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INTRODUCTION

TO THE STUDY OF THE

FORAMINIFERA.

BY

WILLIAM B. CARPENTER, M.D., F.R.S., F.L.S., F.G.S.,
REGISTRAR OF THE UNIVERSITY OF LONDON,
ETC., ETC.

ASSISTED BY

WILLIAM K. PARKER, ESQ.,

AND

T. RUPERT JONES, ESQ., F.G.S.

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PREFACE.

WHEN, some years since, I undertook to prepare for the Ray Society an outline view of the structure, physiology, and systematic arrangement of the Foraminifera generally, I had no idea of contributing anything else than an introduction to my friend Prof. W. C. Williamson's 'Recent Foraminifera of Great Britain.' With the progress of my own researches, however, I came more and more strongly to feel how unsatisfactory are the results of the method pursued by M. D'Orbigny and by those who have followed his lead, both as regards the multiplication of *species*, the distinction of *genera*, and the grouping of these genera into *families* and *orders*. I found, moreover, that notwithstanding the dissimilarity between the lines of inquiry pursued by myself on the one hand and by my friends Messrs. Parker and Rupert Jones on the other, they led to conclusions most singularly accordant. My own studies had been restricted to a limited range of types (for the most part collected by Mr. Jukes on the Australian coast and by Mr. Cuming in the Philippine Seas), which included, however, all the most complex and highly developed forms of recent Foraminifera; and I had specially devoted myself to the elucidation of their structure and physiology, and to the careful comparison of their numerous varietal forms. Theirs, on the other hand, had involved the comparison of the zoological characters of vast numbers of representatives of nearly all the generic types of the group, fossil as well as recent, brought together from various parts of the world, from various depths in the ocean, and from various geological formations; but had not been prosecuted with the same minuteness in regard to the details of internal structure or to physiological relations. Yet we had all been alike brought to recognise—

(1) the extreme latitude of the *range of variation* in this group, which breaks down in almost every instance the boundaries which it has been attempted to erect between *species*: (2) the necessity of a like abolition of the divisions between many reputed *genera* which have been erected on an equally insecure basis; (3) the completely unnatural character of any system which makes a fundamental division between the Monothalamous and the Polythalamous types, and which adopts Plan of Growth (that is, the geometrical arrangement of aggregations of successive segments) as the basis of the subdivision of the *Polythalamia* into *orders*; and (4) the fundamental importance, in the determination of the true affinities of the several generic types, of all that relates to the physiological condition of the animal, especially the texture of the shell, and the peculiarities of conformation which characterise its individual segments.

Not only, moreover, did there prove to be this complete harmony in our general results, but there was also a singular unity in the aggregate of the work we had respectively accomplished, each portion being, so to speak, the complement of the other; so that, on comparing notes, we found that we had between us pretty thoroughly investigated the entire group. Hence I was led to propose to the Council of the Ray Society an enlargement of my original plan, so as to include the results of my friends' labours, and to render the whole an expression of our joint views. This I did in the expectation that we might associate ourselves together in such a manner that whilst the general plan and a part of the details of its working out would rest with me, a large share in the execution would be taken by my coadjutors. We soon found, however, that it would be more conducive both to unity of design and to completeness of effect for the whole to be wrought out by myself; and it has been by the necessity which thence arose for my personal study of many types with which I was previously but little or not at all acquainted, that the delay in the production of the work has for the most part been occasioned. The materials for this study have been most liberally supplied to me by Messrs. Parker and Rupert Jones; and as to many types which they had previously made the object of special researches (such as the *Milioline*, *Nodosarine*, *Textularine*, and *Rotaline* groups), I have found that I had nothing to do but to accept their well-considered and satisfactory conclusions. In certain other cases, especially in regard to the genus *Dactylopora* and to that collection of forms which they had described under the generic designation *Orbitolina* (here referred to the genera *Tinoporus* and *Patellina*), my own investigation of the materials which they have placed in my hands has led me to results in some respects different from those which they had published; but as they have seen reason to accept my modifications, the account of those types here given may be regarded as not less theirs than mine. In regard to the genus *Nummulina*, the most important of all Foraminifera in a geological point of view, we have found ourselves in complete accordance as to the impossibility of drawing definite lines of demarcation between its reputed species; my researches on the varietal forms of the closely related genus *Operculina* having led me to conclusions as to the variability of all the differential characters on which reliance had been placed, precisely corresponding with those at which Messrs. Parker and Rupert Jones had arrived from a careful comparative study of the various forms of *Nummulina* proper. I have endeavoured, as each genus came successively under review, to specify what share in the special investigation of its characters is due to my coadjutors, and what has been more particularly my own; where no such intimation is given, we may be regarded as jointly responsible.

That our work will prove altogether satisfactory, either to the scientific or to the general reader, is more than we can venture to anticipate. Those who look for precise definitions will not find them here, for the simple reason that the conclusion has been forced upon us that *sharply defined divisions*—whether between species, genera, families, or orders—*do not exist among Foraminifera*. And we are satisfied that any one whose study of the group shall have been coextensive with our own must be ready to this extent to endorse our results. It has been our aim, therefore, to set forth (so to speak) the fundamental "idea" of each of the generic types we have adopted, rather than to attempt a precise limitation of its boundaries. That some of our generic distinctions may be invalidated by more extended research, is just as likely as that new generic types may present themselves among the collections from ocean beds yet unexplored, or from geological formations as yet unscrutinised. The whole study of this group must still be regarded as in its infancy; and the utmost that we can hope for this Introduction is, that it may help to give *a right direction* to that study. We have the fullest confidence in the correctness of our general principles; and shall not shrink from the consequences of their application to our own work, however large a part of it may thereby be superseded by something better. I have endeavoured throughout my own scientific career to keep in view the noble character given by Schiller of the true philosopher, as distinguished from the trader in science, that "he has always loved truth better than his system; and will gladly exchange her old and defective form for a new and fairer one." And the readiness with which my coadjutors have accepted my amendments in the instances already alluded to, affords the fullest assurance of their thorough participation with me in the desire, not only that whatever is defective in our joint work may be supplied, but that what is unsound may be demolished, since what shall remain really good and true will then afford a firmer basis for the future labours of others.

