiculina tonga* is no less clearly the *Marginopora vertebralis* of Quoy and Gaimard, the recent type of Lamarck's fossil *Orbitolites complanata*.

its clear demonstration of the close affinity between *Orbitolites* and *Orbiculina*, whereby, as the place of the latter in the group FORAMINIFERA was beyond all question, that of the former also was assured,—the Bryozoic doctrine of Ehrenberg being thus altogether disposed of. And it followed, as a corollary, that any classification of Foraminifera must be based on wrong principles, which ranked two organisms so essentially similar as *Orbitolites* and *Orbiculina* in different Orders.

Having afterwards come into possession, by the kindness of Mr. Jukes, Mr. Hugh Cuming, Prof. E. Forbes, Prof. J. Quekett, and other friends, of a large series of different types of Orbitoline structure, obtained from different localities, including several very perfect specimens which had been taken alive and preserved in spirit, I applied myself afresh to the study of the genus; and soon found it to have a most important bearing on the great question of the "Range of Variation within the Limits of Species," which was occupying the attention of some of the most thoughtful Naturalists of that date (1850–56), before the appearance of the new light thrown upon it by the publication of the Origin of Species. And in 1855 I presented to the Royal Society a Monograph of the genus *Orbitolites* (Phil. Trans., 1856, p. 181), in which I treated all its forms —fossil as well as recent—that I had been able to examine as varieties of one fundamental type, incapable of being ranged under specific definitions, because of the gradational transition clearly traceable throughout the entire series, from the smallest and simplest *Orbitolites marginalis* to the largest and most complex *Orbitolites complanata*,—this transition showing itself alike in the progressive complication of the general structure, and in the exchange of the *spiral* plan of growth for the *cyclical*.

My subsequent studies of other types of FORAMINIFERA gave me a clearer insight into the place of *Orbitolites* in the series: and in the concluding summary appended to my fourth Memoir (Phil. Trans., 1860, p. 571), 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; and sketched-out 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 spiral *Orbiculina*, while the transition from the latter to the perfectly cyclical *Orbitolites* is quite gradational.

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

It was therefore with no small satisfaction that I recognised, among the products of the deep-sea dredgings carried on in the "Porcupine" expedition of 1869, a "missing link" that reproduces the whole of this genetic series in its own single organism, namely, a chambered calcareous disk, of which, though nearly the whole is constructed on the typically Orbitoline plan, the central (or youngest) part shows, in the first place, the simple undivided tubular coil of a young *Cornuspira;* then the partial interruption of that coil by incomplete septa, as in *Spiroloculina;* then the flattening-out of the spire, and its partitioning into chambers by perforated septa, as in *Peneroplis;* then the subdivision of the spirally-growing chambers into chamberlets, as in *Orbiculina;* and finally, the substitution of the cyclical for the spiral plan of growth, constituting it a true *Orbitolites*, —as will be presently set forth in detail in the description of *Orbitolites tenuissima.*

I had pointed out (Phil. Trans., 1860, p. 574) that the shells of the whole of this series—together with that of the fusiform *Alveolina*, which I regarded as another derivative from the same fundamental type—have that *porcellanous* character, whose distinctive importance was first indicated by Prof. W. C. Williamson, though he did not venture to adopt it as a basis of the primary subdivision of the group; and that a precisely parallel relation exists among those generic types of the series forming *vitreous* shells, which present the most highly specialised forms of Foraminiferal organisation. For whilst *Operculina* is (so to speak) a "vitreous" *Peneroplis*, and *Heterostegina* a "vitreous" *Orbiculina*, we have in *Cycloclypeus*, which shows a perfectly cyclical mode of growth in a finely tubulated shell, the "vitreous" parallel of *Orbitolites;* the parallelism being completed by the existence, in the probably "vitreous" *Fusulina*,[1] of the same plan of growth around an elongated axis as is shown in the "porcellanous" *Alveolina*.

In the same concluding summary (1860) I presented, as results of my researches, certain "general propositions" (p. 584), which I think it desirable here to reproduce; because, as my original investigation of the forms of the genus *Orbitolites* then known to

[1] I was obliged at that time to speak with hesitation of the place thus assigned to *Fusulina* (whose fossil shells make up the bulk of certain beds of Carboniferous limestone in Russia and elsewhere), "the metamorphic condition of its shell interfering with the minute study of its structure"; but a subsequent examination of specimens well preserved in the clays of the Carboniferous limestone of Iowa has satisfied me that my original interpretation of its microscopic appearances was correct (*Monthly Micr. Journ.*, vol. iii. 1870, p. 180). By previous systematists, *Fusulina* had been generally associated with *Alveolina*, to which its external resemblance is most remarkable.

me had been the starting-point of my rearrangement of the entire group,—of which it is one of the most conspicuous members,—so the examination I have now made, after a lapse of thirty years, of the vastly greater collection of more diversified forms recently obtained, has given me the opportunity of testing those conclusions by their applicability to a far larger range of facts.

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 greatest part of the *genera* of this group have been founded, and even in some instances those of its *orders*."

No verification of this proposition could be more complete than that afforded by the discovery of the *Orbitolites tenuissima* just referred to. If its development were arrested in its first stage, it would be taken for a young *Cornuspira;* if in its second, it would be ranked as a *Spiroloculina;* if its third stage had been first a little prolonged, and then checked, it would be recognised as a true *Peneroplis;* a specimen which had attained its fourth would be accepted as a true *Orbiculina;* and only when it has entered its fifth and last does it attain that characteristic Orbitoline structure and cyclical plan of growth, which are manifested in the typical *Orbitolites* from the very commencement. Now in the Classification of M. d'Orbigny, which was in 1860 the one generally followed, *Cornuspira* should, in virtue of its undivided cavity, count as a "Monostègue," *Spiroloculina* is an "Enallostègue," *Peneroplis* and *Orbiculina* are "Hélicostègues," and *Orbitolites* is a "Cyclostègue." That the fundamental characters of four out of the seven Orders which constitute, in M. d'Orbigny's view, the primary subdivisions of the group, should be thus presented by one and the same individual in the successive stages of its growth, is a sufficient proof that those assemblages cannot possibly be *natural;* and the proof obviously applies, *a fortiori*, to their generic subdivision; a very marked example being presented by the relation between *Orbiculina* and *Orbitolites*,—some advanced forms of *Orbiculina* abandoning the spiral for the cyclical plan of growth characteristic of the Orbitoline type, whilst all, save the highest and most advanced forms of *Orbitolites*, exhibit in the earlier stages of their development more or less of the spiral arrangement of their chamberlets, which is the distinctive characteristic of the Orbiculine type.

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 the group of FORAMINIFERA; since even if the limits 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."

Not only have my own subsequent studies of this group fully confirmed me in this conclusion, but I have found it accepted by every one of my fellow-workers in this country whose range of study has been similarly wide;[1] the doctrine that in each of the two great series of Porcellanea and Vitrea "everything passes into everything else" being one in which my friends W. K. Parker, T. Rupert Jones, and H. B. Brady entirely accord with me. Not the less, however, do we all recognise the fact that particular types of form *are* transmitted with marked genetic continuity, and the necessity, for the purposes of systematic arrangement and description, of marking these types by distinctive generic and specific names.

The genus *Orbitolites*, as shall presently appear, furnishes a peculiarly illustrative example of our mode of dealing with the subject. Four very well-marked types of form present themselves, round which the entire assemblage of specimens collected over a very wide geographical area, and from a great bathymetrical range, can be arranged without difficulty. Three of them belong to the littoral zone of warmer seas, where (as on the Fiji reef) they are generally found living together; and they differ in little else than *grade of development*, the smallest and simplest (*Orbitolites marginalis*) retaining the greatest resemblance to what may with almost certainty be regarded as the common ancestral type of *Orbitolites* and *Orbiculina;* the next (*Orbitolites duplex*) being a transitional form, in which the generalised ancestral characters very early give place to the distinctive peculiarity of the Orbitoline type, while an indication is given of advance towards the complexity of the highest and most specialised form; and the third (*Orbitolites complanata*) being the one which shows all the peculiarities of the type

[1] It is quite true that our conclusions on this point are not accepted by several Continental zoologists and palæontologists of repute. Prof. Möbius, for example, who a few years since brought home a gathering of *Foraminifera* from a reef off Mauritius, has expressed his dissent from it, on the ground that he sees no reason to believe that species are less sharply defined among *Foraminifera* than they are in other groups of the Animal Kingdom, and that it is a logical error to pass at once from the *individual* to the *genus*. Now I find in Prof. Möbius's own valuable monograph (Foraminifera von Mauritius) a very characteristic illustration of our position. The form he has described as *Orbitolites complanata* is so far from being a characteristic example of that species, that not only the central (or earlier) portion of the animal figured by him (pl. IV., wrongly lettered III., fig. 5), but the whole disk of which he gives a vertical section (pl. V. fig. 2), save its three outer annuli, is formed upon the plan characteristic of my *Orbitolites duplex*, his specimen being a young example of one of the *transitional* forms above adverted to. Now if Prof. Möbius should reply that the existence of such forms only shows that our conception of Foraminiferal species should be enlarged, and that the type I have here distinguished as *Orbitolites duplex* should be merged in *Orbitolites complanata*, I have simply to reply that as the two types are well and clearly differentiated in the hundreds of specimens of each which have passed under my review, and as *Orbitolites duplex* is much more nearly allied in the "simplicity" of its structure to *Orbitolites marginalis* than it is to the "complex" *Orbitolites complanata*, the utmost confusion would be the result of such an enlargement of our conception of the latter, as would be necessary to enable it to include the former. If Prof. Möbius will attentively study Part III. of my Researches on the Foraminifera (*Phil. Trans.*, 1859), he will find that, on the logical principle he advocates, our conception of his *Peneroplis pertusus* must be enlarged to include not only all the species of the genus *Peneroplis*, but also those of the genera *Dendritina* and *Spirolina;* for my series of forms of these types, collected from a very wide geographical area, and under very diversified conditions of climate and sea-depth, shows such a *gradational* passage from one type to another, that it is impossible to break up the assemblage into even *primary* groups—much less into *secondary*—that could be limited by precise definitions. I may add that before committing myself to the publication of an opinion which was at that time opposed to the doctrine taught by all the highest authorities in Systematic Zoology, I had the advantage of submitting it to the criticism of M. Deshayes, one of the ablest Conchologists then living; who, after an attentive examination of the series which I placed before him, avowed his inability to draw a definite line of demarcation through any part of it. And yet to abolish *Peneroplis, Dendritina*, and *Spirolina* as "generic types" would be out of the question.

in their very highest grade of development. And yet, whilst these three types of form are so well marked, and so constantly reproduced genetically, that the whole Challenger collection (with an exception to be presently referred to) can be ranged under one or another of them, yet even in the assemblage that is characterised by the most complex type of structure, certain individuals are found, which, in the earlier stages of their development, are no less characteristically representative of the lowest and intermediate. But the fourth of these specific types, *Orbitolites tenuissima*, in which the pedigree just now traced-out presents itself most completely and unmistakably, is not only (so far as is yet known) remarkably constant in its characters, but, whilst constructed on the very simplest plan, is separated from *Orbitolites marginalis* (which is precisely on the same grade of development with itself) by very sharply-defined peculiarities of its own. And it is not a little remarkable that its *habitat* should be almost entirely different from that of the other three; its home being apparently in the cold depths of the North Atlantic, whence it has strayed into the littoral zone of the Iberian peninsula, and thence along the Mediterranean into the Ægean, where it encounters a similar "outlier" of *Orbitolites marginalis*, which has probably found its way thither through the Red Sea.

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 characterised 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."

Of this principle, the evidence I have now to present of the genetic derivation of the most complex and highly-specialised Orbitoline type from the simplest and most generalised Milioline, will be found—to say the least—peculiarly illustrative; its special value as a "Study in the Theory of Descent" consisting in this, that whilst the ancestral relations of the higher types of organisation are for the most part evinced in transitory phases of development, of which few or even no traces may remain in the adult, we here find the whole genetic history distinctly recognisable in the completed type.

Having thus set forth what I regard as the principles on which alone a Natural System of the FORAMINIFERA generally can be framed, I shall proceed to apply these in the description I have now to give of the genus *Orbitolites*, and of the specific types which my enlarged study of it now enables me to recognise.

DESCRIPTION OF GENUS AND SPECIES.

Orbitolites, Lamarck.

Orbitolites, Lamarck, Système des Animaux sans Vertèbres (1801).
Orbulites, Lamarck, Histoire Naturelle des Animaux sans Vertèbres [1816–22].
Orbitolites, Milne-Edwards, in posthumous edition of Lamarck's Animaux sans Vertèbres.
Marginopora, Quoy and Gaimard, in De Blainville's Manuel de l'Actinologie, p. 412 [1834].
Orbitolites, d'Orbigny, Cours Élémentaire de Paléontologie [1849].
Orbiculina, Williamson, Trans. Micr. Soc., vol. iii. [1852].

The fundamental distinction of this Generic type, which separates it from all other "porcellanous"-shelled Foraminifera (the existing genus *Cycloclypeus*, Carpenter, and the fossil genus *Orbitoides*, d'Orbigny, representing it in the "vitreous" series), consists in its *cyclical* plan of growth, that is, in the arrangement of the sub-segments of the sarcodic body of the animal, connected together by *annular* "stolons," in concentric zones;

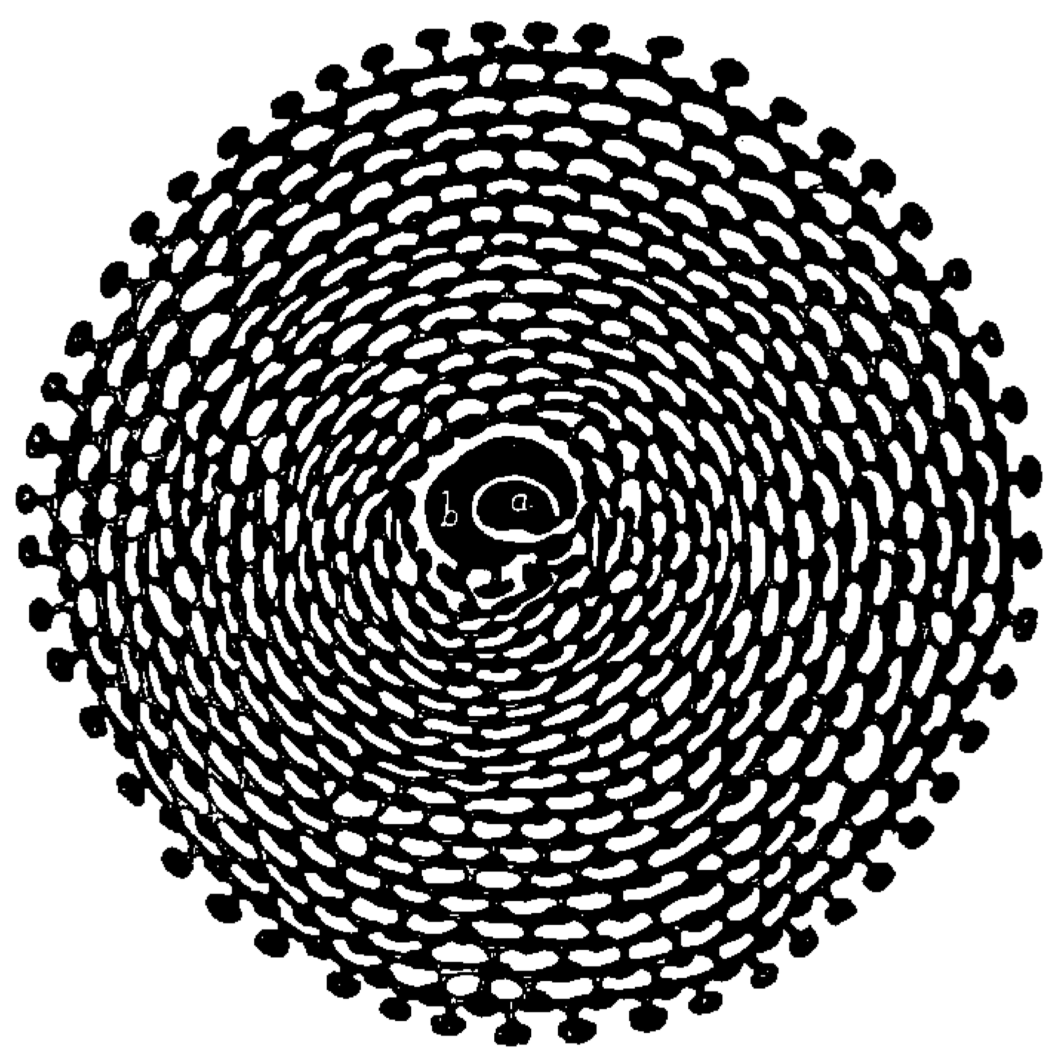


FIG. 1.—Cyclical arrangement of parts of sarcodic Body of *Orbitolites*

a, Primordial segment.
b, Circumambient segment; each subsequent formation divided into sub-segments connected by annular stolons, and each annulus connected with the next by radial stolon-processes.

a new annulus being formed by the extension of *radial* sarcodic "stolon-processes" from the last or outermost of the preceding annuli, giving origin to a new circlet of sarcodic masses, which put forth lateral extensions that unite them with their fellows, and thus complete the ring (fig. 1). The innermost of these sarcodic rings is produced by pullulation from the circumference of the first-formed *nucleus*,[1] which occupies the centre of the disk; and this "nucleus" consists of a "primordial segment" *a*, from one end of which is given off a larger "circumambient segment" *b*, which passes completely round it, and is itself surrounded by the first annulus. The shelly disk (fig. 2) which encloses this sarcodic body, and is (so to speak) modelled upon it, is marked on each surface by a series of distinct concentric circles, the spaces between which are channeled-out in the interior into concentric series of chamberlets, connected together by annular galleries; and the cavitary space of each zone is connected with that of the next by short radial passages, of which one usually

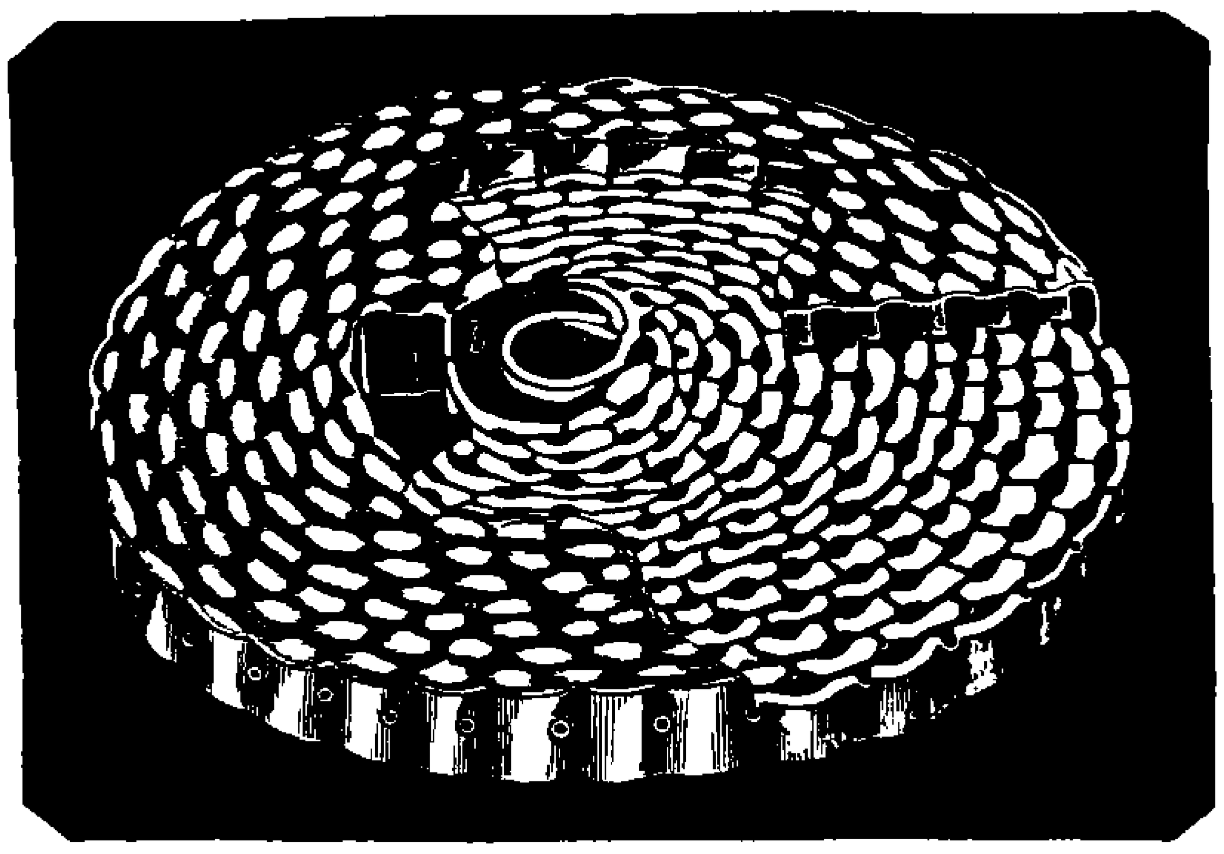


FIG. 2.—Typical plan of structure of shelly Disk of *Orbitolites*.

a, Primordial chamber.
b, Circumambient chamber; together forming a "nucleus," which is surrounded by concentric rings of chamberlets connected with each other by annular galleries and radial passages, the latter appearing as pores along the margin.

passes-off from one of the short galleries that connect the chamberlets of each zone, into a chamberlet of the zone that surrounds it. These passages, in the outermost zone, open as "pores" on the margin of the disk; these orifices constituting the only means of communication between the cavitary system of the disk and the outer world. Each concentric zone, when itself the outermost, thus communicated *directly* with the exterior; but each, when surrounded by another zone, can only do so through its intermediation, what were in the first place its *marginal* pores, being closed-in by a new annulus of shell, and opening into its chamberlets. The "nucleus" of the shell, round which its first annulus is formed, contains a "primordial chamber" (fig. 2, *a*), surrounded by a "circumambient chamber" *b*; and, in the highest or most specialised representatives of the Orbitoline type, radial passages (*e*, *e*, *e*, fig. 3) are given-off from the whole circumference of this "circumambient" chamber, which carry stolon-processes (Pl. V. fig. 18) that swell into the sarcodic sub-segments which occupy the successive annular series of chamberlets *c*, *c*, *c*.