The study of the RHIZOPOD type in general, and of the *Foraminifera* in particular, has peculiar features of interest to the Physiologist, the Zoologist, and the Geologist.

If the views which I have expressed as to the nature and relations of their living substance be correct, that substance does not present any such differentiation as is necessary to constitute what is commonly understood as "organization," even of the lowest degree and simplest kind; so that the Physiologist has here a case in which those vital operations which he is accustomed to see carried on by an elaborate apparatus, are performed without any special instruments whatever,—a little particle of apparently homogeneous jelly changing itself into a greater variety of forms than the fabled Proteus, laying hold of its food without members, swallowing it without a mouth, digesting it without a stomach, appropriating its nutritious material without absorbent vessels or a circulating system, moving from place to place without muscles, feeling (if it has any power to do so) without nerves, propagating itself without genital apparatus, and not only this, but in many instances forming shelly coverings of a symmetry and complexity not surpassed by those of any testaceous animals.

Again, there are certain peculiarities about the *Foraminifera* which makes this group singularly adapted for that kind of comparison, at once minute and comprehensive, amongst large numbers of individual forms, which should be the basis of all Zoological systematization. The size of the greater part of these organisms is so small, that many hundreds, thousands, or even tens of thousands of them, may be contained in a pill-box; and yet it is usually not too minute to prevent the practised observer from distinguishing the most important peculiarities of each individual by a hand-magnifier alone, or from dealing with it separately by a very simple kind of manipulation. Hence the Systematist can easily select and arrange in series such of his specimens as display sufficient mutual conformity, whilst he sets apart such as are transitional or osculant; and an extensive range of varieties may thus be displayed within so small a compass, that the most divergent and the connecting forms are all recognisable nearly in the same glance. I am not acquainted with any other group of natural objects, in which such ready comparison of great numbers of individuals can be made; and I am much mistaken if there be a single specimen of plant or animal, of which the range of variation has been studied by the collocation and comparison *under one survey* of so large a number of specimens as have passed under the review of Prof. Williamson, Messrs. Parker and Rupert Jones, and myself, in our studies of the types to which we have respectively given our principal attention. The extraordinary diversity thus found to exist among organisms which, from the intimacy of the relationship evinced in the gradational character of those differences as well as in the variations observable between the several parts of one and the same organism, must in all probability have had a common origin, seems to me unmistakeably to indicate that the wide range of forms which this group contains is more likely to have come into existence as a result of modifications successively occurring in the course of descent from a small number of original types, than to have originated in the vast number of distinct creations which on the ordinary hypothesis would be required to account for it. Hence I cannot but believe that any systematic arrangement of Foraminifera will be of real value only in so far as its basis is laid in a thorough knowledge of the nature and extent of those variations which every chief modification of this type shows itself so peculiarly disposed to exhibit, and as, in building it up, the idea of *natural affinity* is accepted as expressing not only degree of mutual conformity, but *actual relationship arising from community of descent* more or less remote. For the occurrence of endless gradational departures from any types which we may assume as fixed, and of links of connection between such as present the best-marked differentiations, seems to me to point unmistakeably to this as the only means of escape from that difficulty of indefinite multiplication which attends the doctrine of distinct specific creations when applied to a group in which scarcely any two individuals are alike. The case, in fact, is very analogous to that of the relationship between the various members of the family of Mankind; for whilst the historical evidence of actual change in them is so incomplete, as well as so limited in its range, as to be quite inadequate of itself to establish their community of descent, yet when that evidence is considered in its relations to analogous facts drawn from the far greater variations of domesticated animals, and to the manifold gradations by which the extreme types are connected, physiologists of the highest eminence have felt themselves justified in accepting that community as probable. Now the modifications which any single type of Foraminifera must have undergone, to give origin to the whole series of diversified forms presented by that group, are not greater in comparison with those of which we have direct evidence, than are those which the advocate for the specific unity of the Human Races has no hesitation in assuming as the probable account of their present divergence.

This view of the case derives great force from the fact, which constitutes the special feature of interest which this group has for the Geologist, that there is strong reason to regard a large proportion of the existing Foraminifera as the *direct lineal descendants* of those of very ancient geological periods. This doctrine was first advanced by Prof. Ehrenberg in regard to a considerable number of Cretaceous forms; and has since been fully confirmed and extended as regards the Tertiary fauna by the admirable researches of Messrs. Rupert Jones and Parker on the Rhizopodal Fauna of the Mediterranean, as well as by my own comparison of the recent and fossil types of *Orbitolites*, *Orbiculina*, *Alveolina*, *Operculina*, and *Calcarina;* and it has been shown to be applicable also to the Secondary fauna, as far back as the upper part of the Triassic system, by the remarkable results of the investigations of my coadjutors in regard to a well-preserved sample of it.

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

In applying the results of the foregoing inquiry to the Animal Kingdom generally, it may be at once conceded that no other group affords anything like the same evidence, on the one hand of the derivation of a multitude of distinguishable forms from a few primitive types, and on the other of the continuity of those types through a vast succession of geological epochs. But a nearly parallel case, as regards the first of these points, is presented by certain of the humbler groups of the Vegetable Kingdom; in which it is becoming more and more apparent, from the careful study of their life-history, not only that their range of variation is extremely wide, but that a large number of reputed genera and species have been erected on no better foundation than that afforded by the transitory phases of types hitherto known only in their states of more advanced development. It would be very unreasonable to put aside these cases as so far exceptional, that no inferences founded upon them can have any application to the higher forms of Animal and Vegetable life. For it is only in the *extent* of their range of variation, that *Foraminifera* and *Protophyta* differ from *Vertebrata* and *Phanerogamia*; and the main principle which must be taken as the basis of the systematic arrangement of the former groups—that of ascertaining the range of variation by an extensive comparison of individual forms—is one which finds its application in every department of Natural History, and is now recognised and acted on by all the most eminent Botanists, Zoologists, and Palæontologists.

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

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

II. The ordinary notion of *species*, as assemblages of individuals marked out from each other by definite characters that have been genetically transmitted from original prototypes similarly distinguished, is quite inapplicable to this group; since even if the limits of such assemblages were extended so as to include what would elsewhere be accounted genera, they would still be found so intimately connected by gradational links, that definite lines of demarcation could not be drawn between them.

III. The only natural classification of the vast aggregate of diversified forms which this group contains, will be one which ranges them according to their direction and degree of divergence from a small number of principal family-types; and any subordinate groupings of genera and species which may be adopted for the convenience of description and nomenclature, must be regarded merely as assemblages of forms 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.

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

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

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

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

VIII. As it is the aim of the Physical Philosopher to determine "what are the fewest and simplest assumptions, which being granted, the whole existing order of nature would result,"* so the aim of the Philosophic Naturalist should be to determine how small a number of primitive types may be reasonably supposed to have given origin by the ordinary course of "descent with modification" to the vast multitude of diversified forms that have peopled the globe during the long succession of geological ages, and constitute its present Fauna and Flora.

* Mill's 'Logic,' 3rd edition, vol. i, p. 327.

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INTRODUCTION TO THE STUDY

OF THE

FORAMINIFERA.

CHAPTER I.

HISTORICAL SUMMARY.

The group of Animals now generally known under the designation **Foraminifera** has only of late received even a small measure of that attention which it is entitled to claim, no less in virtue of its physiological interest, than on account of its zoological and its geological importance. It is true that of the minute polythalamous shells of which the group is for the most part composed, many forms have long been familiar to those Testaceologists who did not limit their attention to the larger shells of ordinary Mollusks; but the strong resemblance which many of them bear to the polythalamous shells of the *Nautilus*, *Orthoceras*, &c., led to a general belief that the former belong to animals closely allied in structure to those which produce the latter. Hence Foraminifera were in the first instance ranked as minute forms of *Nautili*: and although a larger acquaintance with their varied forms, and a more exact appreciation of the differential characters of these, led to the institution of a considerable number of new genera for their reception, yet their title to constitute a distinct and peculiar group was not recognised until the year 1825, when it was pointed out by M. D'Orbigny that, whilst the larger polythalamous shells have their septa traversed by a continuous tube or *siphon*, usually membranous, but sometimes shelly, the chambers of these minuter forms communicate by simple *foramina* in the septa which divide them—a difference on which he founded his primary division of the class Cephalopoda into two orders, the *Siphonifera* and the *Foraminifera*. Although, as will presently appear, the latter of these titles was conferred under an entire misconception of the character of the organisms to which it was applied, yet it has continued to be that under which they have been since most generally known, none more appropriate having been yet proposed; and there can be no doubt that M. D'Orbigny's limitation and designation of the group has had a most important influence in promoting that more special study which it has since received, and of which the results are found to possess an interest and importance that bear no proportion to the apparent insignificance of the objects which have furnished them, but are derived from their bearing on the highest and most recondite problems of Physiology and of the Philosophy of Classification.

The history of our knowledge of FORAMINIFERA* may be divided into four periods.

The *first* includes all the observations made and published in regard to them, from the time when they first attracted attention, down to the date when they were grouped together by D'Orbigny as constituting a distinct type of structure. Among the earlier authors in whose works notices of them are to be found, it may be well specially to mention Plancus (LXXXIII), Gualtieri (LI), Ledermüller (LXI), Spengler (CII), Gronovius (L), and Schröter (XCV, XCVI); as it was on the figures and descriptions of the first three that Linnæus founded the accounts of the fifteen species which he admitted into the twelfth edition† of his 'Systema Naturæ' (LXIII), and on those of the last three that Gmelin based the seven additional species which he added in the edition of the same work (XLVIII) published by him in 1788. Nearly all these species, whether straight, curved, or spiral, were ranged under the genus *Nautilus*; one only (*Miliola seminulum*) of those enumerated by Linnæus, and another (*Lituola nautiloides*) of those added by Gmelin, having been referred by them to the genus *Serpula*. It is worthy of notice that the tendency to variation so strikingly exhibited by the shells of this group was clearly perceived by Linnæus; who, instead of erecting every well-marked variety into a separate species (as certain of his followers have done), endeavoured to fix upon the most characteristic variety, and invested it with the appropriate specific name, differentiating other varieties by some mark, number, or subordinate designation. The descriptions given by Linnæus and Gmelin, though sufficient to distinguish the few types to which they apply, either from each other or from the polythalamous Testacea with which they were associated, would not now serve to distinguish them from the numerous allied forms which have since become known; but by an examination of the original figures and descriptions given by the authors from whom those systematists derived their information, Messrs. Parker and Rupert Jones (LXXVI) have succeeded in identifying each of the forms to which they gave specific designations, and have indicated their characters in accordance with the present state of our knowledge of the group.