[1] This use of a term which has an altogether different and well-understood signification in Biology, is doubtless open to objection; and I can only plead in excuse that having employed it in my original Memoir, published when that signification was far more limited, I have not been now able to think of any other which should be equally applicable. The term *centrum* might have been substituted, if it were not that (as I shall hereafter show) the "nucleus" is often *excentric*.

The "simple" ground-plan is amplified in the "complex" edifice built-up on it by a sort of vertical piling of one storey on another, marked externally by the multiplication of the rows of marginal pores. In so far as this is effected by the vertical extension of the sarcodic sub-segments into columns, and by an addition to the number of their annular and radial stolon-processes, the increase may be regarded—like the successive addition of new zones to the periphery—as consisting in *growth* only. But when, instead of a multiplication of similar parts, we meet with a *differentiation* in the arrangement of these, if not in their character, shown in a separation of the two superficial layers of chamberlets from the intermediate structure (Pl. VI. fig. 4), by which the

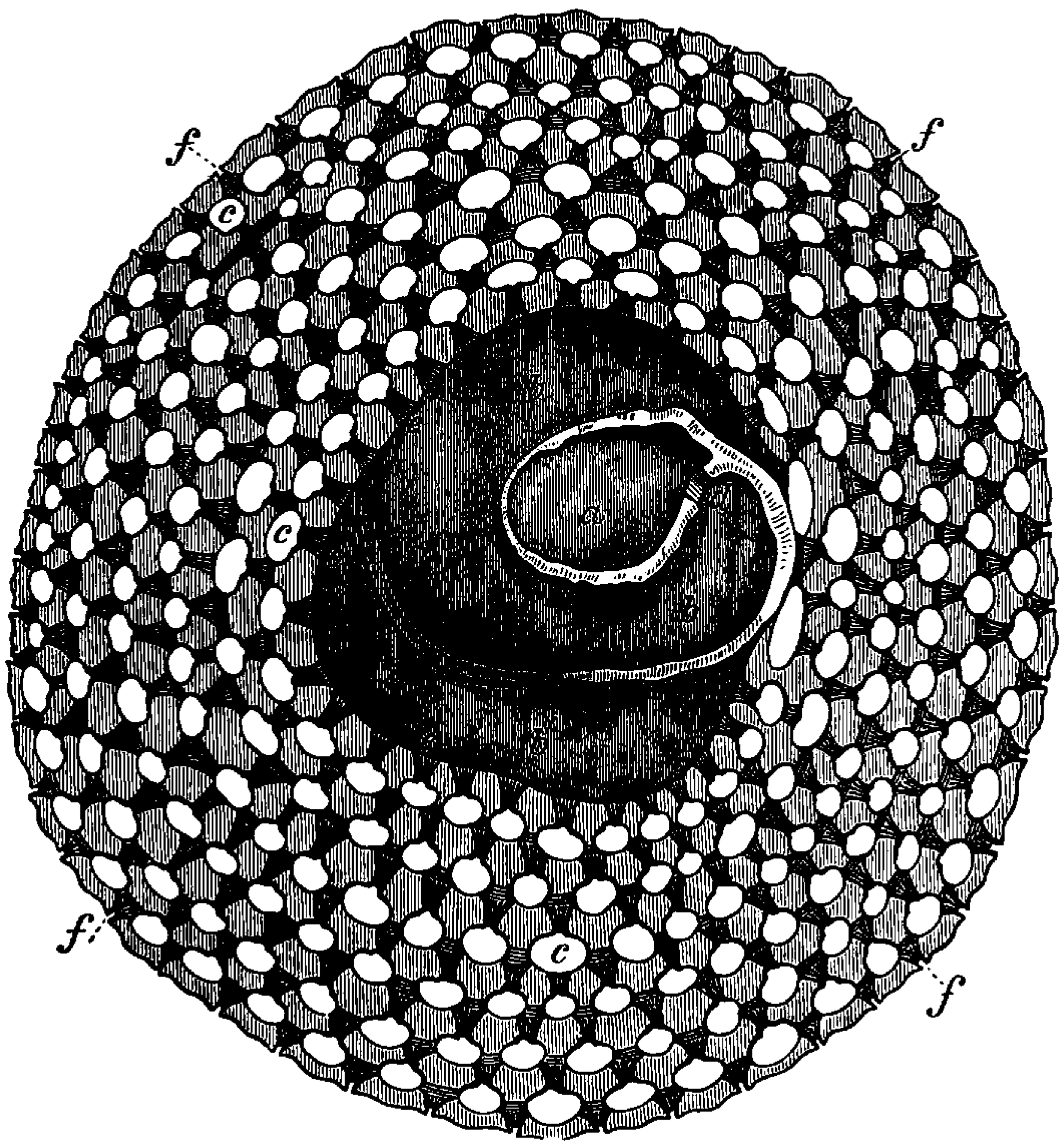


FIG. 3.—Ground-plan of shelly Disk of *Orbitolites complanata*.

a, Primordial chamber.
b, *b*, Circumambient chamber, a part (*b'*) of which is often partially cut off from the rest by an imperfect partition.
c, *c*, *c*, Chamberlets of different successive annuli.
d, Passage from primordial into circumambient chamber.
e, *e*, Radial passages from circumambient chamber into chamberlets of first annulus.
f, *f*, Radial passages opening at the margin of the disk as marginal pores.

"complexity" of the calcareous fabric is considerably increased, this differentiation must be regarded as an act of *development*, marking the highest stage of the evolution of the type.

I have not been able, however, to detect any evidence of local differentiation in the substance of the sarcodic body; every part of which, even in the most complex forms, seems to have the same character as every other part. A curious evidence of this absence of differentiation is afforded by the fact, that in all the specimens in which the sarcodic body has been preserved in alcohol, the cavities of several outer zones are quite empty, whilst those of the "nucleus" and inner zones are quite filled. For the shrinkage of the sarcodic substance, produced by the corrugating action of the spirit, has drawn the substance of the peripheral annuli towards the central portion of the disk; and this could not happen, but for the entire absence,—*first*, of any attachment of the body to the walls of the cavities that enclose it, and, *second*, of any resistance to the complete change of form it must undergo, to allow the passage of the substance that occupies the chamberlets of the outer zones, through the narrow connecting passages which lead to the inner cavities of the disk, in which it so completely fuses with their own body-substance, as not to present the least appearance of heterogeneousness.

This absence of differentiation is further made apparent by the extraordinary reparative power possessed by every form of *Orbitolites;* not only losses of substance to any amount and in any part of the disk being made good, but even a small detached peripheral fragment having the power to develop a new disk, as shown in Pl. I. figs. 6, 7, and in Pl. VIII. figs. 2–10. It is clear that connection with the central "nucleus" is not in the least degree requisite for the continued growth of the peripheral part; and it is also clear that after the cyclical stage of growth has been once attained, the reparative process is entirely directed to the reproduction of the complete discoidal form. This is obviously to be explained by an extension of the homogeneous sarcodic body-substance around the whole margin of the fragment, so as to form an annulus which buds-off a new and complete circlet of chamberlets.

Thus, we have every reason to believe, each sub-segment of the sarcodic body precisely repeats the rest, and would be equally capable of maintaining its own existence if detached from the disk of which it forms part. It is clear that the inner portion of the disk can only be nourished through the intermediation of the outer, as it has no communication with the medium around, except through the marginal pores; and from the analogy of other Rhizopods there is strong reason to believe that during life there is a continual flow of semi-fluid protoplasm from one part to another, so that any nutrient material obtained by the peripheral annulus from without is speedily diffused through the entire mass.

Owing to the smallness of the number of spirit-specimens of the deep-sea type, *Orbitolites tenuissima*, that have come into my possession, I have not thought it well to decalcify any one of them for the examination of its very attenuated body. But the superficial lamellæ which close-in the chamberlets are so transparent, that the general condition of the protoplasmic substance which occupies them can be pretty clearly made out. This seems to have the dark olive-green hue, which is commonly met with in the sarcodic body of the "arenaceous" deep-sea Foraminifera; and it does not present the corpuscular aspect which I shall presently describe in the sarcodic bodies of *Orbitolites duplex* and *Orbitolites complanata.* But in one of these specimens several nuclear-looking bodies can be plainly discerned, which correspond in size and appearance with the nuclei described by Hertwig in the fresh-water monothalamous *Microgromia*,[1] and subsequently in *Spiroloculina*, *Globigerina*, *Rotalia*, and other marine polythalamous forms.[2] The very irregular distribution of these nucleus-like bodies shows that they cannot have any particular *local* function. In the specimen here figured (Pl. II. 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 zones there are as many as five. Elsewhere 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 devoid of them. Their diameter is about $\frac{1}{1750}$th of an inch.

The substance of the sarcodic bodies of *Orbitolites duplex* and *Orbitolites complanata*, on the other hand, consists in great part of an aggregation of spherical corpuscles about $\frac{1}{2500}$th inch in diameter, as shown under a power of 120 diameters in Pl. V. fig. 3, and magnified 180 times in fig. 16. These corpuscles might be easily taken for cells; but not only does a careful examination of them fail to bring into view either nucleus or limitary membrane, but they are found, when subjected to pressure, to break-up into a multitude of separate rounded granules, of extremely pellucid aspect, from $\frac{1}{8000}$th to $\frac{1}{12000}$th inch in diameter. Sometimes the spherical corpuscles are very closely packed together, especially in the primordial segment; in other instances there are considerable spaces between them, as shown in Pl. V. fig. 16.

The whole sarcodic body of *Orbitolites duplex* has a reddish tinge, which is most decided in the primordial and circumambient segments, and in the inner annuli of sub-segments. And in these I can generally observe, more or less distinctly, a limiting membrane (Pl. V. fig. 5), sometimes rather deeply tinged with red, which is probably of a chitinous nature. On the other hand, scattered irregularly in different parts of the disk, certain bodies present themselves (Pl. V. figs. 4, *a*, *b*, *c*, 15, 17), which have a much more distinct cellular nature, having a very thick (apparently cellulose) cell-wall, and a deep red endochrome. These I am strongly inclined to regard as vegetable. Their diameter (usually about $\frac{1}{400}$th inch) is much too great to allow them to have passed through the marginal pores in their present condition; but as there are now several well-established cases of parasitic vegetation, I cannot think it impossible that the germs of these cells found their way in from without, and have undergone their subsequent development in the places they now occupy. The living specimens of the "duplex" type were for the most part obtained in the 18 fathoms' dredging on the bank of the Fiji reef; and it does not seem improbable that their sarcodic bodies derive their red hue from zoospores or other particles of the Rhodosperm *Algæ* inhabiting that zone, which they may take-in as food. For the sarcodic bodies of *Orbitolites complanata*, whose living specimens

[1] *Archiv. für Mikroskop. Anat.*, Bd. x. Supplement-heft.
[2] *Jenaische Zeitschrift*, Bd. ix.–xi.

were for the most part found on the surface of the reef, have a greenish tinge, as if they lived on the corresponding particles of the Chlorosperm *Algæ*. When growing attached to marine plants, the animal bodies of *Orbitolites* may be nourished by the gelatinous investment with which those plants are covered. In my former Memoir I mentioned that some of the spirit-specimens I had then examined by decalcification proved to be invested by a sort of cuticle formed of *Diatoms*, *Desmids*, and other minute *Algæ*; but I have not met with any such investment among the large number of spirit-specimens of both types which I have examined in the Challenger collection.

As to the Reproduction of *Orbitolites*, I regret to be unable to afford the least information, having searched in vain for any further evidence of the mode in which it is effected, than that which I had formerly obtained. In my Introduction to the Study of the Foraminifera (p. 38) I described and figured some extremely young specimens of *Orbitolites*, consisting only of the "nucleus" and a single annulus of sub-segments,—which had been taken out from the grooved margin of a large plicated disk, resembling those figured in Pl. VII. And I have found similar specimens in the same situation in some of the large Fijian disks.[1] As I shall hereafter state more in detail, the marginal annuli of the largest disks often have no radial partitions, their cavities being continuously annular; and as the thin external walls of these annuli, being unsupported by internal partitions, are very fragile, it may not be thought unlikely that gemmules may be formed within these peripheral zones, which may be set free by the rupture of this wall, and may retain for a time the protection of the overhanging superficial lamellæ, which form a deep channel for their lodgment. Of a very curious variation in the *mode of growth* of *Orbitolites complanata*, which seems constantly related to the *size* of the "nucleus" in which it commences, particulars will be given hereafter (pp. 38, 41).

1. *Orbitolites tenuissima*, Carpenter (Pls. I. and II.).

Orbitolites tenuissimus, Carpenter and Jeffreys, Proc. Roy. Soc., vol. xviii., 1869, p. 421, and vol. xix., 1870, p. 155.

This very beautiful and most interesting form of the Orbitoline type (Pls. I. and II.) was first obtained in the deep-sea dredgings of the "Porcupine" expedition of 1869, between the north-west of Ireland and the Rockall Bank; and has been subsequently brought up from abyssal depths in other parts of the North Atlantic, as also from shore bottoms off the coast of Portugal, and within the Mediterranean. It is at once distinguished from all other specific forms by the extreme disproportion between the area and the thickness of its disks; for whilst its largest examples approach in diameter the smaller specimens of *Orbitolites complanata*, and their surface presents the same regular

[1] Such young disks will be found represented in Pl. XVI. figs. 1–4, of Mr. Brady's Report on the Foraminifera of the Challenger Expedition, Zool. Chall. Exp., part xxii.

arrangement of concentric annuli crossed by straight radiating lines (compare Pl. I. fig. 1 with Pl. VI. fig. 4), their thickness does not exceed that of the smallest specimens of *Orbitolites marginalis,* with which this type corresponds in the simplicity of its structure (indicated by the singleness of the row of pores along its margin), but from which it is obviously differentiated by the shape of its chamberlets, indicated by its surface-markings.

The disks of this species, which are usually remarkable for their flatness and regularity, seem to attain a diameter of at least 0·6 inch; but specimens of that size are seldom or never brought up entire, their extreme tenuity, and the slight adhesion of their successive annuli to each other, rendering them extremely fragile. Their thickness does not exceed $\frac{1}{300}$th of an inch. The inner margin of each shelly annulus is slightly grooved, as shown in Pl. I. fig. 4; and the two edges of this groove embrace the thin edge of the preceding annulus, as shown in sectional view at *a, a,* fig. 3. In all but the central portion of these disks (Pl. I. fig. 1), the annuli are complete and of nearly uniform breadth: but the inner portion of the disk shows a marked excentricity, the "nucleus" being considerably out of centre, and the first-formed zones being developed from one side of it only; so that it is not until after repeated additions, that the *cyclical* plan of growth characteristic of the Orbitoline type comes to be established. When the cavity of the disk is laid open, either by grinding or by the action of dilute acid on its thin superficial lamellæ, or even when an unaltered specimen mounted in Canada balsam is viewed by transmitted light, the radiating lines with which the surface is marked are seen to correspond with internal partitions (Pl. I. fig. 2, and Pl. II. fig. 5), which divide each flattened annular chamber into a multitude of narrow chamberlets. This division, however, is not complete; for the radial partitions do not extend to the outer margin of the annulus, so that a sort of gallery is left, into which every one of the chamberlets opens at its outer end. The septum which forms the peripheral wall of this gallery is perforated by pores at regular intervals; and each of these opens into a chamberlet of the next annulus,—those of the outermost annulus opening along the margin of the disk (Pl. I. fig. 5). It is characteristic of this species that the pores are more or less elongated in the plane of the disk, instead of being either circular or vertically-oval, as they are in other *Orbitolites.* Similar pores are seen on the internal (fig. 4) as well as the external margin of any zone that has been detached by fracture; and it is obvious that they constitute the channels of communication between the central and peripheral portions of the cavitary system; whilst the annular galleries, seen in transverse section at *b, b, b,* fig. 3, maintain the like continuity between the different portions of each zone. Thus, whatever may be the number of these concentric annuli, a perfectly free communication exists throughout; the departure shown in this species from the general plan of structure already described, having reference only to the shape of the chamberlets, and their relation to the undivided gallery. And it is at once seen that this departure marks out *Orbitolites tenuissima* as an earlier and less specialised form; since if the chambers of a *Peneroplis* were subdivided by partitions answering to its surface-markings (fig. 7, p. 46), springing from their inner septa between the pores, but not extending to their outer, the result would be exactly what we here find.

Now the peculiar point of interest attaching to this *Orbitolites tenuissima,* is that the structure of the inner part of every disk shows it to have thus originated: for the "nucleus" is here a continuous spire of five or six turns (Pl. II. fig. 3), closely resembling that of a young *Cornuspira,* with an indication of imperfect septal interruptions resembling those of a *Spiroloculina;* the spire, when beginning to open-out (fig. 5, *a*), is interrupted by a complete septum traversed by pores, exactly corresponding to that of *Peneroplis;* whilst the next chamber, *b,* is divided into four chamberlets by three partitions springing from this septum between its pores, this subdivision converting the incipient *Peneroplis* into a young *Orbiculina.* In the specimen here figured, this chamber is not separated by a completely-formed septum from the next chamber *c,* and the latter is undivided save by a single radial partition; and although this is a mere individual variation, it is of interest as showing a reversion to the "peneropline" type, even after the assumption of the "orbiculine." The orbiculine type prevails through several succeeding chamber-additions; but the *spiral* plan of growth characteristic of it soon begins to give place to the *cyclical;* for the next-formed chamber *d, d,* which is divided into chamberlets by radiating partitions that spring from the inner septum between the pores, sends backwards alar extensions *d′, d′,* which begin to enclose the spiral "nucleus." This extension is still more marked in the next chamber *e, e,* whose two alæ, *e′, e′,* reach the ends of the transverse diameter of the original spire; and the alæ of the subsequently-formed chambers extend themselves further and further back around the spire (as shown in Pl. I. fig. 1), until—in the specimen here figured—those of the ninth chamber meet at the opposite side of the spire, so as to enclose it all round, while the tenth forms the first complete annulus, to be itself surrounded by a succession of similar annuli, the number of which in full-sized specimens may exceed thirty.

Thus we have, in this one organism, a complete transition from the simple slightly interrupted spiral tube of the least differentiated *Miliolines,* through the expanded and chambered spire of *Peneroplis,* and the chamberletted spire of *Orbiculina,* to the concentric annulation and subdivided chambers of the typical *Orbitolites.* And we shall presently see how this last plan undergoes, in other species, a progressive modification, until, in its most specialised types, we lose all trace of derivation from a spiral,—the annuli being formed concentrically, from their very commencement, around a discoidal "nucleus," and their chamberlets being so modified in shape and disposition, as not to suggest their origin in the subdivision of a *Peneroplis*-chamber by radial partitions.

Reparations.—As might be expected from the extreme tenuity and fragility of the disks of this species, they are obviously very liable to fracture; scarcely any specimen having presented itself which did not bear some evidence of injury of this kind. Where only small portions of the margin are broken away, the next-formed annuli extend themselves along the fractured edge; and thus the cyclical mode of growth is completely maintained, with only a temporary irregularity. In Pl. I. fig. 6, is shown a disk of which more than one-half, together with the "nucleus," had been lost before the production of the last two zones. These have not only been formed, as ordinarily, round the unbroken margin, but have extended themselves along the fractured edge, and have even filled up the space originally occupied by the "nucleus"; and the annuli being thus completed, the disk will continue to grow on the cyclical plan, and even (as is shown in the like examples of *Orbitolites complanata*, Pl. VIII.) may recover in great degree its circular shape. But even a mere fragment broken away from the margin of a disk may suffice to originate a new one, as shown in Pl. I. fig. 7; the form characteristic of the type being completely restored. Owing to the transparence of this specimen, 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 septal plane, and that these extensions coalesced to form a continuous ring, as in the formation of the ordinary succession of concentric annuli. It is most interesting to observe that the zone of chamberlets to which this sarcodic ring gave origin is formed upon the *perfected* type, without any reversion to the earlier "peneropline" stage.

Geographical and Bathymetrical 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 of this type were obtained in the "Porcupine" dredgings of 1869, at depths of from 630 to 1443 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 Carthagena. That it is an inhabitant of other parts of the Mediterranean I then inferred from having detected fragments of it in the Foraminiferal dredgings made at 250 fathoms' depth by Prof. Edward Forbes and Lieut. (now Admiral) Spratt in the Ægean, in 1842; and it is stated by the Rev. A. M. Norman, in Dr. J. Gwyn Jeffreys's Report on the "Valorous" cruise, that it has been dredged by the Marquis da 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 1350 fathoms, bottom temperature 34°·6 Fahr.), as well as at two Stations in the North Atlantic, both in the parallel of 56°,—No. 12, depth 1450 fathoms, and No. 13, depth 690 fathoms.[1] It has been only once brought up in the Challenger expedition, viz., at Station 44, off Cape Hatteras, on a bottom of 1700 fathoms, over which creeps (there is strong reason to believe) an under-flow of cold water from the Arctic basin. It has since, I understand, been found plentifully in a dredging taken by the "Travailleur," in the Bay of Biscay (Fosse de Cape Breton), at a depth of 1200 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° Fahr. downwards; but that it is also 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°; whilst on the shallow bottom of Setubal Bay, and the shore-slope near Carthagena, the summer temperature must be considerably higher.

Looking to the singular retention, in this beautiful Orbitoline, of the Milioline type, its derivation from which may now be confidently affirmed, and also to that elongated form of its chamberlets which seems to mark it out as more nearly related than either of the other "simple" types to *Peneroplis*, the probability seems strong that it was a very early form; and although no specimens of it have yet been met with in the fossil state, its absence from the Geological Record may be considered as sufficiently accounted for by its extreme fragility. I need scarcely point out how completely the idea of its antiquity is borne out by its persistence in the abyssal depths of the North Atlantic,—the home of so many other early types of animal life.

2. *Orbitolites marginalis*, Lamarck (Pl. III. figs. 1–7, Pl. IV. figs. 1–5).

Orbitolites marginalis, Lamarck, Syst. des Anim. sans Vertèbres [1801].
Sorites orbiculus, Ehrenberg, Familien und Gattungen der Polythalamien. Abhandl. der könig. Akad. der Wissenschaften zu Berlin, 1839.
Orbiculina complanata, Williamson, Trans. Micr. Soc., vol. iii., 1852, p. 115.

This species was established by Lamarck on the basis of specimens discovered by M. Sionest of Lyon, attached to corallines, fuci, &c., in the Mediterranean; and was the only recent type of the genus then known. Lamarck's description of it—*utrinque plana, margine poroso*—is quite insufficient to differentiate it either from the preceding or from the species I shall have subsequently to describe; but as no other Orbitolite is known to inhabit the Mediterranean or Ægean, there is no difficulty in specifically identifying the Lamarckian type with the more highly developed examples of it which are found in the Red Sea, on the coast of Australia, in the Philippine Sea, and on the Fiji reef. The

[1] *Proc. Roy. Soc.*, June 15, 1876.

diameter of Lamarck's specimens is stated by him at only 2 mm., or about 0·08 inch; but that of the Fijian specimens ranges to 0·2 inch, or somewhat more. The form of the complete disks (Pl. III. fig. 1), when their growth has not been interrupted by injury, is very regularly circular; and their surface, in all but their central portion, is marked by concentric circles that divide it into annuli having a pretty constant breadth of $\frac{1}{400}$th inch, each of them marked at regular intervals by dark punctations. When the surface of a peripheral portion of the disk is viewed by reflected light under a higher magnifying power (Pl. III. fig. 3), each of these punctations shows itself as a dark spot surrounded by a lighter space, which is often somewhat elevated; and if the margin of the disk is viewed obliquely, as at *a*, these circles are seen to be the summits of rows of short cylindrical columns, whose projection gives a slight "fluting" to the edge of the disk. When the edge of the disk is turned directly towards the eye (as at fig. 4, *a*), a single marginal pore is seen in each of the depressions between the columnar projections: this pore is usually elongated vertically, so as to form a fissure; and sometimes, when the margin of the disk is unusually thick, as at *b*, the fissure is crossed by a shelly bridge, dividing it into two pores. This, however, is not a real duplication of the pores, such as that which is seen at the margin of the species to be presently described (fig. 13). The central portion of the disk (fig. 2) resembles that of *Orbitolites tenuissima* in the excentricity of its "nucleus," and the incompleteness of the rows of chamberlets first developed around it; presenting in this stage of its growth exactly that conformity to the *spiral* plan, which is shown in the third or "orbiculine" stage of the preceding, and the same early approach to the *cyclical*, which is made by the extension of each new row of chamberlets beyond its predecessor, so that the two ends of the eighth or ninth row meet on the opposite side of the nucleus, forming the first complete annulus.

Although the "nucleus" itself shows more conformity to the Orbitoline than to the Milioline type,—consisting of a rather large primordial chamber nearly surrounded by a circumambient chamber,—yet its character will be presently seen to be most singularly intermediate between the two. Not unfrequently the "orbiculine" centre of the disk is somewhat thicker than the annular portion by which it is immediately surrounded, so as to form a marked projection from its surface. As new annuli are added-on, however, to the exterior of those first formed, and as the vertical thickness of each is usually rather greater than that of its predecessor, the disk as a whole becomes somewhat biconcave.

The marginal thickness of the largest disks I have seen of this species is about 0·006 inch, or about one thirty-fifth of their diameter. The calcareous lamellæ which cover-in the ends of the columnar chamberlets, are so thin as to be translucent, and are very easily abraded; so that specimens of this type picked out from shore-sands often have the cavities of their chamberlets laid open, as shown in Pl. III. fig. 7. The amount of solid substance in these disks is far greater in proportion to the cavitary system, than in *Orbitolites tenuissima;* at least half the breadth of each annulus being occupied by the inter-annular septum, and the partitions that separate the adjoining chamberlets being also much thicker. These partitions are best brought into view by a concentric fracture separating one annulus from another, so that the outer series of chamberlets is laid open on its central aspect, as shown in fig. 5 ; but such a separation is much less easy in this type than in the preceding, in consequence of the much larger surface of adhesion between the successive annuli. When the cavitary system is laid open by a section in the radial direction, so as to traverse a succession of annuli (fig. 6), there is seen in each of the partitions that divide the chamberlets a large fissure on its peripheral side, by which the adjoining chamberlets of the same annulus are brought into connection. This fracture also shows that the columnar chamberlets of the marginal portion of the disk are not straight, but arcuate; their two extremities bending inwards, or towards its centre.

It is only, however, by reducing the thickness of the disk by grinding, so that it can be examined by transmitted light, that its internal structure can be properly traced out. If only one of its surfaces be ground away, so that the sectional plane passes near the other, it will traverse the chamberlets, but not the passage-system which connects them, as is seen in Pl. IV. figs. 1, 2, 3 ; but when this plane is made, by grinding from both surfaces alike, to pass through the middle of the thickness of the disk, the communications between the chamberlets are brought into view, as shown in fig. 4. Here we see the flask-shaped primordial chamber *a*, opening at its neck into the circumambient chamber *b*, which almost completely surrounds it; while from the other end of this, there issues a passage that leads into the undivided chamber *c*.

Taking this chamber as our starting-point for comparison with the "orbiculine" portion of the disk of *Orbitolites tenuissima,* we find the parallelism extremely close. The septal plane which bounds it externally is traversed by two passages that lead into two chamberlets *d*, which are connected with each other laterally by a passage left in the partition between them. The septal plane that closes-in these two chamberlets is traversed by five radial passages, leading to as many chamberlets in the next row *e;* of these passages two proceed from each of the chamberlets in row *d*, and one from the passage that connects them; and all five chamberlets are brought into lateral connection with each other by passages left in the radial partitions, as shown in Pl. III. fig. 6. The next septal plane is traversed by a radial passage from each of the passages of communication between the chamberlets of the preceding series, and also by passages from the chamberlets themselves; and as each of these leads to a chamberlet of the succeeding row, the number of these is further increased. The same mode of growth continues, until the lateral extension of the rows of chamberlets (each representing a single "peneropline" chamber) brings together their extremities so as to complete the circle;

and every new annulus that is afterwards formed, exhibits exactly the same arrangement. As a general rule, the chamberlets in each annulus *alternate* in position with those of the annuli internal and external to them; the radial passages which lead to them from the preceding annulus having their origin, not in its chamberlets, but in the annular passage that connects them. And it is only when an additional chamberlet is interpolated, in accordance with the increased diameter of the added ring, that the passage leading to it comes off directly from a chamberlet of the previous one. And thus it comes to pass that the pores seen along the margin of the disk (Pl. III. fig. 4) open *between* the columnar chamberlets, each of them communicating with the chamberlet on either side of it, as shown at *f, f*, Pl. IV. fig. 4.

The meaning of these arrangements is made clear by reference to Pl. IV. fig. 5, which shows the sarcodic body of *Orbitolites marginalis*, obtained by the solution of its calcareous shell by dilute acid. The primordial segment *a* communicates by a narrow pedicle or stolon-process with the circumambient segment *b*, and this, again, by a similar pedicle with the segment *c*, which answers to the segment *a*, Pl. II. fig. 1. From this are given off the two radial pedicles that enlarge into the two sub-segments *d;* and these are united laterally by a pedicle, that gives off the radial extension which enlarges into the sub-segment *e* of the next band. The same plan is maintained through each successive addition, the sub-segments of each row showing themselves as enlargements of a continuous cord of sarcode, on which they are threaded, as it were, like beads upon a string. Each row of sub-segments represents the entire segment which occupies the undivided chamber of a *Peneroplis;* and so, when the first annulus is completed by the meeting of the two extremities of that cord, it has still the same equivalent, which is, of course, equally to be recognised in all subsequent annuli. In the outer portions of the disk of *Orbitolites marginalis*, the sub-segments acquire a columnar form by vertical growth, which is in striking contrast with their extreme flattening in *Orbitolites tenuissimus.*

Thus, not only in the "orbiculine" stage, but throughout the whole later growth of the disk in this type, we recognise the same essential features as in the preceding;—the subdivision of the "peneropline" chambers into chamberlets, and of the segments of the body into sub-segments, taking place on precisely the same plan in both, and exactly the same system of communications being maintained between the subdivisions;—the only difference being in the *form* of these subdivisions, which is obviously a character of comparatively trivial import. The question now suggests itself, what is the relation between the "spiroloculine" shell of *Orbitolites tenuissima*, and the "nucleus," consisting of "primordial chamber" and "circumambient chamber," of *Orbitolites marginalis.* This will be best answered by comparing the sarcodic bodies of the two types; for whilst the small primordial segment of the one gives off a long, slender, slightly interrupted cord, which coils round it several times before it begins to expand (Pl. II. fig. 1), the large primordial segment of the other gives off a far thicker cord, which only makes a single turn. It can scarcely be doubted, I think, that this circumambient segment represents the whole of the original "spiroloculine" coil drawn up into itself, and thus perpetuates, under a form which at first sight appears entirely unrelated, the "milioline" plan of origin; thereby giving the key to the import of this "nucleus" in the more specialised forms to which we shall next proceed.

From this point of view, it is a circumstance by no means insignificant, that even the varietal forms of this well-marked species present a gradational transition to the next, in the diminished excentricity of the "nucleus," the less marked restriction of outgrowth to one side of it, and the consequent earlier exchange of the spiral for the cyclical plan of growth.

Geographical and Bathymetrical Distribution.—This species appears to be pretty generally diffused along the littoral zone of the warmer temperate and tropical seas, being met with abundantly in shore-sands and in shallow-water dredgings. It seems least common, however, in West Indian seas, where it is replaced by the small varieties of *Orbiculina adunca.* The largest specimens of it hitherto obtained are those brought up in the 18 fathoms' dredging of the Challenger on the Fiji reef. So far as can be judged from the specimens contained in shore-sands, this type attains a much smaller size in the Red Sea, although numerically abundant. And it would seem to die out in the Mediterranean and Ægean, where it is a comparatively rare form, and stunted in its growth. Hence its most congenial habitat may be said to be the littoral zone of tropical or sub-tropical seas.—It is worthy of note that the small Red Sea disks often have their surface-layers thickened by an irregular exogenous deposit of shell-substance, which obscures the cyclical arrangement that i- so conspicuous in the large Fijian specimens. The somewhat larger disks of Philippine and Australian shores often exhibit irregular radiations of such deposit; but between these radiations the cyclical arrangement is generally conspicuous.

Geological Distribution.—Among the *Orbitolites* that have been described as fossil there does not seem any that is distinctly referable to this type. I am inclined to think, however, that the *Cyclolina armorica* of d'Archiac, the *Archiacina armorica* of M. Munier-Chalmas (to whose kindness I am indebted for specimens of it), may be regarded as an ancestral form of *Orbitolites marginalis.* Though the diameter of its disk does not exceed that of the largest specimens of *Orbitolites marginalis,* its thickness is two or three times greater; this excess being partly due to the thickness of the superficial shell-deposits, and partly to that of the chambered layer they enclose. The cavitary system appears, in its earlier stage, to have been distinctly "peneropline," without division of the chambers into chamberlets; and to have early become "cyclical" by the extension of the chambers around the "peneropline" umbilicus, so that they completely enclose it annularly. But the chambers, instead of being partitioned into chamberlets, show only the indications of subdivision which are marked on the "internal casts" of the sarcodic body[1] as slight constrictions;—the type thus presenting as complete a link between the undivided "peneropline" and the labyrinthic "orbitoline" systems of chambering as it does between their respective geometrical plans of growth. It occurs in the "sables de Fontainbleau," near Rennes, which form part of the "Oligocene" Tertiaries.

3. *Orbitolites duplex*, Carpenter (Pl. III. figs. 8–14; Pl. IV. figs. 6–10; Pl. V. figs. 1–10).

Amphisorus hemprichii, Ehrenberg, Familien und Gattungen der Polythalamien. in Abhandl. der könig. Akad. der Wissenschaften zu Berlin, 1839.

Orbitolites, duplex type, Carpenter, Phil. Trans., 1856, pp. 220, 224, and Introd. to Study of *Foraminifera*, 1862, p. 118.

Orbitolites macropora (?), Lamarck, Animaux sans Vertèbres, ed. 2, tom. ii. p. 196; figured in Goldfuss's Petrefacta, pl. xii. fig. 8.

In my former Memoir (Phil. Trans., 1856, §§ 4, 59, 68) I indicated the existence of a well-marked type of Orbitoline structure, which differs from the ordinary "simple" type in having a double series of marginal pores, and from the "complex" in the limitation of the pores to two rows. My knowledge of this *duplex* type was at that time chiefly derived from the small and worn specimens of it which I had picked out of some shell-sand brought from the Red Sea; and these I could pretty certainly identify with the forms on which Prof. Ehrenberg had founded his genus *Amphisorus*, and which he had ranked with his *Sorites* (*Orbitolites marginalis*) among BRYOZOA. But the large number of unworn specimens of this type—many of them alive when captured—that are contained in the collection made in the 18 fathoms' dredging of the Challenger on the Fiji reef, enables me now to furnish a more accurate and complete account of it than it was formerly in my power to give.[2] As this type is sufficiently and constantly differentiated by the character I have just specified, I designate it as *Orbitolites duplex*.

The disks of this species (Pl. III. fig. 8) have usually a very regular circular form, and a nearly plane surface; their thickness being almost uniform, with the exception that the inner or central portion of any disk is usually rather thinner than its outer or peripheral portion. The greatest diameter I have met with in the disks of this species is 0·32 inch, and the greatest thickness 0·012 inch, the proportion of the two dimensions being thus that of a

[1] I am not fully satisfied that I am correct in my interpretation of the structure of this fossil; the *shell* of which seems to me to have undergone the same kind of softening that is common in that of deep-water *Miliolines*, whilst the cavitary system appears to have been occupied by a calcareous deposit of much firmer consistence.

[2] In my former description of it, I fell into the error of supposing that the doubling of tha series of pores indicates the existence, not only of two tiers of chamberlets, but of two annular canals. There is, as I shall presently show, only a single annular canal, and, strictly speaking, but a single series of chamberlets, although there is frequently a want of continuity between the upper and under portions of each cylindrical cavity.

rather thin coin. Departures from the typical flatness, however, are not unfrequent; one of the most common being a sort of plaiting into radial folds, which, beginning near the centre, increases towards the margin—as is slightly indicated in the above-cited figure, but is more strongly shown in the specimen represented in Pl. XVI. fig. 7 of Mr. Brady's Report on the *Foraminifera*. Each surface of the disk is marked-out into regular concentric annuli; but the division between these is not so conspicuous as in *Orbitolites marginalis*; and specimens not unfrequently present themselves, whose surface in certain aspects looks rather "engine-turned" (like that of the section shown in Pl. IV. fig. 6) than concentrically annular. This appearance, however, does not mark any difference of internal structure, and seems to depend upon the manner in which the light is reflected from the thin films of shell-substance that cover-in the individual chamberlets, which are often slightly convex. When a portion of the surface of a specimen containing the sarcodic body of the animal is viewed under a sufficient power by reflected light (Pl. III. fig. 10) the cavity of every chamberlet is marked by a circular or oval spot, surrounded by a thick wall of shell-substance, which is divided by a definite line from the walls of contiguous chambers. It is further noticeable that the double wall which thus separates two contiguous chamberlets of the same annulus, is quite as thick as that which separates the chamberlets of consecutive annuli. The chamberlets of successive annuli generally alternate with one another in position, so as to lie in oblique rows, which, when the interior of the disk is viewed under a low magnifying power (Pl. IV. fig. 6), seem like parts of excentric circles.

The inner (first-formed) portion of the disk in *Orbitolites duplex* shows only a very slight approach to that "orbiculine" spire which is typical alike of *Orbitolites tenuissima* and of *Orbitolites marginalis*, approximating much more closely to the true cyclical plan of *Orbitolites complanata*. The nucleus consists, as in *Orbitolites marginalis*, of a small primordial chamber, which is surrounded by a circumambient chamber; and round this nucleus is seen (Pl. III. fig. 14) a row of chamberlets, which often at once forms a nearly entire annulus, the ring being soon completed in succeeding circlets, and all subsequent additions being made on the cyclical plan. When this nucleus is examined in thin section (Pl. IV. fig. 10) it is seen that this early assumption of the cyclical plan arises from the fact that the circumambient chamber b, b' gives off *several* passages on its outer margin, which lead into as many chamberlets; so that it is as completely surrounded by chamberlets, after three or four successive additions, as it is in *Orbitolites marginalis* (fig. 4) after twelve or more. In this particular, then, *Orbitolites duplex* presents us with a very interesting transition from *Orbitolites marginalis*, in which only a single chamber is put forth from the extremity of the circumambient chamber, to *Orbitolites complanata*, in which it sends forth passages round its entire margin, so that the very first series of chamberlets forms a complete annulus (Pl. VI. figs. 1, 2, 3). The arrangement of parts in the sarcodic body of the animal (Pl. V. fig. 6) entirely answers to the structure of the shell moulded upon it. The flask-shaped primordial segment *a* gives off the circumambient segments *b*, *b′*, the further portion of which often (as in the instance here figured) splits, as it were, into two parts *b′*, *c*; and the first-formed sub-segments *d* pullulate by short stolons (not seen in this figure) from its sarcodic substance.

Turning now to the margin of the disk (Pl. III. fig. 13), we see that it presents a *double* series of pores, very distinctly separated from each other by the elevated ridges of shell by which they are severally surrounded; and that those of the upper and lower series usually alternate with one another in position,—an arrangement whose meaning will presently become apparent.

The general plan of structure in *Orbitolites duplex* closely corresponds with that which has been described in *Orbitolites marginalis;* the principal difference being in the mode in which the successive annuli of the sarcodic body communicate with one another, which will be best understood by examining the structure of the decalcified body in the first instance. Its surface-aspect, when viewed under a power of 25 diameters, is shown in Pl. V. fig. 1; the circles of somewhat rounded spots being the expanded summits (shown on a larger scale in fig. 10) of the separate columnar sub-segments (fig. 2), which spring in two series (*a*, *a′*, *b*, *b′*) from the continuous annular stolon *c*, *c′*; the columns of the lower series usually alternating with those of the upper in position, as at *a*, *b*, but being occasionally opposite, as *a′*, *b′*. Between the bases of these columns, the annular cord gives off a double series of short and slender stolon-threads *d*, *d*, *d′*, *d′*; these pass obliquely, the one upwards the other downwards, through passages in the septal plane; and while, in the interior of the disk, these passages lead from the annular canal of each ring of shell, into the upper and lower chamberlets of the one exterior to it, those of the last-formed ring open on its exterior as the marginal pores. Now as the columnar sub-segments of the upper and lower series usually alternate with each other, the upper and lower series of stolon-processes that intervene between the columns of either row will have the like alternation; and this expresses itself (so to speak) in the alternate position of the marginal pores of the upper and lower series.