The next important contribution to our knowledge of Foraminifera was made by Messrs. Boys and Walker, in their work (IX) on the minute shells found in the sand in Sandwich Bay and its neighbourhood, the descriptions being by Jacob, and the drawings by Walker, from specimens collected by Boys. An account of this work having been already given in Prof. Williamson's monograph (CX, Introduction, pp. vi), it will be sufficient here to remark that (as Messrs. Parker and Rupert Jones have pointed out), amongst the Foraminifera which they

* I have thought it advisable to limit my historical summary to the most important among the many contributions to our existing knowledge of the group. A far more minute history, in regard to *Nummulites* and their allies, is given by MM. D'Archiac and Haime in their 'Monographie des Nummulites' (I). And in Professor Williamson's 'Recent Foraminifera of Great Britain' (to which valuable Monograph an excellent Bibliography is appended) special notice is taken of all who have contributed to our knowledge of this department of the British Fauna.

† "Previous editions," says Professor Williamson, "contained the *Polythalamia* ('Nautili') enumerated by other writers; but in the ninth, Linnæus separates them into species, in the tenth he gives them specific names, and in the twelfth he attaches to them the synonyms of other authors."

enumerated are some fossil types that must have been washed by the action of the sea and of the streams from the neighbouring tertiary clays and sands, and thus have been mixed with the recent shells in the mud and sands of the coast. The twenty-two forms which they characterised as distinct species were for the most part referred by them to the genera *Nautilus* and *Serpula;* but it is a curious exemplification of the ignorance then prevailing as to the true characters of the lower tribes of animals, that *Globigerina bulloides* should actually have been referred by them to the genus *Echinus*, under the name of *E. lobatulus*. All the forms recorded by these authors have been identified by the pains-taking inquiries of Messrs. Parker and Rupert Jones (LXXVII).

By far the most elaborate of all the older contributions to the study of Foraminifera were contained in the works of Soldani (C, CI) on the recent and fossil shells of the Mediterranean and its shores. These works, the product of long-continued and careful research, added very largely to the knowledge previously existing of the microzoic forms belonging to this group, of which a vast number (many of them only entitled to rank as varieties) are figured, usually with such accuracy as to admit of being at once recognised; but from the binomial nomenclature not having been adopted by the author, his materials were not rendered so available as they might have been to subsequent systematists, and many of the types well figured and described by him have received a multitude of synonyms at the hands of his successors.

The British Foraminifera soon afterwards underwent a new scrutiny on the part of a most able conchologist, Colonel Montagu, who, in his 'Testacea Britannica' and its Supplement (LXV), enumerated thirty-six species—the chief addition to those of Boys and Walker being from the *Milioline* group, several species of which he described under the generic designation *Vermiculum*, associating with them under the same designation several species of *Lagena* and *Entosolenia*. It is evident that Montagu was much perplexed by the difficulty of defining the limits of species in this group; for in describing his *Vermiculum intortum* (now known as one of the varieties of *Miliola seminulum*) he distinctly states that this is so variable in its formation that without great attention it might be formed into several species. Yet, notwithstanding the warning he might hence have drawn, he was unable to follow the authors next to be noticed in their comprehensive grouping of widely divergent varieties; for when speaking in his Supplement of the numerous forms of *Nautilus* (*Cristellaria*) *calcar* delineated by MM. Fichtel and Moll, he remarks—"If these can be admitted to be the same species, we may bid defiance to specific definition." The species described by Montagu have all been identified by Messrs. Parker and Rupert Jones (LXXVII).

Contemporaneously with the first publication of Montagu, a most important treatise by MM. Fichtel and Moll, specially devoted to the minute Polythalamia (XLV), appeared at Vienna. This treatise formed but a portion of a much larger work, which would have been brought out by its authors if they had received sufficient encouragement to do so; and it includes only those forms which they ranked under the genus *Nautilus*. These—unlike the forms described in the works of Walker and Montagu, which are, for the most part, dwarfed by their northern habitats—are, generally speaking, large, well-grown specific types, mostly from the Mediterranean area, but partly also from the Red Sea; and they are so carefully described, and so admirably figured, that the work will always remain a valuable standard of reference in regard to the forms of which it treats. Its authors appear to have been strongly impressed with the difficulty of defining species in this group, and they revert to the Linnean principle of seizing what appeared to be the most characteristic variety, and distinguishing it by the specific name, whilst they designate the rest by the addition of Greek letters. In this manner they differentiated no fewer than twelve varieties of *Nautilus* (*Cristellaria*) *calcar*, five of *Nautilus* (*Calcarina*) *Spengleri*, five of *Nautilus* (*Cristellaria*) *cassis*, five of *Nautilus* (*Nummulina*) *lenticularis*, three of *Nautilus* (*Peneroplis*) *planatus*, and two of several other species. Still they were so far trammelled by the notion of the Cephalopodous character of these Polythalamia, that they did not advance nearly as far in this direction as there now seems good reason for doing. It was their great merit, however, to have recognised the difficulty which presents itself whenever large numbers of these forms are brought together, instead of evading it by selecting their specific types, and then putting aside, as of no account, all which do not conform to them, after the manner of certain other systematists. The species described in the work of Fichtel and Moll have been critically studied with their usual care, and their present appellations given, by Messrs. Parker and Rupert Jones (LXXVIII).