The upper and lower rows of columnar sub-segments do not arise from the annular stolon in the same vertical plane, or stand on it perpendicularly to the surface of the disk; but both of them slope considerably towards its centre, and therefore towards each other, the chamberlets they occupy having the same arcuate shape as those of *Orbitolites marginalis* (Pl. III. fig. 6); and thus it comes to pass that when they are seen either from above or from beneath, as in Pl. V. figs. 7, 9, instead of in side view, as in figs. 2, 8, they seem to lie *between* the annular stolons, instead of *upon* them. The part of each column which is continuous with the annular stolon is generally much smaller than the part nearer the surface of the disk (fig. 8); so that while the expanded terminals of the columns often lie very close to each other, as in fig. 10, a section taken parallel to the surface of the disk on a deeper plane (fig. 9) shows their diameters to be smaller, and the intervals between them (filled-up by the shell-substance of the disk) to be wider; and another cross-section taken just above the plane of their junction with the annular cord (fig. 7) shows the still further reduction exhibited laterally in fig. 8. Now it is this deeper and slenderer pedicle of each columnar segment (fig. 8) that receives the stolon-process from the sarcodic cord of the annulus next interior to its own; and it is the connection of this pedicle with the sarcodic cord of its own annulus that brings that cord into continuous connection with that of its interior annulus. Thus, while both series of columnar sub-segments of any one annulus are all connected together by its annular sarcodic cord, the connection between the successive annuli is established by the radial stolon-processes that pass from the upper and lower margins of each annular cord to the upper and lower columnar sub-segments of the next annulus.

When this arrangement has been rightly apprehended, there is no difficulty in understanding what is otherwise somewhat perplexing in the structure of the calcareous disk. When the surface-layer of an empty disk has been removed by grinding or by the action of acid, so as to lay open the chamberlets that lodge the columnar sub-segments, these chamberlets are looked into from above (Pl. III. fig. 12), not in the direction of their axes, but in lines more or less oblique to them; so that, instead of seeing downwards into the annular canals, we are really looking, in each chamberlet, against the oblique septum that separates it from the chamberlet of the next interior annulus,—as is shown in the accompanying diagram (fig. 4), in which A B, A′ B′ are the superficial planes of the disk, *ch*, *ch*, the chamberlets lying obliquely to it, *s*, *s*, the septa that divide them, and *o*, *o*, *o*, *o*, the lines of sight. The pores, *p*, *p′*, seen in each hollow correspond to the marginal pores, *mp*, *m′p′*, of the peripheral ring; being the outlet of the passages which lead into each chamberlet from the annular canal, *ac*, *ac*, of the interior ring, and which convey from its sarcodic annulus the radial stolon-processes that originate the new columnar sub-segments. When, again, we carry our section through the median plane of the disk, we lay open the concentric annular galleries (Pl. III. fig. 11); and along the *concave* (or *inner*) borders of the septa that divide them, we see the small pores forming the entrances of the passages just described, which lead to the chamberlets of the next annulus; while along their *convex* (or *outer*) borders of the septa (as shown also in the transparent section, Pl. IV. fig. 7) are seen the larger oblique passages, which are occupied by the pedicles of the columnar sub-segments of their own annuli. When this median stratum has been removed, the chamberlets of the lower layer are laid open (Pl. III. fig. 9, *a*); and these being viewed, like those of the upper, in an oblique direction, but being seen from their

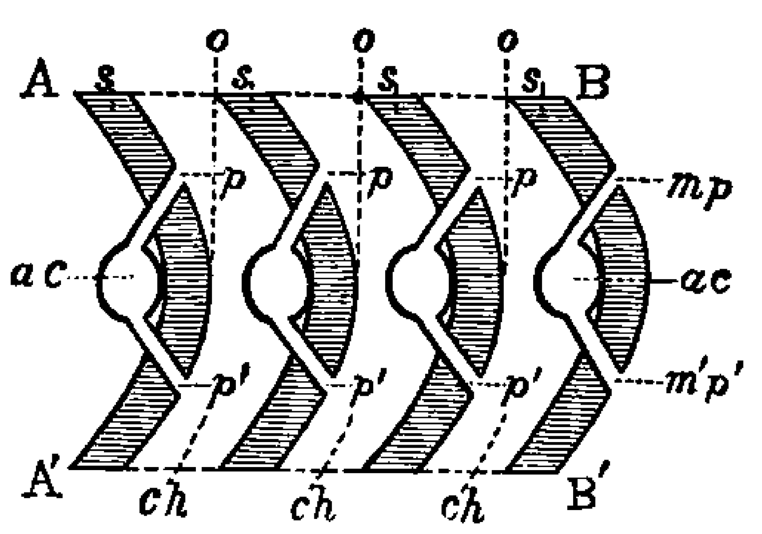


FIG. 4.

medial instead of from their superficial ends, seem to be crossed by the septal planes that divide the annular canals.[1] The meaning of this appearance is best seen in a transparent section (Pl. IV. fig. 8); which, traversing the annular galleries, shows the large orifices *c, c, c,* along their floors, that lead to the chamberlets of the plane beneath; and the small orifices *st, st,* along the *concave* borders of the septa, that lead into the chamberlets of the next annulus.

Thus the cavitary system of the disk of *Orbitolites duplex* is composed of a median series of annular concentric galleries, each freely opening, as in *Orbitolites marginalis,* into a double tier of chamberlets, one above and the other beneath; but each having *two* series of passages, that lead severally to the upper and the lower tiers of chamberlets of the next annulus. The cavitary system of every part is here in as free communication with that of every other part as it is in the "simple" forms previously described: but there is an advance in the development of this type, which shows itself *first,* in the suppression of the "orbiculine" stage, and the assumption of the cyclical plan almost from the beginning; and *second,* in the foreshadowing of the coming separation between the upper and the lower tiers of columnar sub-segments in *Orbitolites complanata,* which is given in the replacement of the *single* row of radial stolon-passages on the mesial plane, communicating between the cavitary system of each annulus and the next, by the *double* series that lead into the chamberlets of its upper and its lower tiers respectively.

Geographical and Bathymetrical Distribution.—This species appears to have the same general range, alike in area and in depth, with *Orbitolites marginalis;* but though small forms of it are abundant in the Red Sea, I have not been able to trace it as accompanying that species into the Mediterranean. Like *Orbitolites marginalis,* it acquires its maximum size in waters of no great depth off tropical shores.

Geological Distribution.—Though it is impossible to identify, with any certainty, our *Orbitolites duplex* with any of the fossil species described by Lamarck, yet as worn specimens of it often present a close resemblance to the representation given by Goldfuss (Petrefacta, Pl. XII. fig. 8) of his *Orbitolites macropora,* which he distinguishes by its *poris utroque latere majusculis,* I think it probable that the two are identical. The fossil habitat of Lamarck's specimens is given as "la montagne Sainte Pierre."

4. *Orbitolites complanata,* Lamarck (Pl. V. figs. 11–18; Pl. VI., VII., VIII.).

Orbitolites complanata, Lamarck, Syst. des Anim. sans Vertèbres [1801].
Marginopora vertebralis, Quoy and Gaimard, in De Blainville's Manuel de l'Actinologie [1834], p. 412.
Orbiculina tonga, Williamson, Trans. Micr. Soc., vol. iii. 1852, p. 115.

We come, lastly, to the large and highly differentiated form which must be regarded

[1] The relation of fig. 9 (Pl. III.) to fig. 11 will be better understood by conceiving the former to be turned a quarter round, so that the side *a* of fig. 9 should correspond with the lower border of fig. 11.

as the type of the genus,—the *Orbitolites complanata* of Lamarck, which, at first known only as a fossil in the Calcaire Grossier of the Paris basin and other parts of France, has been since found to present itself as a living form in such abundance on Australian and Polynesian reefs, that its accumulated disks sometimes constitute no inconsiderable proportion of their material.[1] The disks of this species were the earliest examples of the Orbitoline type that attracted attention; and, as I have already pointed out (pp. 1, 2), many strange ideas were entertained in regard to their character. When Lamarck constituted the genus *Orbitolites* (p. 2), he defined this species as follows:—*Orbitolites tenuis fragilis, utrinque plana et porosa;* his idea having apparently been that the porosity of each of its surfaces differentiated it from *Orbitolites marginalis*, which is also *utrinque plana*, but porous at the margin also. This differentiation is altogether incorrect, being founded on fossil specimens whose outer lamellæ have been worn away, so as to lay open the subjacent chamberlets, which are closed in perfect recent specimens of *Orbitolites complanata*, as in *Orbitolites marginalis*. The first intimation of the present existence of this species seems to have been given by Defrance (Dict. des Sci. Nat., tom. xxxvi., 1825, pp. 294, 295), who, in describing the well-known fossil type, states that living specimens closely allied to it had been found on the coast of Australia. These were probably the disks collected by MM. Quoy and Gaimard in that locality during the "Voyage de l'Astrolabe," which they designated by the generic term *Marginopora;* and this designation was adopted by M de Blainville (Man. d'Actinologie, 1834, p. 412), who was the first to publish a description of the recent type, under the name *Marginopora vertebralis*, in immediate sequence to that of the recent *Orbitolites marginalis* already cited (p. 21). As in the previous case, Blainville's account of it was not only incomplete, but in some respects inapplicable to the ordinary form of the type; so that I should not have felt sure of its identity, if I had not myself examined (in the Paris Museum) the very specimens for which the genus *Marginopora* was created, and which are exactly conformable to one of the varieties of the recent *Orbitolites complanata* which I am about to describe. The closeness of the relationship borne by his *Marginopora vertebralis* to *Orbitolites complanata* was held by Blainville to be further indicated by the conformity of the internal structure of the two disks; each being found, when one of its surfaces is rubbed away, to present a series of concentric canals, separated by annular partitions, and themselves divided into cells. He doubted, however, whether either *Orbitolites* or *Marginopora* should be considered as a true polypary, allied to *Eschara* or *Retepora;* and thought it more likely that the Orbitoline disk is "quelque pièce intérieure." I have already alluded to the extraordinary error committed by Prof. Ehrenberg, in not only ranking *Orbitolites* among his Bryozoa, in close proximity to *Lunulites*, but in actually

[1] I was informed by the late Prof. J. Beete Jukes, whose specimens were the first which I had the opportunity of examining, that at certain spots on the Australian coast the great mass of his dredgings consisted of the entire disks and fragments of *Orbitolites complanata*, with fragments of Corallines (chiefly, I believe, the *Corallina palmata* of Ellis).

figuring an eight-tentacled polype as extending itself from one of its (supposed) open cells. It was under the influence of his authority that, when I first published (Quart. Journ. Geol. Soc., 1849, p. 31) the results of my examination of the structure of the Australian *Marginopora* (*Orbitolites*), in specimens collected by Prof. Jukes, and kindly placed in my hands by Prof. Edward Forbes, I did not feel justified in calling its Bryozoic characters in question, though I expressed myself doubtfully as to its claim to that position. It was Prof. W. C. Williamson, as I have already pointed out (p. 5), who first asserted the Foraminiferal nature of *Orbitolites*, on the basis of its near affinity to the well-known *Orbiculina adunca;* describing, under the designation *Orbiculina tonga*, what are clearly small specimens (only $\frac{1}{4}$ of an inch in diameter) of *Orbitolites complanatus*, which he had obtained from shore-sand. This determination partly rested on the structure of the central " nucleus " of the disks, which had been wanting in my own specimens; and of this Prof. Williamson gave a very accurate description, which I was subsequently able to verify in the perfect specimens received from Prof. J. Beete Jukes himself, as well as from other sources,—some of these having been preserved in spirit, and containing the sarcodic body of the animal. It was on these specimens that I based the description of what I then distinguished as the " complex" type of *Orbitolites*, which I gave in my original Memoir on this genus (Phil. Trans., 1856). And having lately made a careful re-examination, both of the shelly disks and of the sarcodic bodies of their contained animals, collected by the naturalists of the Challenger on the slope and summit of the Fiji reef, I am in a position not only to confirm that description in every particular, but to add to it several particulars of much interest.

It is probable that the younger and more delicate forms of *Orbitolites complanata* habitually attach themselves to the surface of marine plants, the most perfect of those which I received from Prof. Jukes, whose surfaces were nearly flat, having been found thus attached; and some of them being so thin in proportion to their diameter, that I can scarcely think it possible that they could remain unbroken in the turbulent water of a reef-slope if not thus supported. The case is different, however, in regard to those more massive disks whose thickness increases as rapidly as their diameter, so that they become more or less deeply biconcave; for as such could only adhere at their margins, they must be liable to become easily detached; and as they are brought up alive by the dredge, they probably go through the later stages of their growth in the free condition. That such must be the case in regard to these large, irregular, " laciniate " forms, of which examples are figured in Pl. VII., is very obvious; and I learn that the specimens of these which contain the coloured sarcodic body were taken alive from sheltered nooks in rock-pools on the summit of the reef, while the dead specimens (distinguished by their absence of colour) were picked up on its surface.

It is of the disks of this species that the great bulk of the Challenger collection on the Fiji reef is composed; and these disks present a range of diameter from 0·04 inch, or even less, to nearly 1 inch, and a thickness of from 0·012 inch to 0·100 inch. This range is less, however, in the disks brought up in the 18 fathoms' dredging, than in those collected nearer the surface, the average diameter of what seem to be the adult forms in the former not exceeding 0·7 inch; and there is an almost entire absence in them of those irregular outgrowths which are frequent in the large disks found on the summit of the reef. The disks are sometimes almost plane, with a slight central depression; but are more commonly decidedly biconcave. The central portion, consisting of the "nucleus" and the annuli that immediately surround it, is almost invariably the thinnest, and round this there is usually a progressive increase in the thickness of the next succeeding annuli. If this increase continues, the disk of course becomes thickest at the margin; but it not unfrequently ceases, so that the rest of the disk is plane; and sometimes, at about half the distance between the centre and the circumference, the thickness of each succeeding annulus diminishes, so that the marginal portion of the disk is no thicker than the central.

The concentric bands into which each surface of the disk (Pl. VI. fig 4) is marked out, are complete in the typical forms of this species, to the very margin of the nucleus; not the least vestige being here seen of any "orbiculine" spiral, but the *cyclical* plan of growth characteristic of the Orbitoline type being exhibited from the very commencement. The breadth of each zone averages about 0·003 inch, and the number of zones bears a pretty uniform relation to the diameter of the disk. In one of the largest disks that I have examined there are 166 zones, while the smallest has only three. Each zone is crossed by radial lines, which mark out areolæ that are usually somewhat rectangular in shape and sometimes approach a square, but are more commonly at least twice as long (in the radial direction) as they are broad, their long sides being nearly parallel to each other. The margin does not usually show any such convexities as are formed in *Orbitolites marginalis* by the projection of the columnar chamberlets; but the marginal pores are usually arranged more or less regularly in vertical rows, which are, however, often incomplete,—the two adjacent rows, in such cases, usually inclining towards each other. There is no constancy in the number of pores in the different vertical rows of even the same annulus; and there is no such regularity in their disposition as would mark out a horizontal stratification.

The "nucleus" is much larger in the typical forms of this species than in either of the preceding; and though it exhibits a considerable range of dimension, as shown in Pl. VI. figs. 1, 2, 3, yet even the smallest nuclei of those disks whose innermost annuli are formed on the "complex" plan are many times larger than those of *Orbitolites duplex*. Its two surfaces are generally flat, or nearly so, but are sometimes slightly convex. The pyriform primordial chamber *a*, as in *Orbitolites marginalis* and *Orbitolites duplex*, is surrounded by a large "circumambient" chamber; and this usually shows a partial division by an incomplete partition.

The circumambient chamber is completely enclosed peripherally by a circular wall; and this is traversed by a series of passages at regular intervals all around, each of which leads into a separate chamberlet,—the very first series of chamberlets thus forming a complete annulus. The sarcodic body which occupies the cavity of the nucleus, consists of a large pyriform primordial segment (Pl. V. fig. 18, *a*), from the small end of which proceeds the stolon-process that connects it with the circumambient segment *b*, *b′*. This last is very large, a portion of it (*c*) being usually in part separated from it by a partition in the shelly chamber (fig. 3, p. 13); and it buds off, all round its periphery, a succession of radial stolon-processes, of which one traverses each passage in the surrounding wall, to become the origin of one of the sub-segments forming the first annulus.

Each of the chambered zones by which the "nucleus" is surrounded, even from the first, consists of two *superficial* layers, between which is interposed an *intermediate* stratum.

The *superficial* layer of each annulus (Pl. VI. fig. 4) is made up of oblong chamberlets, the partitions between which correspond with the radial surface-lines. These partitions extend continuously across the annulus, so that the adjacent chamberlets have no lateral communication. And as the circular septa that form the end-walls of these superficial chamberlets are alike imperforate, the chamberlets of the successive annuli have no direct communication with each other. When, however, the chamberlets have been so laid open by grinding or by the application of acid (as at *f*, *f*), that their floors are brought into view, a pore is seen at either end; and each of these pores is shown by vertical sections to open into an annular gallery (*g*, *g′*, *g″*) that passes beneath it; so that, as each superficial chamberlet lies across the interval between two galleries, and communicates with both of them, an indirect connection is established, through their intermediation, between each annular gallery and that which is internal and external to it, and thus throughout the entire system. This will be best understood by looking at the disposition of the sub-segments of the *sarcodic body* which occupy the chamberlets, so as to form its surface-layer (Pl. V. fig. 11). These present themselves under a low amplification as narrow elongated blocks, very uniform in size and figure, arranged in concentric annuli; and when a portion of the layer is more highly magnified (fig. 13), it is noticeable that though these sub-segments generally alternate in position in successive annuli, this arrangement is by no means constant, there being no direct connection between them. Their relations to other parts of the sarcodic body are best brought into view by vertical sections (fig. 14), which show that every block of each of the superficial rows (*c*, *c′*) is connected by a pedicle at either end with one of the annular stolons (*a*, *b*, *b′*) that intervene between the superficial layers of sub-segments and the sarcodic columns (*d*, *e*) of the intermediate stratum. Each stolon thus gives off two series of pedicles: one to the row of sub-segments internal to it, and the other to the row external to it; and these usually (though not always) alternate in position.

An indirect communication is thus established, not only among all the sub-segments of the same annulus, but among those of all the annuli of each superficial layer.

The *intermediate stratum*, which, as already stated, constitutes the principal part of the thickness of the disk, is the distinguishing feature of this type of structure. When laid open by a section taken parallel to either surface, the appearances it presents differ according to the plane traversed by the section. For if this plane be that of the concentric annular galleries that lie immediately beneath the superficial layer, the section (Pl. VI. fig. 4, *g*, *g'*) lays open these galleries; in the floor of every one of which is a series of large rounded openings *h*, which are the summits of annular rows of nearly cylindrical chamberlets that lie beneath the galleries. In sections taken beneath these galleries, however, so as to pass either in or near the median plane of the disk, the concentric arrangement seems to have altogether given place to the excentric or "engine-turned" (*i*, *i*), the directions of the excentrics being opposite (as shown at *k*, *k*) in successive planes. There is no change, however, in the concentric arrangement of the rows of chamberlets; what is different being merely the mode of communication between them. These communications are in reality just what have been shown in fig. 3 (p. 13) to be characteristic of the Orbitoline type; each chamberlet communicating both with its own adjacent chamberlet, and also with the two chamberlets which alternate with it in the annulus external to its own, by a pair of passages. Now the columnar chamberlets forming the successive annuli of this intermediate stratum have vertical successions of pairs of such communications; but the two passages that form each pair, instead of lying in the same plane, alternate with each other vertically, so that no horizontal section can pass through both sets at once,—although it not unfrequently happens, in consequence of a flexure in the disk, that different parts of the same sectional plane show passages of opposite obliquities. And thus it comes to pass that each horizontal section lays open a series of oblique galleries, formed by the one-sided communications between the chamberlets of successive annuli; and that in a section taken in a plane either a little above or a little beneath, the direction of the obliquity is reversed. This arrangement, again, is better understood by reference to the sarcodic body of the animal, as seen in vertical section (Pl. V. fig. 14); for each of the cylindrical sub-segments of the nearer zone (*d*, *d*) is seen to communicate with two sub-segments of the zone *e* behind it, by two rows of stolon-processes; those which pass from each of the two contiguous columns in zone *d* towards the single column that alternates in position with them in zone *e* behind, inclining towards each other, so as to enter that column nearly in the same vertical line, though in different horizontal planes. By this arrangement each of the several pores (Pl. VI. fig. 4, *d*, *d'*, *d''*) that form the vertical rows at the margin of the disk, instead of opening, like the single pore of the simple type (fig. 2, p. 12), into both the chamberlets of the last-formed annulus between which it lies, opens into only one of them,—the pores of the same vertical series opening alternately into the chamberlets on either side.