At the same period, Lamarck was engaged in the study of the fossil Foraminifera which are so abundantly found in the *Calcaire Grossier* and other Eocene beds of France, especially in the neighbourhood of Paris. These he described and figured, for the most part, as Cephalopods, but in some instances as Corals, in his series of Memoirs on the Invertebrated Animals found in a fossil state in the vicinity of Paris (LVIII); and he subsequently repeated these descriptions and figures in his contribution (LIX) to the 'Tableau Encyclopédique et Méthodique,' with others derived from the works of preceding authors, and especially from that of MM. Fichtel and Moll. In the original edition of his great systematic treatise on Invertebrate animals (LX), Lamarck repeated his specific descriptions of the foregoing types, with some slight additions, and he distributed them under generic assemblages, many of which he then first introduced. Although these new genera were created under a total misapprehension of the true nature of the group, and were by no means satisfactorily defined, yet many of them (such as *Nodosaria*, *Cristellaria*, *Rotalia*, *Nummulites*, *Polystomella*, *Orbitolites*, and *Orbiculina*) were truly natural, and have been retained in all subsequent classifications. The species enumerated by Lamarck have been critically examined and identified by Messrs. Parker and Rupert Jones (LXXIX).

A very different appreciation of the value of characters was shown by Denys de Montfort, who introduced into his systematic and illustrated treatise on Conchology (LXVII) descriptions and figures of several of the minute shells now ranked as Foraminifera, stating in his introduction that he was far from pretending to have given all their genera, but that he aimed at making some, at least, of their singular forms known to naturalists. To this end he selected several of the types figured and described by Soldani and by Fichtel and Moll, and added others from his own collection, distributing the whole according to his own notions. His delineations of them, however, are of the rudest and most inaccurate character, and his descriptions are no less erroneous, whilst his systematic arrangement displays the worst form of the worst school of naturalists,—varieties being erected, not only into species, but even into genera, upon the slenderest possible basis of difference, and without the least regard to the constancy of the characters assumed for their definition. And thus it has come to pass that out of about sixty new generic names introduced by De Montfort, only a single one, *Peneroplis*, has been adopted by subsequent writers, until I found reason to accept another, *Tinoporus*, as having been recognised by him as a distinct generic type, though he entirely misapprehended its nature. The forms described by De Montfort have been identified and referred to their proper synonyms by Messrs. Parker and Rupert Jones (LXXX).

It would not be right to pass by the labours of MM. Blainville and Defrance in the same field. In the articles which they contributed to the 'Dictionnaire des Sciences Naturelles' upon Mollusca and Zoophytes, fossil as well as recent, they gave an account of several new and important types of Foraminifera, without any correct appreciation, however, of their real nature.

The *second* period in the history of the group of which we are treating commences with the presentation to the Académie des Sciences, in 1825, of M. D'Orbigny's systematic arrangement of the Cephalopoda (LXIX), in which he first separated these chambered shells, under the title of FORAMINIFERA, from the Siphonifera; still retaining the former, however, like the latter, as an order of Cephalopods. The entire group of Foraminifera, as then known to him, consisting of none but multilocular shells, he subdivided into five orders, according to the geometrical plan on which the segments are successively added. In the first of these, *Stichostègues*, the segments are arranged end to end in a single line, straight or slightly curved. In the second, *Hélicostègues*, the segments are in like manner disposed end to end, but their common axis forms a spiral. In the third, *Enallostègues*, the segments are added alternately on the one and on the other side of the first, along two or even three distinct axes, which may be either straight or curved. In the fourth, *Entomostègues*, the segments are arranged on the like alternating plan, but the double axis forms a spiral, as in the Hélicostègues. In the fifth, *Agathistègues*, the successive segments cluster one over the other around a central axis, each segment forming half of the circumference. Each of these orders is subdivided into two families, according as the growth of the segments is equilateral or inequilateral. And the characters of the genera* (of which a large number were then first instituted by him) were based in part on the relation of the segments to one another, but chiefly on the number, form, and situation of the apertures of the last chamber. To the foregoing orders he subsequently added that of *Monostègues*, in which there is but a single chamber, and that of *Cyclostègues*, in which the segments are very numerous, and are arranged in concentric circles around that from which they originate.

No suspicion appears at that time to have crossed the mind of M. D'Orbigny, that the place of these organisms might be amongst the lowest, instead of among the highest, of the Invertebrata; and if his determination of their Molluscous nature was based on any actual observations of these animals in their living state, it is certain that such observations must have been of the most superficial character. As his labours have contributed far more than those of all his predecessors put together, to the extension of our knowledge of the diversified forms belonging to this group, it was most unfortunate that they should have been commenced and carried on under the influence of views regarding the *value of characters* which have since been proved to be altogether erroneous.

A correct appreciation of the differences presented by the members of any natural group

* A set of models in plaster of Paris, representing on a large scale the generic and sub-generic types of these (so-called) microscopic Cephalopods, was issued by M. D'Orbigny about the same time; and these have proved very useful in the determination of specimens, whose place in his classification could not readily be ascertained from his descriptions.

can only be based on the careful study of its own plan of organization and of the modifications which this shows itself disposed to undergo; and cannot be safely deduced by analogy from the study of any other group, however closely related. Least of all can any analogy be truly available, which is drawn from one of the highest groups of Invertebrate animals, and applied to one of the very simplest types of animal structure. Had the inquiries of M. D'Orbigny been conducted on a more philosophic method, he must have necessarily been led to the discovery, by the mere comparison of sufficient numbers of individuals, that this analogy is altogether fallacious, and that the *range of variation* among Foraminifera is so much greater than it is in any of the higher tribes of animals, as to render of no account among the former such differences as in the latter would be of even primary value. But his practice having been (as I have good authority for stating, and as clearly appears also from his results) to select, or to cause to be selected, out of any large assemblage of Foraminifera only the strongly differentiated types, and to leave the intermediate forms altogether out of view, his dominant misconception was not likely to undergo any modification in the course of his researches, and we find it still clinging to him even after he had been satisfied that the true place of this group is among the lowest instead of the highest of the Invertebrate series. Hence it follows that, notwithstanding the immense value and extent of M. D'Orbigny's contributions to this department of Zoology,—in the first place by having brought together the scattered components of the group of *Foraminifera*, and so differentiated it that it thenceforth took rank as a special object of zoological and physiological study; secondly, by having brought together from all quarters of the globe and from geological deposits of various periods a vast number of forms previously unknown; thirdly, by having so far investigated their characters as to be enabled to group them in generic assemblages, of which a considerable proportion are tolerably natural; and fourthly, by having furnished a classification which, although eminently artificial, is still preferable to the chaotic confusion in which they would have otherwise been left, and which has answered a useful purpose as a provisional arrangement,—there is scarcely any part of his work which is likely to stand the test of time and further research. For, as will hereafter appear, a large proportion of his species cannot be legitimately ranked higher than varieties, and many even of his genera must be brought down to the same level; whilst the basis of his primary and secondary subdivisions of the group is so unnatural, that it separates under distinct orders not a few types which have the closest mutual affinity, and brings into near approximation others which ought to be no less widely differentiated. It will be sufficient here to remark that it is now clearly established that the very same type may develope itself either as a *Stichostègue*, along a straight or slightly curved axis, or as a *Hélicostègue*, along a spiral axis; and that certain of the *Cyclostègue* order are generically, if not specifically, identical with certain *Hélicostègues*. Some suspicion, indeed, of the unsoundness of his fundamental assumption that the geometrical plan of increase is a character of primary value, appears to have crossed the mind of M. D'Orbigny; for he admits (LXXIII, p. 17) that affinities exist among all the orders, which arise out of a change in the plan of growth that is liable to occur in many types with the advance of life. This change he affirms (quite erroneously, as we shall hereafter see) to be always in the direction of simplification;—the more complicated or special mode of increase peculiar to the order giving place to one of a more general character, as where in a *Hélicostègue* the spiral extends itself as a straight line, or in an *Enallostègue* the alternating arrangement of the segments gives place to a uniserial direction of increase.

The results of M. D'Orbigny's researches on Foraminifera are for the most part recorded in local Faunas. Thus he furnished to the great work of Ramon de la Sagra upon Cuba (XCII), an important article upon the Foraminifera of that island; a similar contribution to the account of the Canary Islands, by MM. Barker-Webb and Berthelot (V); and a description of the Foraminifera of South America to his own travels in that country (LXX). So, in his 'Faune de la Craie blanche de Paris' (LXXI) he described the Foraminifera of that deposit; and in a subsequent work on the fossil Foraminifera of the Tertiary Basin of Vienna (LXXIII) he took the opportunity afforded by the extraordinary richness of the collection he thence obtained through Baron Hauer, to give a general conspectus of the entire group as then known to him, at the same time expressing his entire change of opinion in regard to the nature of the animal by which the shells of the Foraminifera are formed. His latest views on the general classification of Foraminifera are contained in his 'Elementary Course of Palæontology and Geology' (LXXIV), wherein we find a description of all the generic types that occur fossil, to which the number of such as are only known at the present epoch bears an insignificant proportion. It is here that we meet for the first time with his order *Cyclostègues*, which includes only four genera;—*Orbitolites*, previously ranked among corals; *Cyclolina*, instituted by himself in 1837, but previously ranked among the *Hélicostègues*; with *Orbitolina* and *Orbitoides*, instituted by himself in 1847, but not previously introduced into his classification.

The *third* period, with which our knowledge of the true nature of the Foraminifera really commenced, is inagurated by the discovery, first announced by M. Dujardin to the Académie des Sciences in June, 1835, of the *Rhizopod* type of structure (XXXIII), which was followed by the demonstration of the essential identity between the *Amœba* and other simple fresh-water Rhizopods (described by Prof. Ehrenberg among the Polygastric Animalcules) and the *Cristellaria* and similar composite forms of marine Foraminifera which had been previously ranked among Cephalopod Mollusks (XXXIV). The general results of M. Dujardin's observations were, that the animal body consists, alike in the naked and in the testaceous Rhizopods, of a mass of *sarcode*, a gelatinous, somewhat granular substance, not enclosed in a distinct membrane, and capable of extending itself into threads of extreme tenuity; that there is neither mouth nor digestive cavity, but that alimentary particles, received into the very substance of the body, are gradually incorporated with it; and that both the introduction of these particles and the movements of locomotion are effected by means of pseudopodial prolongations of the *sarcode*, put forth in the testaceous forms through apertures in the shell, and capable, when retracted again, of coalescing with the general mass. In the case of the composite forms, he considered the entire animal to be made up of a series of segments which are essentially repetitions one of another, each possessing an independent vitality of its own (XXXVI). He seems to have continued for some time, however, in uncertainty as to the extent to which this description of the animal would be applicable to all the bodies ranked by M. D'Orbigny among the Foraminifera; as we find appended to the names of several of those described by him in the 'Dictionnaire Universelle d'Histoire Naturelle' (as *Nonionina*, *Nummulites*, and *Rotalia*) the abbreviation *Moll.?* as well as *Foram.*

In the article '*Foraminifères*' contributed by M. D'Orbigny in 1844 to the same Dictionary (LXXII), he altogether abandoned the notion of the Cephalopod affinities of the group (without giving the least hint that he had ever himself entertained it), and described the structure of the animal in a manner which showed that he accepted M. Dujardin's account of it, though without the least reference to the real discoverer of its Rhizopod character. He assigned to the group a place among the Radiata of Cuvier, intermediate between the Echinodermata and the Polypifera, on no other grounds, as it would appear, than a fancied analogy between the pseudopodia issuing through the pores of the shell and the ambulacral cirrhi of an *Asterias*, and between those put forth from the aperture of the last chamber and the oral tentacles of a *Hydra*. This account is repeated *verbatim* in his subsequent work on the 'Fossil Foraminifera of the Vienna Basin' (LXXIII).