The cylindrical chamberlets of the intermediate stratum, as seen in vertical section (Pl. VI. fig. 9, *c, c*), generally pass in a nearly straight, parallel and separate course through its whole thickness; but this is by no means constantly the case. For not only are there occasional communications between the adjacent chamberlets of the same row, but sometimes a chamberlet, after extending through only a part of the thickness of the disk, will merge, as it were, in the two chamberlets on either side of it, which, when no longer kept apart, incline towards one another, as shown externally in the direction of the rows of marginal pores (fig. 4, *d''*). The same departure from strict regularity is shown in the columnar sub-segments of the sarcodic body (Pl. V. fig. 14, *d, e*); adjacent columns of the same annulus inosculating not unfrequently with one another. But all the columns of any one annulus terminate above and below in the two annular stolons (*b, b*)' of their own annulus, which thus unite them into one continuous system.

By these varied methods every part of the labyrinthic cavitary system of this most complex type of Orbitoline structure is brought into free communication with every other part; so that a circulation of the protoplasmic body-substance may be constantly maintained, which shall diffuse through the whole of it whatever nutrient material is drawn in through the marginal pores, and also get rid, through those pores, of any effete matter which is unfit to be kept in the organism. Notwithstanding the extent to which *structural* specialisation is here carried in the shelly disk—as manifested in the separation of the superficial layers from the intermediate stratum—I have not been able to trace any indication whatever of a corresponding *functional* specialisation. There is not, so far as I have been able to make out, any differentiation of parts throughout the entire sarcodic body, every portion of it presenting the same aspect, and possessing the same attributes, as the rest. This homogeneousness is further manifested in two ways:—first, by the production, from any part of the disk, of outgrowths which present, under strangely irregular forms, its characteristic peculiarities of internal structure; and second, by the completeness with which injuries of any part of the disk are repaired, its cyclical plan of growth being renewed, and its discoidal form more or less perfectly restored.

Irregularities.—The tendency to form irregular outgrowths shows itself especially in the large and massive specimens, which, as already stated, were found living in the rock-pools on the summit of the Fiji reef; and may be taken to indicate an exuberance of formative power, that probably depends upon the higher temperature and greater abundance of food which the animals there enjoy. In Pl. VII. is given a series of portraits of such disks, all drawn to the same scale of four diameters; a full-sized disk of regular form being represented for comparison in fig. 3. The disk portrayed in fig. 1 exhibits an incipient "crumpling" of the marginal annuli, which shows their peripheral extension to have been more rapid than their radial, so that these annuli are thrown into irregular folds; whilst a small vertical outgrowth, having the character of a perfect half-disk, but very thick in proportion to its diameter, arises from the central portion, probably from its "nucleus." Similar central outgrowths are by no means uncommon, and sometimes show themselves at an early stage, as in the small disk which is represented in Pl. VIII. fig. 1, under a magnifying power of ten diameters. Another curious irregularity in a young disk is shown in Pl. VIII. fig. 3. Whether from accident or from some obstruction to the growth of the disk on its left side, the peripheral additions do not pass completely round the central portion, and the thick vertical crest seems to represent a fold of the peripheral annuli produced by the exuberance of their material. Another small specimen represented under the same power in Pl. VIII. fig. 11, has a very curious "twin" disk, which must have either begun as a "double monster," or (which the distinctness of the "nuclei" seems to render more probable) have been the product of the partial "fusion" of two originally separate disks, attached side by side to contiguous parts of the same surface; the vertical half-disk in either case being the joint product of the two mutually-encroaching horizontal disks, whose continued increase at their line of junction could only take place in this direction. In the large disk, represented in Pl. VII. fig. 2, the peripheral folds are much deeper than are those of fig. 1, but the central semi-discoidal outgrowth is smaller. There are, however, other considerable vertical outgrowths from the surface of the disk, the under side of which shows the same exuberant productiveness. In the large disk represented in fig. 4 the central outgrowth has the form of a small knob; this, however, instead of being a solid mass of shell-substance, has a properly "labyrinthic" interior, as is shown by the distribution of the pores characteristic of that arrangement over the whole of its surface (fig. 4, *b*). One of the peripheral folds extends itself as a vertical crest for some distance inwards, and four other incipient half-disks arise from different parts of the surface, of which two have united themselves together, as shown on a larger scale in fig. 4, *a*. Another large disk, represented in fig. 5, shows a general crumpling of the margin, without the formation of any well-marked vertical fold, with a small central knob and several irregular protuberances from the annuli forming the inner part of the disk. In the large disks represented in figs. 6 and 7, the crumpling of the peripheral annuli is very strongly marked by the production of vertical folds proceeding inwards towards the centre. In both cases the growth of the disk seems to have been regular, up to a certain epoch marked by the concentric elevation of the annuli, after which the crumpling appears to have commenced. Such epochs are often indicated, even in the normal disk, as shown in fig. 3; and it would not seem improbable that they mark some change in the external conditions of the disks, which may have lived attached in their earlier stages, and have been afterwards transferred by the action of the waves into situations more favourable to the production of these outgrowths.[1]

[1] Other examples of this "laciniate" form, with a vertical section showing the divarication of two lamellæ, and the incompleteness of the partitioning of the last-formed annuli, will be found in PL. XVI. of Mr. H. B. Brady's Report on the Foraminifera.

The examination of a large number of specimens of this type, which show every gradation between the regular smooth discoidal form (fig. 3) and the strongly "laciniate" forms represented in figs. 6 and 7, has satisfied me that the latter type has no claim to be distinguished *specifically*. Both in kind and degree the peripheral "laciniation" is subject to the widest extremes of individual variation; and there is neither constancy nor regularity of disposition in the outgrowths from the inner portion of the disks, those of the two sides of the same disks being generally quite dissimilar. It may be questioned whether they have even a greater claim to be distinguished as constituting a well-marked variety than have, for example, the deeply plicated specimens of *Waldheimia australis*, which are found adherent to the same blocks of stone as the smooth, with a series of intermediate forms establishing a gradational transition from the one to the other.[1]

Reparations.—There seems no more limit in this species to the reparative power than in those "simple" types in which its operation has been previously described; an entirely new disk, perfect in every part except its centre, being producible from a small fragment broken away from the margin of an older one, as shown in Pl. VIII. fig. 10,—which is the exact counterpart to Pl. I. fig. 7, though representing a much larger and older disk of this "complex" type, under a comparatively low magnifying power. So, in Pl. VIII. fig. 2, we have the exact counterpart to Pl. I. fig. 6; the former, which represents a repaired disk of *Orbitolites complanata* nearly half an inch in breadth, showing that a fracture across its diameter when about half its present size did not in the least interfere with its subsequent growth, and that, from the very first, new annuli were formed all along its fractured edge, as around its normal margin; so that, except in the modification of shape produced by the loss of half the earlier portion of the disk, no departure from the normal type is discernible. In fig. 8 the proportion of the disk lost by transverse fracture is smaller, so that the growth of peripheral annuli all round has more nearly restored the circular form. In fig. 6 this restoration has been yet more complete, though the early loss of a considerable proportion of the disk has given the nucleus an excentric position. In fig. 4 there seems to have been a marginal breaking away of several portions of the disk, leaving a very irregular outline; the broken portions have been filled-in, and the circular form has been almost exactly restored. In the specimen represented in fig. 9 a sort of notch has been cut out from the margin of an advanced disk, and this has been filled-in by an extension of the later-formed peripheral annuli. It is obvious that if the growth of this disk had proceeded much further the notch would have no longer shown itself at the margin. In the disk represented in fig. 5 the more considerable loss has been less completely repaired, the new growths from the two sides not having as yet met: but it is obvious that the addition of a few more peripheral

[1] See pl. i. of the Monograph of the genus *Terebratula*, in Lovell Reeve's "Conchologia Iconica." The original of this plate—a block brought by Prof. J. Beete Jukes from Port Jackson—is in the British Museum.

annuli would completely fill up the gap, and that a continuance of subsequent growth would restore the circular figure. The specimen represented in fig. 7 is of peculiar interest, as showing the early stage of this reparation; to exhibit which more clearly the specimen has been laid open by grinding it down towards its median plane. An irregular fracture has obviously been sustained along nearly half the margin of this disk, previously to the formation of the last two concentric annuli; and these annuli can be traced along the entire length of the fractured margin (of which a portion is shown on a large scale in fig. 7 *a*), just as along the unbroken periphery,—except that while the arrangement of the chamberlets in these last two annuli is conformable to that of the annulus with whose unbroken margin they are continuous, these chamberlets lie *un*conformably along the broken edge to those of the preformed structure.

Relations to Simple Type.—We have now to consider the relations of the "complex" plan of growth which is characteristic of *Orbitolites complanata*, to the "simple" plan exhibited in *Orbitolites tenuissima*, *Orbitolites marginalis*, and *Orbitolites duplex;* and have especially to inquire whether there is any evidence of the genetic derivation of the higher type from either of the lower.

In describing *Orbitolites complanata*, I have purposely limited myself to that typical form which presents its characteristic features in their highest development, those features being (1) the origin of thedisk in a large and thick "nucleus"; (2) the immediate assumption of the *cyclical* plan of growth, as shown in the primal pullulation of chamberlets round the whole periphery of the nucleus, so as to form a complete annulus; and (3) the immediate assumption of the *complex* plan of growth, shown in the separation, even in the very first annulus, of the two superficial layers by an intervening stratum, as shown in vertical section in Pl. VI. figs. 9, 10. But I find a considerable number of disks, especially in the 18 fathoms' collection, which present that *intermediate* condition on which I laid great stress in my former Memoir (§§ 57, 58), as indicating that the "complex" type is only a more developed form of the "simple." In such disks the central portion is formed in every respect upon the "simple" plan, which afterwards gives place to the "complex," sometimes rather suddenly, but generally more gradually, at a variable distance from the centre. Such a "simple" condition may be inferred to prevail in the interior part of any disk, whose peripheral portion is shown to be "complex" by the multiple arrangement of its marginal pores, when its central portion is very thin, its nucleus small, its first formed annuli not complete, and the form of its surface-divisions circular tending to square, as in *Orbitolites duplex;* the passage to the complex type being marked by the rapid thickening of the disk, and the narrowing of the surface-divisions, so that they take-on the elongated form characteristic of the superficial chamberlets of *Orbitolites complanata.* This last change is well shown in Pl. V. fig. 11, which represents half of the sarcodic body of one of these sub-typical forms; the sub-segments of the *central* portion of the disk (which are the summits of "simple" columns) having exactly the same aspect when viewed from above, as have those of the "duplex" type (fig. 1), whilst those of its *peripheral* portion have the equally characteristic form of the sarcodic "blocks" (fig. 13), of which the superficial layers of the "complex" type are composed.

But it is in *vertical sections* of the calcareous disk (Pl. VI. figs. 5–10) that the passage from one type to the other, and the mode in which it is effected, can be most distinctly traced out. The absence of an intermediate stratum, and the "simplicity" of the plan of growth, are marked in the singleness of the annular canal, which lies in the middle plane of the section, as is seen in the whole of that portion of the disk whose vertical section is represented in fig. 5, which extends from *a*, the nucleus, to *b*, *b*, the *twenty-third* zone. In fig. 6, on the other hand, the singleness of the annular canal extends only to the first *three* zones; the zone *b*, *b* is formed on the "duplex" plan, the annular canal being still single, but the radial passage being doubled, so that there would at that stage have been a double row of marginal pores; whilst in all the later annuli the annular canals are double, and the intermediate portion becomes progressively thicker. In fig. 8, again, the *five* annuli, *a*, *a*, to *b*, *b*, that immediately surround the nucleus, are formed on the "duplex" type, the annular canals being single, but the radial passages double; whilst from *b*, *b* to *d*, *d* the annular canals are double, and the intermediate portion progressively increases in thickness. If, then, the growth of either of these disks had been checked within the first zone at which its annular canal becomes double, it would have been accounted as belonging to the "simple" type; and the wide variation that shows itself in regard to the stage of growth at which the transition takes place, sufficiently shows that these intermediate forms are not entitled to rank as constituting a separate group, but that their peculiarities are to be regarded as individual.

Looking, then, at the morphological relations of the "simple" and the "complex" types, we see that the passage from one to the other does not consist (as might at first sight appear) in the development of the two superficial layers of chamberlets as additions to the intermediate stratum, the latter representing the original disk; but in a separation of the two superficial layers of the original disk by the interpolation of the intermediate stratum between the duplicated annular galleries; it being in this duplication that the transition essentially consists. Under this aspect the previous duplication of the radial passages, which is the distinctive feature of the "duplex" type, is of peculiar interest; for while in itself quite conformable to the original "simplicity" of the Orbitoline plan, it is obviously a preparation for the assumption of the "complex."

In the first stage of that assumption, the three parts of each cylindrical chamberlet all lie in the same line, the annular galleries making no break in the continuity between the superficial and the interpolated portions of the columnar cavities, as is shown in the first zones beyond *b*, *b*, figs. 6 and 8. But as we pass towards *d*, *d*, we see a change taking place in the relative positions of the zonal septa of the three planes; those of the superficial layers being shifted half the breadth of a zone, so that the chamberlets of those layers lie over the zonal septa of the intermediate layer, and the zonal septa of the superficial layers over the annular galleries into which the cylindrical chamberlets of the intermediate stratum open at either end, as already described. When, by this shifting, the complex plan of growth has been fully established, all subsequent increase takes place in accordance with it.—The successive stages of this transition through the "sub-typical" to the "typical" form of *Orbitolites complanata* are diagrammatically represented on a larger scale in fig. 5.

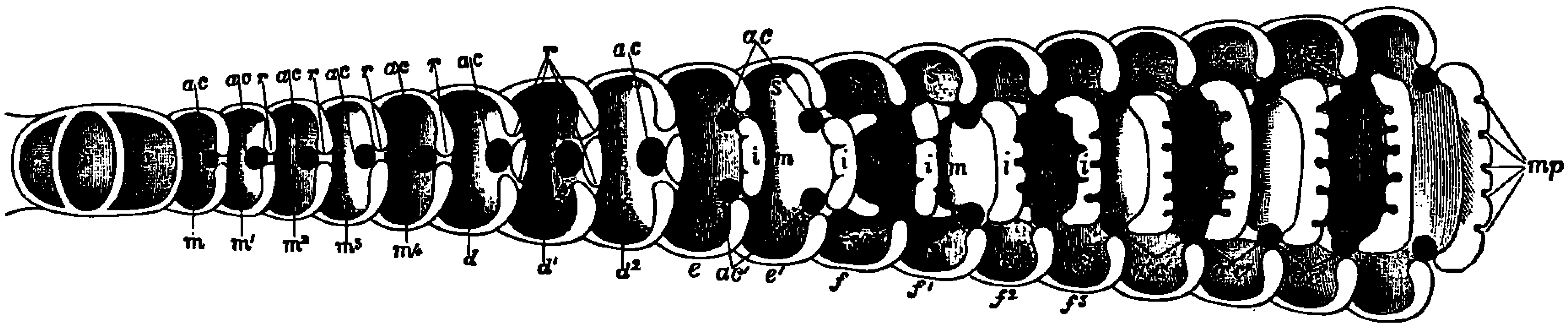


FIG. 5.—Diagrammatic representation of the progressive development of the Simple type of *Orbitolites* into the most Complex.

p, primordial chamber; *c*, *c'*, circumambient chamber; m, m^1, m^2, m^3, m^4, chambers of successive zones of *Orbitolites marginalis*, each having its single annular canal, *ac*, and its radial stolon-passage, *r*; d, d^1, d^2, chambers of successive zones of *Orbitolites duplex*, each having its single annular canal *ac*, and its double radial stolon-passage *r*; *e*, *e'*, chambers of intermediate (fossil) form of *Orbitolites complanata*, each having a pair of annular canals *ac*, *a'c'*, with an interposed septum *i*, *i*, and having its superficial portions, *s*, *s'*, still in continuity with the median columns *m*, *m*; f, f^1, f^2, f^3, chambers of the typical form of *Orbitolites complanata*, each having its double annular canal, its median columnar portion *m*, separated from that of the next annulus by the interposed septum *i*, traversed by oblique pores, which appear as marginal pores, *mp*, at the edge of the disk; but the superficial chamberlets, *s*, *s*, and *s'*, *s'*, alternating in position with the median, and each of them communicating with the annular canals of two zones, as shown at *ac*, *a'c'*.

The morphological differentiation which thus shows itself in the sarcodic body of this "complex" type is thus of the very simplest character, involving (so far as our means of judgment extend) no functional differentiation whatever. Its first stage consists in a partial splitting of the single annular stolon of each zone (Pl. V. fig. 2, *c*, *c'*) throughout its entire length, and the vertical separation of its two halves from each other; their continuity being maintained, however, at certain intervals, so that, when drawn apart, they still remain connected by the cylindrical columns (*d*, *d*, fig. 14) which form the intermediate stratum. When these interpolated columns are looked at, not as parts of the regular annular system of sarcodic sub-segments, but as bands of adhesion between the two sarcodic semi-annuli that are drawn out by their separation, the frequent irregularities that may be remarked in their arrangement (p. 35) are at once understood as confirming this view of their homology. Each of the separated semi-annuli carries with it its own row of half columns (fig. 2, *a*, *a'*, *b*, *b'*); and these form the superficial planes of sub-segments (fig. 14, *c*, *c'*), which are at first in continuity with the interpolated shafts. And the displacement of these in the subsequently-formed annuli constitutes the second stage of this differentiation.

Even when it has been completely carried out, the connections of the superficial sub-segments remain exactly what they are in the "duplex" type. For there, as has been shown, each half-column springs from its own sarcodic annulus, and receives at its base a radial stolon from the annulus next interior to it; the connection between the successive annuli being made by the passage of two series of radial stolons from each annulus (Pl. V. fig. 2, *d, d, d,'d'*), into the two series of half-columns of the annulus exterior to it. And in the "complex" type, as a careful examination of fig. 5 (p. 40) will show, the pedicle by which each superficial sub-segment is connected with the sarcodic annulus lying beneath its *outer* extremity (see Pl. V. fig. 14) may be considered as its own proper base, whilst that which connects its *inner* extremity with the annulus next interior to it is the homologue of the radial stolon of the "duplex" type.

Now as the displacement, which at first sight conceals this homology, shows itself in the life-history of certain individuals of the type which are developmentally less advanced than the rest, it may be pretty safely affirmed to have taken place in the genetic history of the race. And we have a curious confirmation of this assumption in the fact that the fossil specimens of *Orbitolites complanata*, which are so abundant in the Paris Tertiaries, show an incompleteness in the process of differentiation, which stops at the stage at which the chamberlets of the superficial layers are still continuous with the cylindrical chamberlets of the intermediate stratum.

If then we were able to trace out the entire Palæontological history of the Orbitoline type, we should pretty certainly find a long succession of intermediate forms, gradationally leading up from the "simplest" to the most "complex"; the typical *Orbitolites complanata* of the present time being the most highly specialised form of it with which we are acquainted. But although its descent from some "simple" form can scarcely be doubted, yet we cannot fairly assume that either of the species previously described represents its ancestral type, and is capable of evolving itself under favourable conditions into the "complex" form. For I not only find a very constant limitation of size to prevail, alike in *Orbitolites marginalis* and in *Orbitolites duplex*, of each of which forms I have examined many hundred specimens; but I have met, in several of the largest examples of each, with that undivided or imperfectly partitioned condition of the peripheral annuli, which seems to indicate the feebleness (so to speak) of old age, rather than such an excess of vigour as would be needed to carry them on to a higher grade. It appears to me, therefore, that the two species just named are to be considered as perpetuating earlier types of the genus; whilst the occasional occurrence of the "simple" plan in the central portion of the disks of *Orbitolites complanata* marks a *reversion* to that earlier plan, which indicates a want of developmental power in the individuals presenting it. And a clue to this deficiency is, I think, to be found in that remarkable inferiority in the size of the "nuclear mass," which I have already spoken of (p. 38) as a constant feature in these sub-typical forms.

Whether such disks constitute a distinct *race*, or are merely *individuals* which have begun life as "starvelings" that do not inherit the characteristic vigour of the species, it can scarcely, I think, be doubted that they represent an ancestral form in which the "simple" *Orbitolites* was undergoing evolution into the "complex"; the early growth of *every* disk in that stage having probably been simple, as we still find it to be in *some*. In those, on the other hand, in which the perfected type has fully established itself, the earlier "simple" Orbitoline stage drops out, as the Peneropline and Orbiculine stages had previously done; so that the "complex" plan of Orbitoline growth now immediately succeeds the Milioline, in all those forms in which the primordial segment carries with it the full developmental capacity of its predecessor. It is not a little curious, however, that in the marginal annuli of even this highest type, a *reversion* to the undivided Peneropline condition should not unfrequently show itself, in an almost entire want of subdivision of the annular zones into chamberlets; the interzonal septa, however, being formed as usual, and being marked by multiple ranges of pores.