It cannot but seem surprising that, notwithstanding the light thrown upon the inquiry by M. Dujardin in 1835, Prof. Ehrenberg should in 1838 have announced to the Berlin Academy his conclusion, professedly based on observations of certain forms of these animals in their living state, that their true place in the animal kingdom is among the *Bryozoa* (XXXIX). He described them as possessing a distinct alimentary canal, which extends from segment to segment; this, however, instead of being single, as in *Nonionina*, may (he tells us) be multiple, as in *Geoponus;* so that we must regard each segment of the latter, however apparently resembling the simple segment of the former, as in reality composed of several adhering bodies. In one instance (he affirms) he found the mouth surrounded by a plumose sensory and prehensile apparatus, like that of the *Flustræ* and *Halcyonellæ;* but, generally speaking, he admits that this is altogether wanting, the mouth being a simple aperture. He saw minute extensile tentacula proceeding from all parts of the sieve-like shell, as described by Dujardin, and admitted their resemblance to the pseudopodia of *Difflugia*, &c.; but he remarks, "the rest of their organization, which Dujardin has overlooked, removes them from the Infusoria quite as far as from a chaotic primitive substance." Besides the alimentary canal, Prof. Ehrenberg described a yellowish-brown granular mass as accompanying and sometimes surrounding it up to the last of the spirals; this he considered as an ovary (XL).—To these views he has lately expressed his continued adhesion (XLIV), notwithstanding their complete inconsistency with the results of all the more recent and trustworthy observations upon the structure of Foraminifera; and he has contested those of Prof. Schultze in particular with an irritation and tenacity difficult to reconcile with the single-minded devotion to truth which a Naturalist who has rendered such services to science might be expected to manifest.*

Our appreciation of the value of the characters afforded by the form, position, and multiplication of the apertures of communication between the chambers of the shell, must obviously differ essentially, according as we suppose these to give passage to an organ of such fundamental importance as an alimentary canal, or regard them as merely serving for the connexion of the different segments by *stolons* of sarcode. For variations which in the former case must be regarded as indicative of such essential differences, both in structure and function, as would rightly characterise distinct genera or even distinct families, may easily be admitted on the latter view to be of such comparatively trivial moment as to rank no higher than specific characters, or perhaps even to be matters of individual difference. As I have already pointed out, the essential importance of this consideration was altogether disregarded

* The Classification of Foraminifera based by Professor Ehrenberg upon views so erroneous, could not be expected to replace that which was previously in vogue; and as it is now seldom or never referred to save as a matter of historical interest, there is no occasion to discuss its demerits in detail.

by M. D'Orbigny; and the influence of his doctrines upon those who interested themselves in the extension of this department of inquiry was for a long time such, as to prevent any other progress than that which consisted in the discovery of new forms from time to time, and in the reference of these to their places in his classification.

It was in the year 1839 that Prof. Ehrenberg announced to the Berlin Academy the remarkable results which he had obtained from the study of the Chalk formation; a large proportion of the material of which he affirmed to consist of the shells, either entire or comminuted, of Foraminifera; whilst among the types sufficiently well preserved to admit of being determined, he showed that as many as ten could be identified with species now existing (XL).

The commencement of that *fourth* period in which the discovery of M. Dujardin has received its full recognition, may be regarded as dating from the appearance of two Memoirs published by Prof. W. C. Williamson (of Manchester) in 1847 and 1848. In the former of these, which was a Monograph of the genus *Lagena* (CVI), the important truth was for the first time formally advanced in regard to this type, that the comparison of a sufficiently large number of individuals would bring to light such a gradational transition from one supposed species to another, as to demonstrate that their differences must be accounted as of individual variation only; a truth which has since been not only most fully confirmed by the demonstration of its applicability to the reputed species of every genus of Foraminifera that has been worked out with similar completeness, but has been found capable of extension to many generic and even to some ordinal differences. The latter was a communication to the Microscopical Society, on the structure of the shell and animal of *Polystomella crispa* (CVII), in which for the first time were given the results of a minute microscopical investigation of thin transparent sections of the Shells of Foraminifera, and which must consequently be regarded as having furnished the starting-point for all future investigations of a like kind. Among the facts revealed by this method of research were several that became of essential value to myself, in the inquiry on which I was engaged at the same time in regard to the structure of *Nummulites* (XII), and served to confirm the inferences I had deduced from the other features of that important type, as to its participation in the characters of the Foraminifera generally. In the course of that inquiry I made the discovery, not only of an elaborate and previously unsuspected structure in the shell itself, but also of a system of canals, by which it is traversed, and which seems to have an important function in its nutrition. The subsequent examination of the minute structure of the shells of numerous recent types by Prof. Williamson (CVIII, CIX), Mr. Carter (XVIII—XXI), and myself (XIII—XVI), has not only added greatly to our knowledge of the distribution and purposes of this canal-system, but has led to a much more correct appreciation than was previously attainable of the value of the several differential characters presented by the respective types; and a sound basis has thus been furnished for a truly natural classification, which cannot, however, be erected otherwise than provisionally, until the same kind of investigation shall have been carried through a much wider range of types.