Geographical and Bathymetrical Distribution.—So far as is at present known, *Orbitolites complanata* inhabits only the shallow waters near shores, or on the slopes of reefs, in tropical or sub-tropical seas. It has been met with abundantly in such situations on the coast of Australia, on the Fiji and other reefs in the Pacific Ocean, and in the Philippine Sea; but, notwithstanding the abundance of *Orbitolites marginalis* and *Orbitolites duplex* in the Red Sea, this most highly developed type has not hitherto been found there. As already stated, its largest and most exuberant forms are found in surface-water; whilst it is among those brought up by the dredge from a deeper part of the littoral zone, that those "sub-typical" specimens occur in largest proportion which in the earlier stage of their growth present the "simple" type of formation.

Geological Distribution.—As already stated, the specimens upon which not only the *species* but the *genus* is constituted belong to the early Tertiary period: the Calcaire Grossier of the Paris basin, and corresponding (Middle Eocene) formations elsewhere, containing *Orbitolites complanata* in such abundance, that the rock in some situations is chiefly composed of its disks. These are often found 0·8 inch in diameter, thus equalling in size all save the very largest of those brought from the Fiji reefs. *Orbitolites complanata* seems also to occur in the Nummulitic Limestone of the north-west of India; but from the external similarity of its disks to those of *Orbitoides*, which genus also flourished at the same period, they cannot be certainly distinguished by the imperfect descriptions of them hitherto given. This difficulty of identification, which applies also to the genus *Orbiculina*, prevents it from being certainly stated at what Geological period *Orbitolites complanata* made its first appearance. It is reported as having been found in certain Jurassic strata; and the Cretaceous forms to which the generic name *Cyclolina* was given by d'Orbigny may perhaps be referable to it. But without a careful examination of their internal structure, it cannot be said with any certainty whether these were *Orbiculinæ* (as the prominence of their centre would seem to indicate) or true *Orbitolites*. It seems to have been in the comparatively shallow and probably warm waters of the Maestricht Chalk that the more specialised Orbitoline type first became conspicuous.

CONCLUDING SUMMARY, WITH A STUDY OF THE THEORY OF DESCENT.

Thus it has been shown, that whilst an examination of the central nucleus of the disk of *Orbitolites tenuissima* enables us to trace back the pedigree of the Orbitoline type to the very simplest "jelly-speck" that can form a porcellanous shell, an examination of the inner rings of certain disks of the highly specialised *Orbitolites complanata* makes it clear that this most "complex" of Orbitolites (the most heterogeneous in structure of all existing "porcellanous" FORAMINIFERA) has had its origin in the most "simple." And yet, as has been also shown, this progressive complication of the calcareous skeleton does not seem to involve either any corresponding differentiation of parts in the sarcodic body, or any such change in its physiological character as implies a higher or more special adaptation to the conditions under which these animals exist.

It was sagaciously remarked by Sir James Paget,[1] long before the Biological revolution wrought by the publication of the Origin of Species, that "the highest laws of our science are expressed in the simplest terms in the lives of the lowest orders of creation." And in accordance with this view, I propose to make this remarkable group of facts the subject of a "Study in the Theory of Descent," for which it presents the following specia advantages:—

First, that the remoter ancestry, instead of being indicated (as it commonly is in the developmental history of the higher organisms) by obscure and transitory phases, is here distinctly represented in the earlier stages of the completed form. Thus, if the development of a very young *Orbitolites tenuissima* were checked in its early Milioline stage, it would be accounted a *Spiroloculina;* if checked in its short Peneropline stage, it would be accounted a true *Peneroplis;* and if checked in its Orbiculine stage, it would be accounted a true *Orbiculina*. And so, if the development of the "sub-typical" variety of *Orbitolites complanata* were checked in its first stage, it would rank as an *Orbitolites*

[1] Lectures on Repair and Reproduction, delivered at the Royal College of Surgeons in 1848.

marginalis; if checked in its second, as an *Orbitolites duplex;* and if checked in its third, as the earlier (fossil) form of *Orbitolites complanata.*

Second, that all these ancestral types are still living; and that, so far as we know the external conditions of their existence, they are precisely the same as those of the completed form.

Third, that the absence of any distinguishable differentiation in the parts of the sarcodic body of even the most "complex" Orbitolines, seems to make their physiological relation to their "environment" precisely the same as that still held by the whole series of ancestral forms.

In considering the genetic relations of these several forms, and the circumstances under which one has given origin to another, it is requisite to keep the distinction clearly and constantly before the mind, between *growth* and *development*;—the former consisting

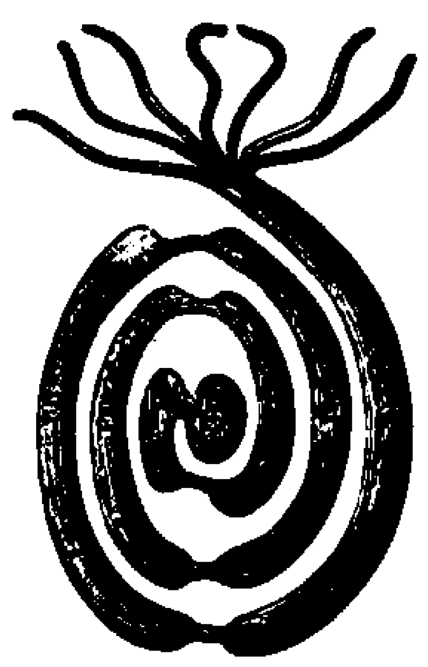


FIG. 6.—Diagrammatic representation of the sarcodic body of *Miliola.*
o, Primordial segment.
1–6, Successive segments, marked off by constrictions at intervals.

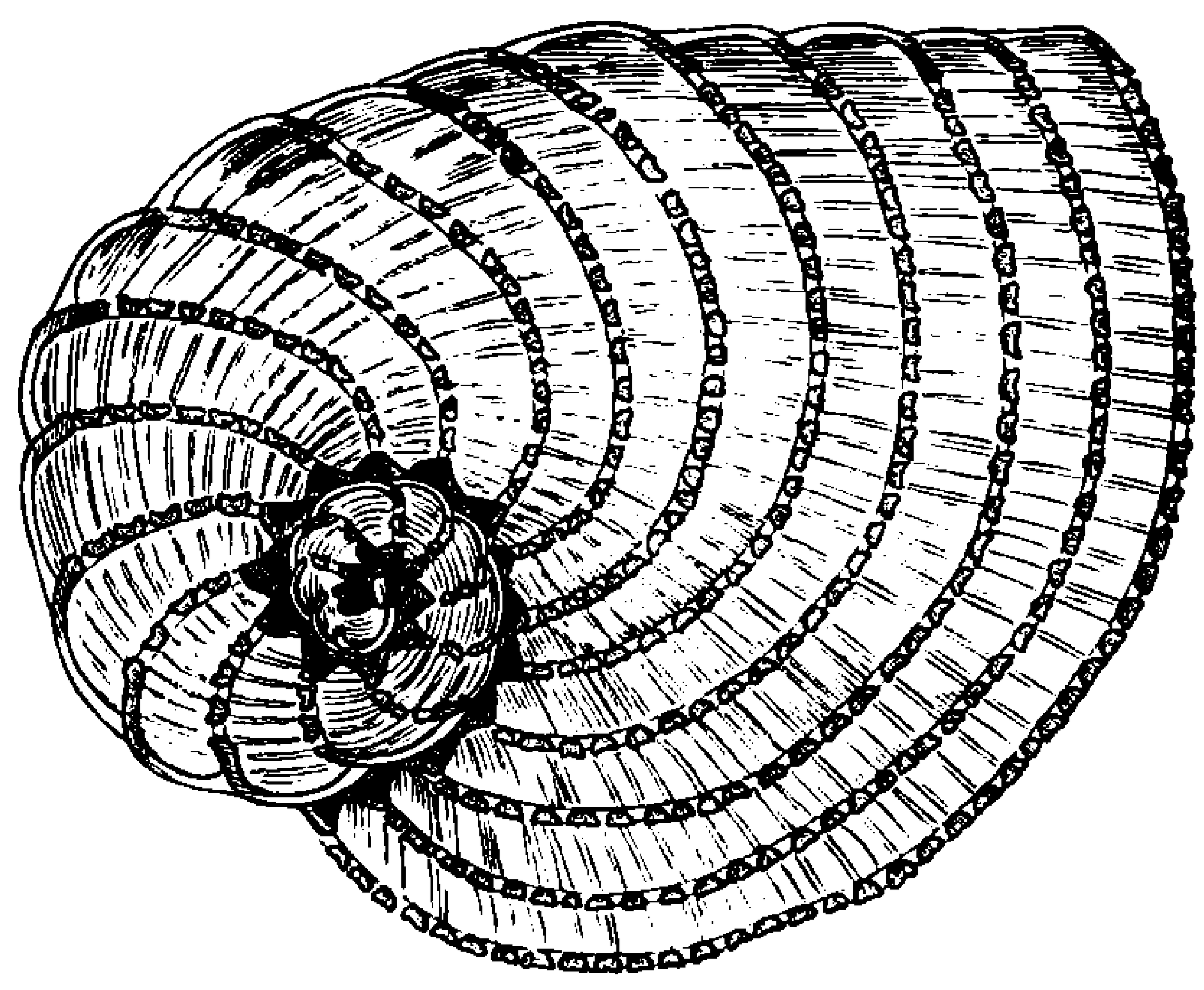


FIG. 7.—Shell of *Peneroplis*, showing its successive septa traversed by pores at regular intervals.

in the extension of the original fabric on the *same* plan, by the multiplication of *similar* parts; whilst the latter involves a *change* of plan, of which *dissimilarity* (consisting in the supersession of the original homogeneousness by heterogeneousness) is the essential feature. Thus, a *Cornuspira* that begins its life in the form of a conical tube coiled into a nautiloid spire, may expand itself, as it grows, into a flattened tube, rapidly increasing in the breadth of its mouth, without any greater change than we see in an *Amœba,* which, at one time an almost spherical lump of protoplasm, quickly flattens itself out into a disk with pseudopodial extensions. But if, instead of flattening itself out, the body of a *Cornuspira* should undergo constriction at intervals, as in fig. 6, and should form at each constriction a partial septum across its tube, we recognise a new departure that constitutes an advance in development; whilst as long as further additions are made upon this new (Spiroloculine) plan, the process is one of growth only. When, however, the flattening of the spire is followed by the formation of a complete septum across its mouth, traversed by a series of perforations at regular intervals, as in *Peneroplis* (fig. 7), another very decided advance in development is marked; and this might have been followed, as in the preceding case, by a second period of growth upon the newer (Peneropline) plan. But in our *Orbitolites tenuissima* we find it constituting only a transition-stage to the next developmental advance, namely, the subdivision of the chambers into Orbiculine chamberlets; after which, again, development gives place for a time to growth, every addition being a mere multiplication of similar parts. In *Orbiculina* it seems a matter of indifference whether the later growth continues the spiral of the earlier, or changes to the cyclical plan. But in *Orbitolites* the spiral is only a transitory phase; the multiplication of chamberlets producing such a rapid extension of each successive zone, as early to bring about a completion of the annuli, and the establishment of that cyclical plan of growth which is the distinctive feature of the Orbitoline type. When that type has once been reached, the increase of the disk in the horizontal plane to any extent, by the multiplication of its annuli of chamberlets, is a mere process of growth; but the production of the "complex" type from the "simple" involves, as we have seen, a degree of structural differentiation, which marks a great advance in development.

And yet, with all this, the physiological condition of the sarcodic body remains (so far as can be made out) essentially the same. The sub-segmented body of the spiral *Orbiculina* is nourished by the food-particles drawn in through its septal pores, precisely as is the segmented body of *Peneroplis;* and the arrangement of its sub-segments in complete annuli, instead of along the expanded mouth of a spire, cannot make any alteration in the mode either of the reception of nutriment, or of its transmission from the peripheral to the central portion of the body. The adult cyclical *Orbitolites tenuissima* or *Orbitolites marginalis* must feed in exactly the same manner as it did in its young (Orbiculine) spiral phase; and the multiplication of the rows of marginal pores in *Orbitolites complanata*, corresponding with the increased thickness of its disk, merely serves to increase its ingestive capacity, in accordance with the increased requirements of a more bulky body. The animal of each disk, whatever be its mode of obtaining nutriment, can benefit only by the food-particles which come in its way; and its pseudopodial extensions will draw-in these just as well, whether they issue from one, two, or multiple rows of pores,—just as will those of the Peneropline type, whether they issue from the single row of separate passages which traverse the narrow septal plane of the typical *Peneroplis*, from the partially-coalesced multiple passages of the widened *Spirolina*, or from the single large dendritic orifice formed by the complete coalescence of separate passages in the broad septal plane of *Dendritina*.[1]

The external conditions under which the FORAMINIFERA exist are so uniform, except as to temperature and depth of water—which seem to affect *growth* rather than *develop-*

[1] See the account of these types given in my Third Memoir, *Phil. Trans.*, 1859, pp. 1–12.

ment, the multiplication of similar parts rather than differentiation into dissimilar,—that the *onus probandi* obviously lies on those who would find in them a *vera causa* for that advance of development, which shows itself in the *production* of the forms among which "natural selection" is to operate. A single dredging brings up three types of *Orbitolites*, all living and thriving on the same bottom, and therefore, it may be inferred, equally well adapted to their common "environment"; yet one is of the very simplest structure and limited size, whilst another is of extraordinarily complex structure, and of comparatively gigantic dimensions. And it is difficult to imagine that the "complex" structure of the large shelly disk of *Orbitolites complanata* can give it the least advantage in the "struggle for existence" over the small and "simple" *Orbitolites marginalis* which is living along side of it.

Again, while abundance of food and a favourable temperature might produce in the spiral shell of *Cornuspira* a large extension upon the same simple plan, we can scarcely attribute to any such influences the peculiar change that shows itself in the periodical interruption of growth by the formation of a partial septum, which converts it into a *Spiroloculina*. Still less would it give any account of the formation of the complete septum traversed by a row of pores, which marks the assumption of the *Peneroplis* type; or of the subdivision of the spirally-growing chambers into chamberlets, which lifts it upwards into an *Orbiculina;* or of the exchange of the spiral for the cyclical plan of growth, which converts it into an *Orbitolite*. For what possible advantage can be supposed to be gained by any of these modifications, when we find that all those intermediate types, which show them in various grades of advance,—as if arrested in their developmental progress,—maintain their ground under exactly the same conditions, as though none had passed them in the race?

Looking now to the other essential condition of the "environment" of *Orbitolites*,—the preying of higher marine animals upon them,—I find it difficult to conceive that any of the foregoing modifications of structure can give to either type the least advantage in the "struggle for existence." We know that the smaller FORAMINIFERA serve as food both to Echinoidea and to Asteroidea, since the stomachs of these animals are found to be full of them; and it is probable that the larger forms are eaten by Crustacea and Fishes. But it seems scarcely possible that such creatures can have any preference for a cyclical over a spiral form, or for a complex over a simple. The very fact that—like the vast variety of *Operculinæ* which I formerly described (Phil. Trans., 1859, p. 15) from Mr. Cuming's gatherings—they all abound in the same localities, seems to forbid the idea that any one form is better fitted for survival than another. Getting out of the way of enemies is obviously out of the question with FORAMINIFERA; and the Fishes whose teeth are adapted to browse upon hard Corals, would not be likely to pick out one species of Orbitolite from another, when even a practised Foraminiferalist cannot distinguish them without examination with a magnifying-glass.

Altogether, while I hold it utterly illogical to impute to "natural selection" a power of *originating* any varietal forms whatever (since it can only take effect upon varieties which have already come into existence), and find it difficult to conceive that it can have had any share in even *perpetuating* the particular types of Orbitoline structure which form the subject of this Report, the developmental advances by which they have been successively evolved seem to me to lie altogether beyond the power of any known influence of "environment" to account for. We have evidence, in the size and luxuriance of the specimens of *Orbitolites complanata* growing in the rock-pools of the reef, that a warm temperature and abundance of food may stimulate *growth*; but we have no evidence whatever that they can of themselves cause an advance in *development*; and it seems inconceivable that they should produce a complete change in the *plan* of a fabric. There must have been an inherent capacity for elevation in certain of these organisms, for any change in the "environment" to produce *developmental* advances; for without such capacity, no amount of warmth or food could do more than produce an increase of *growth* on the lower grade. And there must have been some fundamental difference between that primordial jelly-speck which could evolve itself in a long series of generations into the highest type of *Orbitolites*, and that which perpetuates the humble form of *Cornuspira* still living under precisely the same conditions. Moreover, the passage from the lower type to the higher has always taken place (so far as we know) through the same series of intermediate forms; and each of these—as already pointed out—continues to maintain its existence on its own grade. Finally, it would seem as if the developmental capacity of the primordial germ exhausted itself in the production of the most complex form of *Orbitolites*; there being no reason whatever to believe that it leads up to any higher form of organic structure.

The general pointing of this study seems, therefore, to be, that the evolution of the highly complex Orbitoline type from the simplest monothalamous Milioline, has taken place according to a definite *plan*, of which we have the evidence in the wonderful uniformity and regularity of the entire sequence of developmental changes; whilst we are entirely unable to account for those changes, without attributing to the subjects of them a capability of being affected by external agencies in modes so peculiar as to indicate a *previous adaptation*. The question whether the variations on which "natural selection" takes effect are *aimless*, or whether they have a *fixed direction*, has so important a teleological bearing, that I have thought it worth while to work out with considerable care an instance in which that fixity seems to me very conspicuous. And I would specially point to the doubling of the radial stolons in the "duplex" type (pp. 27, 28) as a change altogether meaningless in itself, but very significant when considered as *anticipatory* of that greatest of all the developmental advances—the duplication of the annular canals (p. 40)—which marks the passage from the "simple" to the "complex" type.

PLATE I.

PLATE I.

Structure of Calcareous Disk of *Orbitolites tenuissima*.

Fig. 1.—Surface of young disk, showing its excentric 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.

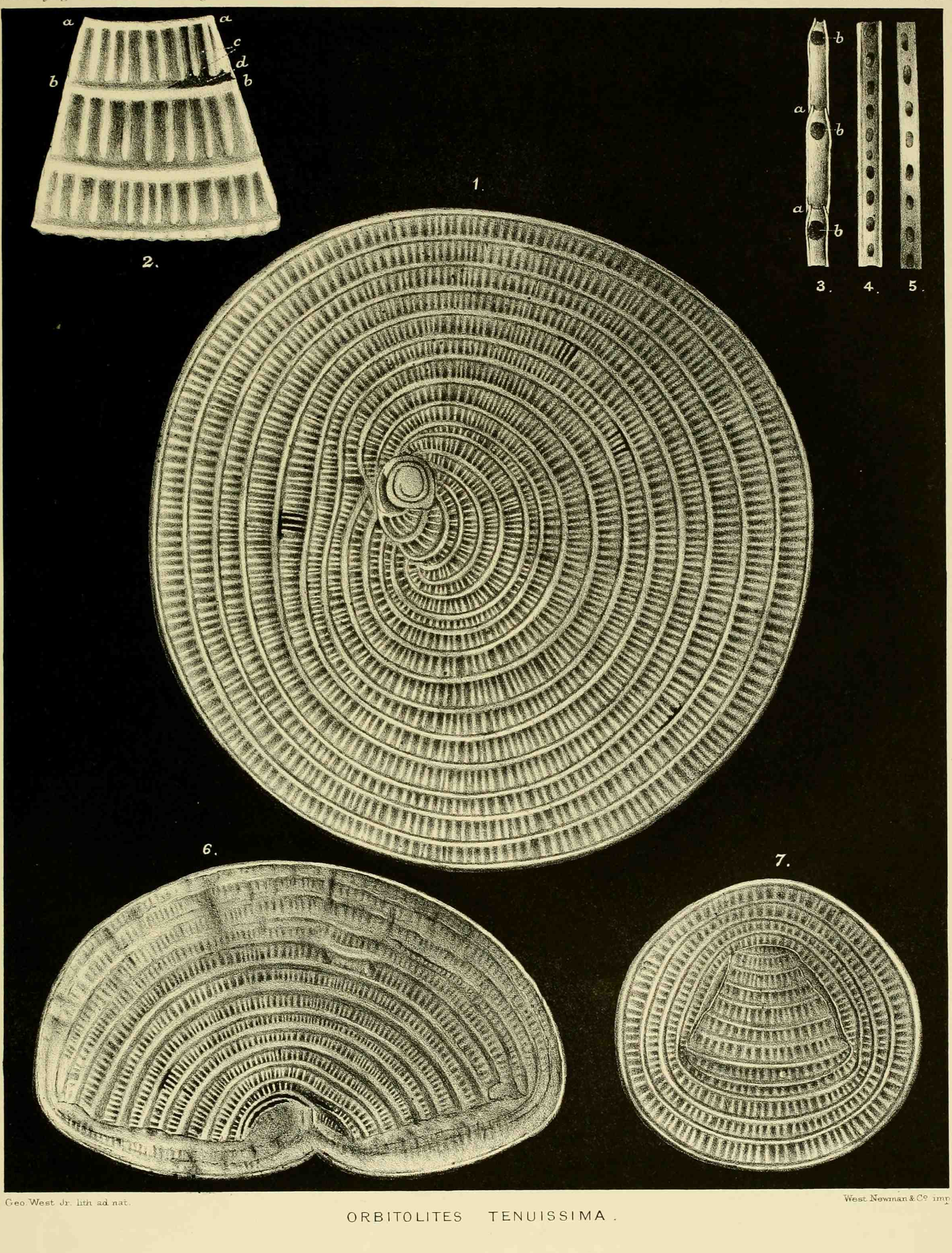
Fig. 3.—Vertical section of three annuli of the disk, taken in the radial direction, so as to traverse the chamberlets lengthways; *a*, *a*, junctions of two annuli with the annuli external to them; *b*, *b*, *b*, annular galleries traversing the septa between the chamberlets. At *a*, *a* are seen the 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.



Geo. West Jr. lith ad nat.

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ORBITOLITES TENUISSIMA.

PLATE II.

PLATE II.

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

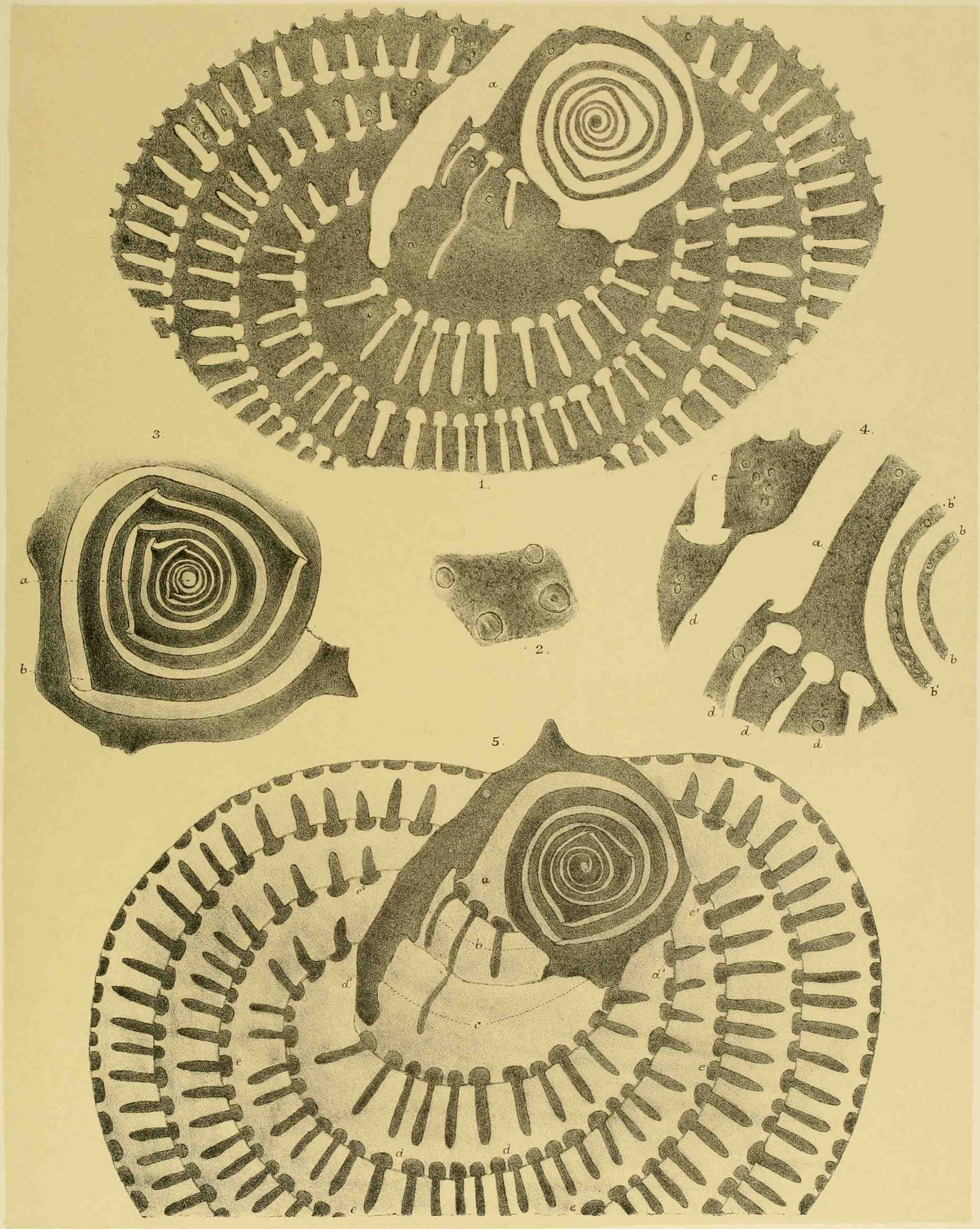
Fig. 1.—Sarcodic body of the central portion of the disk; showing the primordial segment giving off the spiroloculine coil, the sixth turn of which, *a*, begins to open out into a peneropline form, afterwards becoming divided into rows of orbiculine sub-segments, which are connected together laterally 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.

PLATE III.

PLATE III.

Structure of Calcareous Disks of *Orbitolites marginalis* (figs. 1–7), and *Orbitolites duplex* (figs. 8–14), as seen by reflected light.

Orbitolites marginalis.

Fig. 1. Surface of disk. Magnified 16 diameters.

Fig. 2. Inner portion of the same, showing its excentric "nucleus" and the orbiculine arrangement of its earlier zones of chamberlets. Magnified 64 diameters.

Fig. 3. Peripheral portion of the same, viewed somewhat obliquely, so as to show at *a* the columnar arrangement of the margin. Magnified 64 diameters.

Fig. 4. Marginal view of two disks, *a* thin, *b* thick; showing the marginal pores elongated vertically, some of those in *b* being traversed by shelly bridges, which do not, however, completely divide them. Magnified 64 diameters.

Fig. 5. Interior view of a portion of an annulus separated by fracture from that which it enclosed; showing the vertically-elongated radial passages opening into its chamberlets. Magnified 64 diameters.

Fig. 6. Vertical section, taken in radial direction, of peripheral portion of disk, showing the single annular canal of each annulus, and the arcuate direction of the chamberlets. Magnified 64 diameters.

Fig. 7. Peripheral portion of disk, of which the upper surface has been ground away, so as to lay open the columnar chamberlets, the walls of whose last annulus form the fluted margin *a*. Magnified 64 diameters.

Orbitolites duplex.

Fig. 8. Surface of disk. Magnified 16 diameters.

Fig. 9 Horizontal section of a disk, taken beneath the plane of the annular canals, showing at *a* the openings into the lower series of columnar chamberlets, crossed by the annular septa; and at *b* the deeper plane from which the median stratum has been entirely removed. Magnified 50 diameters.

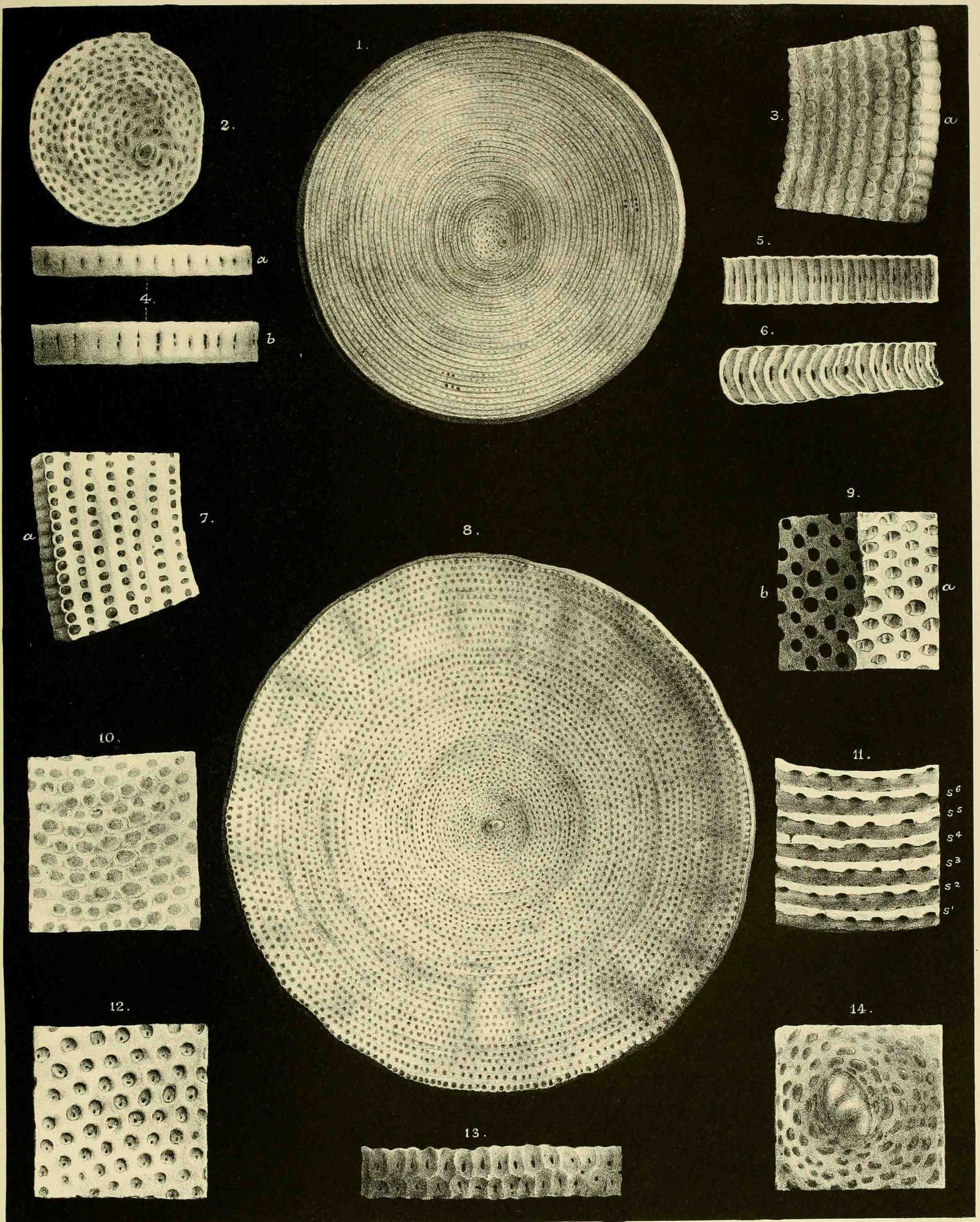
Fig. 10. Peripheral portion of the surface. Magnified 50 diameters.

Fig. 11 Horizontal section through the median stratum traversed by the annular canals, which are separated by the successive septa s^1–s^6; on the convex sides of these septa are seen the large passages leading obliquely downwards into the columnar chamberlets (*see* fig. 9) of their own lower series, while on the concave sides of the septa are seen the small radial passages that pass from each annular canal into the columnar chamberlets of the next annulus. Magnified 50 diameters.

Fig. 12. Portion of disk laid open by removal of its upper surface, showing upper series of columnar chamberlets, with the pore in every one, which is the opening of the oblique radial passage from the annular canal of the preceding annulus. Magnified 50 diameters.

Fig. 13. Margin of disk, showing the marginal pores arranged in two series, generally alternating in position, and separated by elevated ridges. Magnified 64 diameters.

Fig. 14. Central portion of disk, showing small "nucleus" and imperfect annulation of first-formed zones. Magnified 64 diameters.



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FIGs 1—7. ORBITOLITES MARGINALIS, FIGs 8—14. O. DUPLEX.

PLATE IV.

PLATE IV.

Structure of Calcareous Disks of *Orbitolites marginalis* (figs 1–5), and *Orbitolites duplex* (figs. 6–10), as seen by transmitted light.

Orbitolites marginalis.

Fig. 1.—Thin disk, mounted in Canada balsam, showing the general arrangement of its concentric annuli around an excentric " nucleus " and orbiculine interior. Magnified 30 diameters.

Fig. 2.—Interior portion of the same. Magnified 64 diameters.

Fig. 3.—Peripheral portion of the same. Magnified 64 diameters.

Fig. 4.—Thin section of inner portion of a disk, showing the communications between its chamberlets :—*a*, primordial chamber; *b*, circumambient chamber, leading by a single passage into next chamber, *c*, which opens by three radial passages into as many chamberlets forming the first zone *d*, and these into the chamberlets of the next zone *e*, the chamberlets of each zone communicating with each other laterally. The radial passages open at the outer side of each zone, as marginal pores, *f*, *f*. Magnified 90 diameters.

Fig. 5.—Sarcodic body occupying inner portion of disk :—*a*, primordial segment giving off *b*, circumambient segment, and this giving off the single segment *c*, from which proceed the stolon-processes that form the first imperfect zone of sub-segments *d* ; from this, again, are given off the stolon-processes that form the more complete zone *e* ; and each zone increases in length, until the ninth and tenth completely enclose the circumambient segment. At *f*, *f* are seen the sarcodic annuli which connect together the chamberlets of each zone, and the radial stolon-processes that issue from this to form the next annulus. Magnified 90 diameters.

Orbitolites duplex.

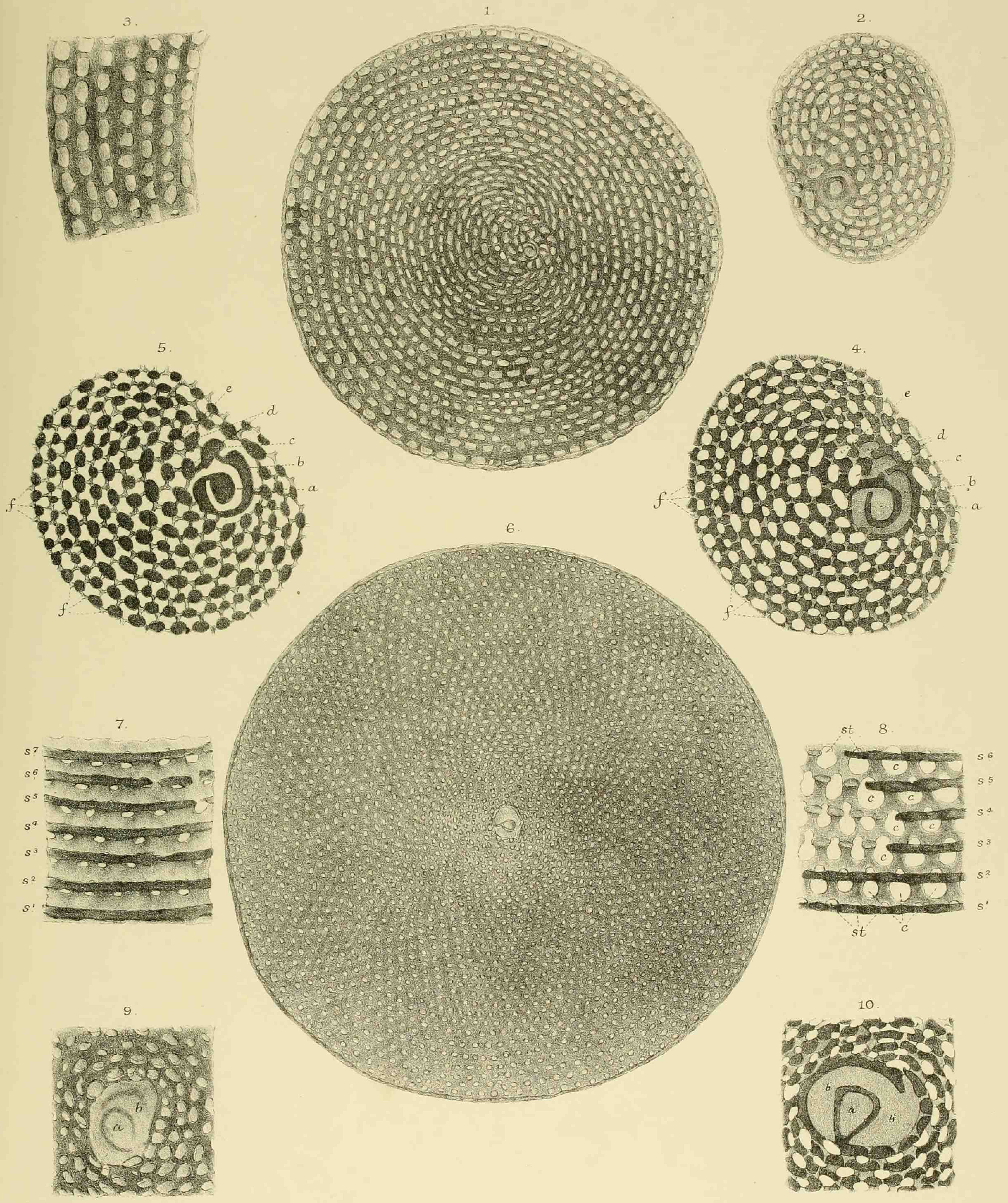
Fig. 6.—Section of disk through superficial plane, showing its " engine-turned " aspect. Magnified 16 diameters.

Fig. 7.—Section through median plane, showing annular canals laid open, and the large passages for the pedicles of the lower series of columnar sub-segments. Magnified 50 diameters.

Fig. 8.—Section through a somewhat deeper stratum, showing the successive septa, s^1–s^6, that divide the annular canals, with the columnar chamberlets *c*, *c*, into which they open beneath, and the oblique stolon-passages *st*, *st*, which pass to the chamberlets of each zone from the annular canal of the preceding zone. Magnified 50 diameters.

Fig. 9.—Surface-aspect of central portion of disk, showing at *a* the primordial chamber, and at *b* the circumambient chamber, the first-formed zones around which are irregular and incomplete. Magnified 64 diameters.

Fig. 10.—Section of central portion of disk through median plane, showing at *a* the primordial chamber, and at *b*, *b* the circumambient chambers, from one side only of which last are given off the stolon-passages that dilate into the first imperfect zone of chamberlets. The successive zones, however, complete themselves so as to enclose the " nucleus " much more speedily than in *Orbitolites marginalis;* so that the " nucleus " has but a slight excentricity. Magnified 90 diameters.



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FIGS. 1–5. ORBITOLITES MARGINALIS, FIGS. 6–10. O. DUPLEX

PLATE V.

PLATE V.

Structure of Sarcodic Bodies of *Orbitolites duplex* (figs. 1–10), and *Orbitolites complanata* (figs. 11–18).

Orbitolites duplex.

Fig. 1.—Decalcified body, showing the concentric arrangement of its columnar sub-segments. Magnified 25 diameters.

Fig. 2.—One of its separate annuli, showing at *a*, *a′* and *b′*, *b′* the upper and lower series of columnar sub-segments, with expanded summits, issuing from the annular sarcodic cords *c*, *c′*; from which also issue the two rows of stolon-processes *dd*, *d′d′* that go to form the succeeding annulus. Magnified 60 diameters.

Fig. 3.—Two of the columnar sub-segments more enlarged, to show the corpusculated character of the sarcodic substance. Magnified 150 diameters.

Fig. 4.—Thick-walled (parasitic ?) cells, *a*, *b*, *c*, of a deep red colour, lying irregularly in the sarcodic substance of certain specimens. Magnified 200 diameters.

Fig. 5.—Small sub-segments of central portion, surrounded by chitinous (?) wall. Magnified 150 diameters.

Fig. 6.—Sarcodic body of "nucleus," showing at *a* the primordial segment, which gives off the large circumambient segment *b*, *b′*, a partly-separated portion of which, *c*, gives off the first incomplete zone of sub-segments. Magnified 120 diameters.

Fig. 7.—Section of sarcodic body close to the median plane, showing the sarcodic annuli *c*, *c*, giving off obliquely the narrow bases of the columnar sub-segments. Magnified 50 diameters.

Fig. 8.—Lateral view of two sarcodic annuli *cc′ cc′*, with their columnar sub-segments. Magnified 64 diameters.

Fig. 9.—Section of sarcodic body above the median plane, showing an increased diameter of the columnar sub-segments as compared with their narrow bases shown in fig. 7. Magnified 50 diameters.

Fig. 10.—Surface view of expanded summits of columnar sub-segments. Magnified 50 diameters.

Orbitolites complanata.

Fig. 11.—Decalcified body of sub-typical specimen, the inner part of which is formed on the "duplex" plan, as shown by the surface-aspect of its sub-segments, while the outer shows the aspect characteristic of the "complex" type. Magnified 25 diameters.

Fig. 12.—Surface-aspect of sarcodic sub-segments of inner part of sarcodic body, enlarged to 40 diameters, showing its exact correspondence to that of fig. 1.

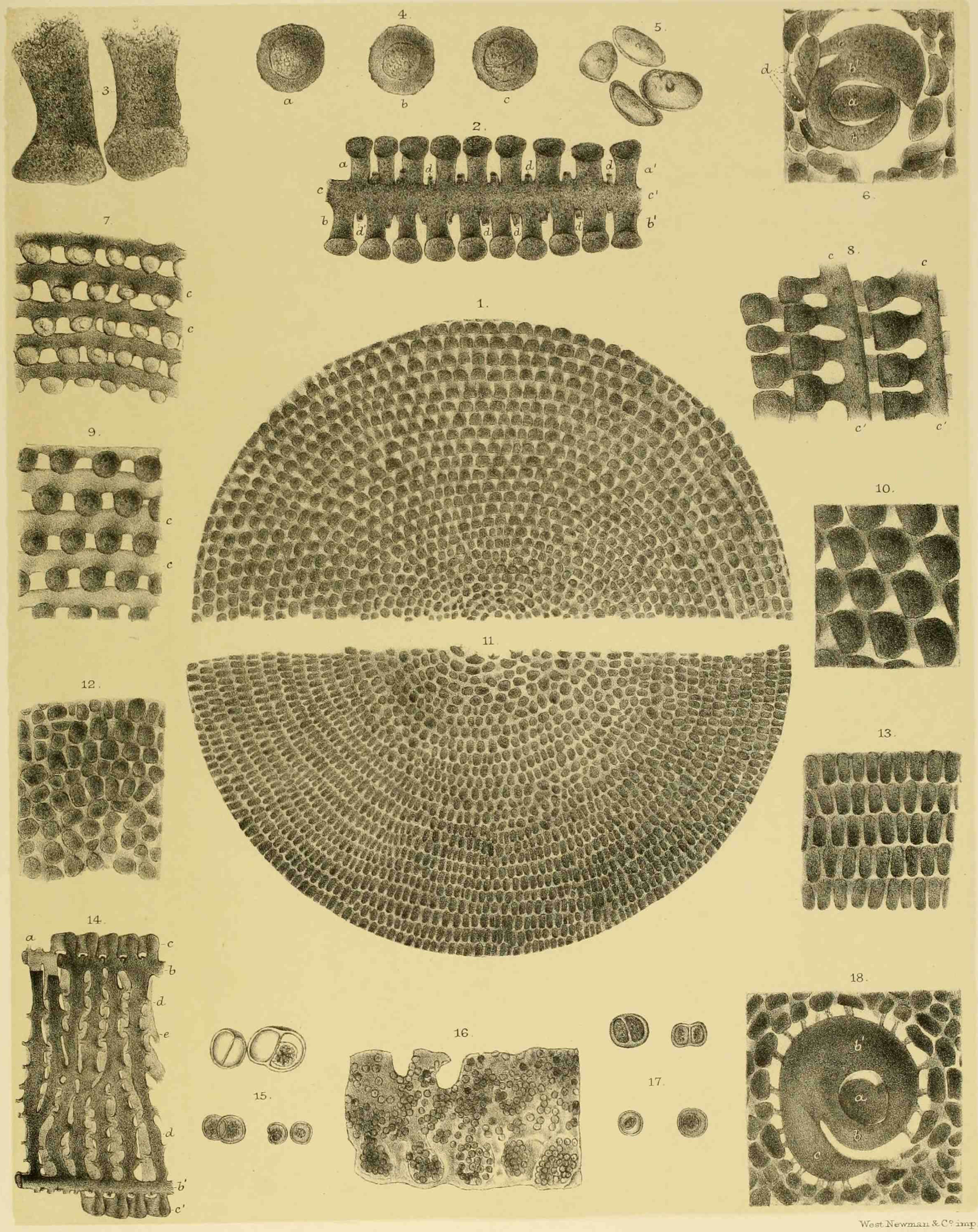
Fig. 13.—Surface-aspect of sarcodic sub-segments of outer part of sarcodic body, occupying the chamberlets of the superficial planes. Magnified 50 diameters.

Fig. 14.—Portion of sarcodic body of "complex" type seen in vertical section :—*a*, *b*, annular cords of upper series; *b′*, an annular cord of lower series; *c*, *c′*, sub-segments of upper and lower planes, each connected with two annular canals; *d*, *d*, columnar sub-segments of interposed stratum, communicating with those of next annulus, *e*, by oblique alternating stolon-processes. Magnified 150 diameters.

Figs. 15 and 17.—Parasitic (?) cells lying irregularly in sarcodic substance. Magnified 130 diameters.

Fig. 16.—Sarcodic substance of annulus and superficial sub-segments, containing spherical corpuscles, closely aggregated together in some parts, separate in others. Magnified 180 diameters.

Fig. 18.—"Nucleus" of typical form, showing at *a* the primordial segment, which gives off the large circumambient segment *b*, *b′*, with its partly detached portion *c*, round the entire margin of which are given off stolon-processes that give immediate origin to a complete annulus of sub-segments. Magnified 84 diameters.



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FIGS. 1—10. ORBITOLITES DUPLEX. FIGS. 11—18. O. COMPLANATA.

PLATE VI.

PLATE VI.

Structure of the Calcareous Disk of *Orbitolites complanata*, as seen by reflected light.

Figs. 1–3.—Three young typical specimens, showing the large size of the "nucleus" (originating in the primordial chamber *a*), and the completeness of even the very earliest annuli of chamberlets. Magnified 35 diameters.

Fig. 4.—Ideal representation of a typical disk, laid open in various modes to show its interior structure:—*a*, primordial chamber; *b*, circumambient chamber; *c*, *c*, concentric annuli of oblong superficial chamberlets; *d*, marginal pores of peripheral annulus; *d′*, *d″*, corresponding pores of inner annuli, once marginal, but now connecting the interior with exterior annuli; *e′*, *e′*, vertical section in radial direction, showing intermediate stratum distinct from superficial layers; *f*, *f*, floors of superficial chamberlets, with an aperture at either end of each; *g*, *g*, annular canals running beneath these floors, with large apertures leading to the columnar chamberlets of the intermediate stratum; *g′*, similar canals near the other surface of the disk; *g″*, similar canals laid open through the plane on which they give off the two passages to each superficial chamberlet; *g‴*, annular canals cut through in vertical section; *h*, passage of horizontal section through summit of intermediate stratum, showing the tops of the columnar chamberlets; *i*, *i*, *i*, and *k*, *k*, *k*, passage of horizontal section through two different planes of intermediate stratum, showing connection between columnar chamberlets of successive zones, by oblique passages running in opposite directions.

Fig. 5.—Vertical section, taken in the radial direction, of a "sub-typical" example, whose earlier development has taken place on the "simple" plan:—*a*, cavity of "nucleus"; from *aa* to *bb* the annular canal single in each zone; from *bb* to *cc* the annular canals double in each zone, and separated from each other by an interposed stratum, the chamberlets of which are generally continuous with those of the superficial planes, much irregularity in this respect showing itself between *cc* and *dd*. Magnified 50 diameters.

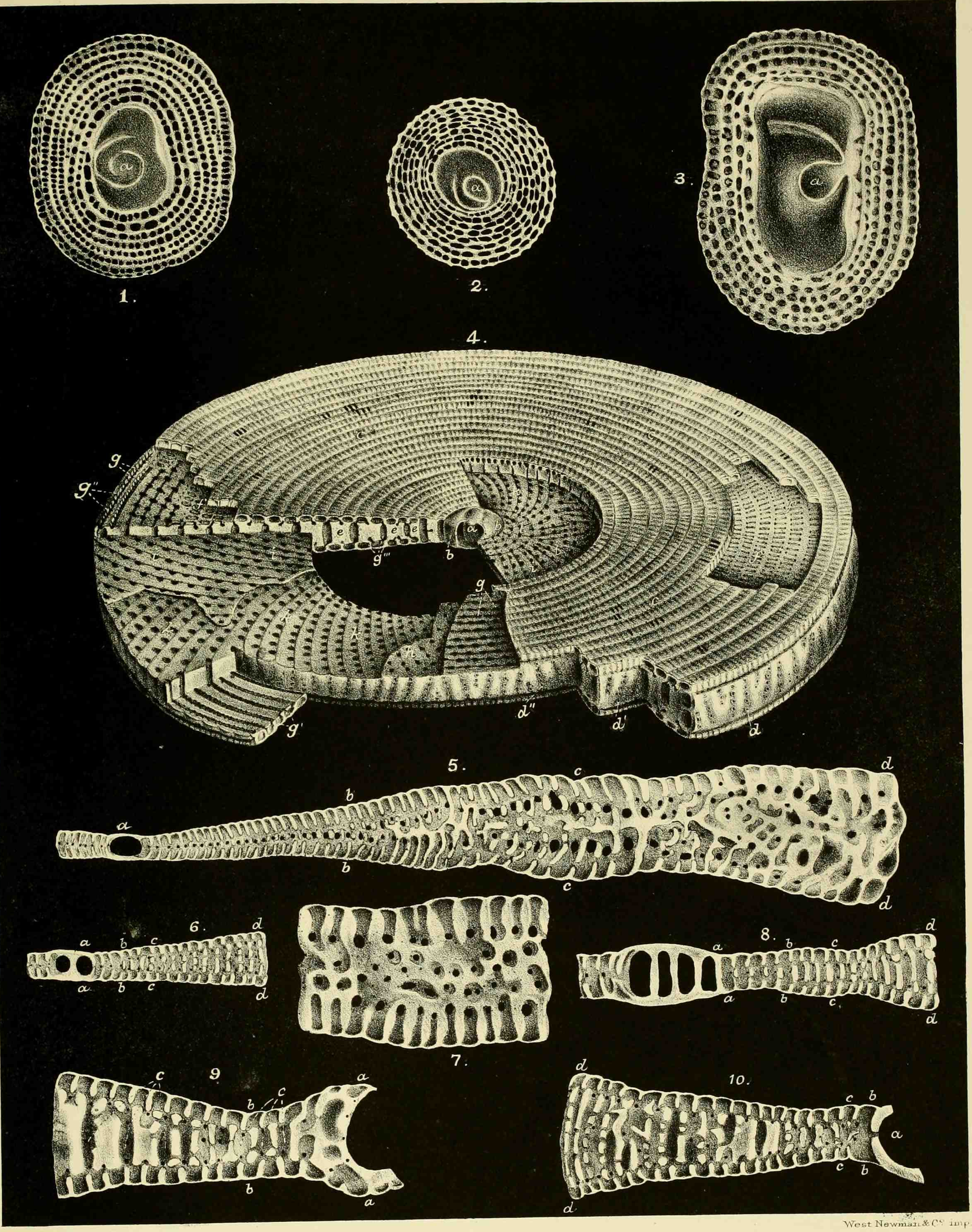
Fig. 6.—Central portion of a disk, the first three zones of which, between *aa* and *bb*, are formed upon the "simple" type, each having but a single annular canal and one row of septal passages; at *bb* the "complex" type is assumed, the annular canals being doubled, and separated by an interposed stratum; but the columnar chamberlets of this stratum that lie between the annular canals are continuous from *bb* to *cc* with the chamberlets of the superficial layers, this continuity giving place between *cc* and *dd* to the alternation in their positions characteristic of the most typical Orbitoline disks. Magnified 50 diameters.

Fig. 7.—Tangential vertical section of a typical disk, taken near the thick margin; showing the two layers of superficial chamberlets, the double series of annular canals, and the interposed stratum traversed by the radial passages that open on the periphery as marginal pores. Magnified 50 diameters.

Fig. 8.—Vertical section of a disk, of which the first five zones, *aa* to *bb*, are formed on the "duplex" type, each having but a single annular canal, but a double series of radial passages; between *bb* and *cc* the annular canals are double, and the chamberlets of the interposed stratum are continuous with the superficial chamberlets; while from *cc* to *dd* the superficial chamberlets alternate in position with those of the interposed stratum. Magnified 48 diameters.

Fig. 9.—Vertical section of inner part of typical disk, showing the circumambient chamber, *aa*, immediately surrounded by annuli of the complex type, having the two superficial layers of chamberlets, *b*, *b*, completely dissociated from the columnar chamberlets, *c*, *c*, of the interposed stratum. Magnified 48 diameters.

Fig. 10.—Vertical section of inner part of typical disk, showing the circumambient chamber, *a*, communicating by only a single passage with the "simple" chamberlets of the first annulus *b*; but this at once passing at *c*, by the doubling of the annular canal, into the "complex," which is thenceforth maintained, *c*-*d*, with a progressive increase in the thickness of the disk. Magnified 48 diameters.



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ORBITOLITES COMPLANATA.

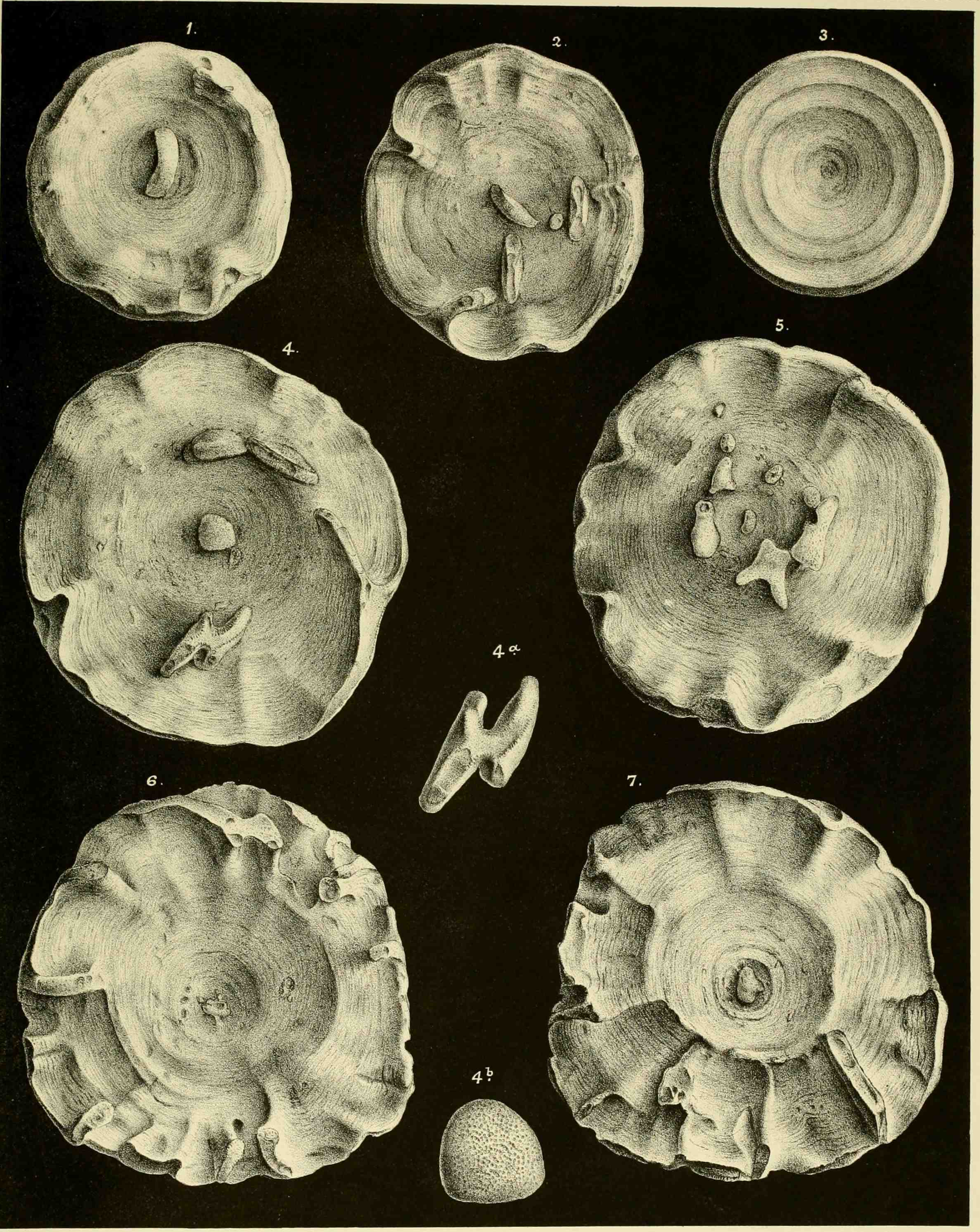
PLATE VII.

PLATE VII.

Laciniate specimens of *Orbitolites complanata.*

All the disks represented in this Plate are magnified four diameters; and, with the exception of fig. 3 (which represents a *normal* disk of the massive type), show in a greater or less degree the "laciniation" of margin, which seems to depend—like the irregular outgrowths from the central and intermediate portions—on an excess of productive power.

Figs. 4 *a* and 4 *b* show, under a higher power, the central and one of the intermediate outgrowths seen in fig. 4, so as to exhibit the pores which correspond to the marginal pores of the regular annuli.



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ORBITOLITES COMPLANATA. (VAR. LACINIATA.)

PLATE VIII.

PLATE VIII.

Irregularities and Reparations of disks of *Orbitolites complanata.*

Fig. 1.—Young disk, with vertical crest growing from central portion. Magnified 10 diameters.

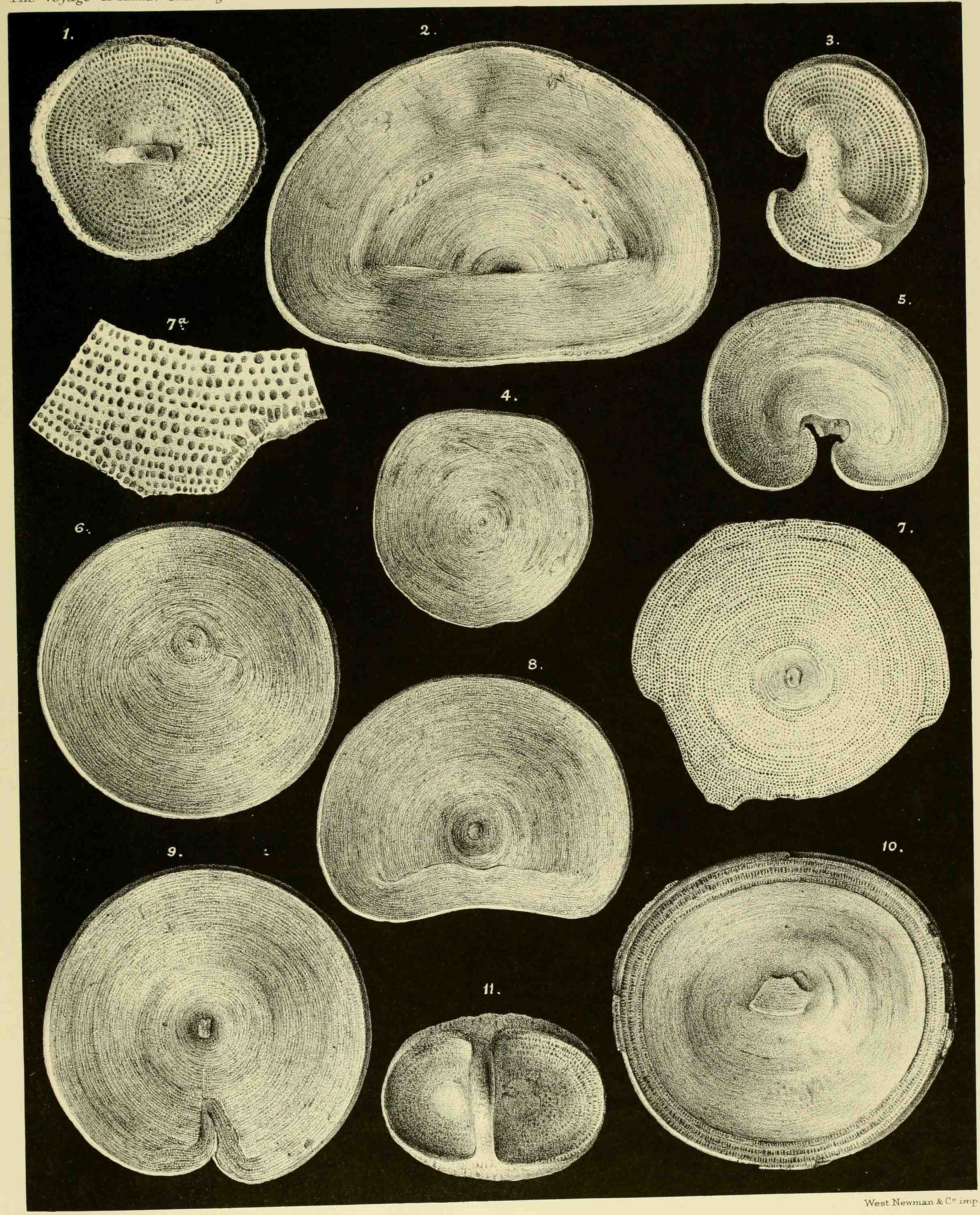
Fig. 2.—Reparation of disk that had been broken across at an early stage. Magnified 8 diameters.

Fig. 3.—Irregular growth of young disk, with vertical crest. Magnified 10 diameters.

Figs. 4–9.—Reparations of disks fractured in various ways, all tending to reproduce the discoidal form. Magnified from 4 to 6 diameters.

Fig. 10.—Production of complete disk around marginal fragment of older disk. The outer annuli of this disk are deficient in radial partitions. Magnified 6 diameters.

Fig. 11.—Double monster, probably formed by fusion of two originally separate individuals. Magnified 10 diameters.



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ORBITOLITES COMPLANATA. — IRREGULARITIES.