Among the most important of the recent contributions to our knowledge of the organization and life-history of the Foraminifera, must unquestionably be ranked the treatise published by Prof. Max Schultze in 1854 (XCVII). The author has enjoyed the opportunity of studying several typical forms of the group in their living state, and has most carefully described and most beautifully delineated the remarkable phenomena which they present. His observations, which fully confirm and supplement those of M. Dujardin, at present constitute our best source of knowledge on this part of the subject; and they have since been extended by further researches (XCVIII, XCIX), especially in regard to the Reproductive processes, which still, however, greatly need elucidation. In his investigations of the structure of the testaceous coverings of these animals, on the other hand, Prof. Schultze has been less successful, in consequence (as it would appear) of his want of acquaintance with the best method of preparing thin sections of them; and he has consequently fallen into some important errors (such as the denial of the existence of the canal-system, of which the most perfect demonstration is now afforded by the examination of the internal casts of these organisms, to be presently noticed), and has failed to obtain that insight into the real relations of the forms he has studied, which could alone justify him in proposing a new distribution of the group. Although his Classification is in many respects an improvement upon that of M. D'Orbigny, yet (as I think I shall hereafter succeed in showing) it is so far from satisfactory as to leave the way quite open for another attempt, based upon a more thorough knowledge of the objects to be systematically grouped.

A Classification still more recently proposed by Prof. Bronn (XI) is chiefly founded upon that of M. D'Orbigny, whilst it adopts certain modifications proposed by Prof. Schultze. It cannot, in my opinion, be regarded as less open to objection than either of the systems for which it is proposed as a substitute.

An entirely new and most valuable source of information in regard to the organization of the Foraminifera has recently been afforded by the discovery, first announced by Prof. Ehrenberg (XLIII) in 1853, that their shells occasionally undergo an infiltration of silicate of iron, that completely fills, not merely their chambers, but their canal-system, even to its minutest ramifications; so that if a shell thus infiltrated should itself undergo decomposition, a perfect internal cast remains of the original body of the animal, with its extensions throughout the shell. Of such casts it has been shown by Prof. Ehrenberg that the Green Sands which present themselves in various geological formations, from the Silurian system upwards, are in great part composed: and his discovery has thus a twofold value, as, on the one hand, it places before us far more exact representations of the configuration of the animal body, and of the connexions of its different parts, than we could obtain even from living specimens by dissolving away their shells with acid (its several portions being disposed to heap themselves together in a mass when they lose the support of the calcareous skeleton); whilst it also enables us to identify with great certainty the types of Foraminifera by which these casts were originally formed, notwithstanding the entire destruction of their shells. It was soon afterwards shown by Prof. Bailey (U. S.) that a like process of infiltration is taking place at the present time over certain parts of the ocean-bottom (III), and that beautiful internal casts are obtainable by treating with dilute acid Foraminiferous shells whose cavities have thus filled. By the application of this method to portions of Mr. Jukes's Australian dredgings, Messrs. W. K. Parker and T. Rupert Jones have obtained a series of internal casts of most wonderful beauty and completeness, which I have had the advantage of carefully examining; and it is with great satisfaction that I can state that in no instance has this examination afforded any other result, than that of confirming the conclusions to which I had been previously led by the study of the shell.

A very different line of inquiry has been recently prosecuted with great success by the same careful and diligent observers—that of the comparison of large numbers of individuals presenting gradational modifications of the same fundamental types; a method first applied by Prof. Williamson to *Lagena*, and afterwards by myself to *Orbitolites*, *Orbiculina*, *Peneroplis*, *Operculina*, and *Calcarina*. The particular results to which they have been thus conducted will be detailed in their proper place; at present it will be sufficient to state that they have been led most fully to accept the views of Prof. Williamson and myself in regard to the wide range of variation which prevails in the group of Foraminifera generally, and that they have given to those views a most remarkable development (LXXV—LXXX). The same observers are engaged upon an extensive comparison of the Foraminiferous Faunas of different localities and epochs, with a view to elucidate the conditions that determine the prevalence of particular types. Of this comparison the results already given to the world are replete with interest (LIV, LV, LXXXI).

CHAPTER II.

OF THE RHIZOPODA GENERALLY; THEIR ORGANIZATION AND PHYSIOLOGICAL HISTORY; AND THEIR DISTRIBUTION INTO SUBORDINATE GROUPS.

1. Neither the Morphological characters nor the Physiological history of the *Foraminifera*, nor their position in the Animal Kingdom, can be properly understood, without a preliminary survey of the entire Class of RHIZOPODA (of which they constitute by far the most important section), and an exposition of its most distinctive features as made known by modern research.

2. The Class of RHIZOPODA constitutes, with the Classes of PORIFERA (*Sponges*), INFUSORIA, and GREGARINIDA (to all which it is very intimately related), the Sub-Kingdom which Zoologists have now agreed to designate by the title PROTOZOA, indicative of the simplicity of its type of organization, or, as it might be almost said, its deficiency in any definite organization. In none of its members can any traces be found either of a nervous or of a muscular system; their digestive apparatus is reduced to its simplest possible condition; of a circulating system a mere rudiment only can be distinguished; special organs for respiration and excretion seem altogether wanting; and although there is reason to believe that true sexual products are formed by many of them, yet these develope themselves out of the general substance of the body, instead of in distinct organs set apart for their evolution. Yet, as will hereafter appear, these creatures perform all the functions which constitute in their aggregate the life-history of an Animal. They obtain food either by moving actively in search of it, or by putting forth prehensile appendages which bring it to them; they introduce their food into the interior of their bodies, and subject it to a process of digestion whereby its nutritive material is extracted from the indigestible residue, which is cast forth by an act of defecation; they diffuse this material through the general substance of the body, both by the general movements of its walls, and by the agency of what seems to be a special contractile organ; and they apply it to the augmentation of their own bodies by growth, and to the propagation of their race by reproductive operations of various kinds.

3. As less differentiation of parts exists among RHIZOPODA than in either of the other classes, and as the beings of which that class is composed may be considered as exhibiting the distinctive attributes of Animal life in their least specialised condition, its place is obviously at the bottom of the series. In fact, a state of greater simplification can scarcely be conceived to exist in any living organism, than that which is presented by the creatures

which present the most characteristic types of the group, such, for example, as the *Actinophrys.*

4. The designation of this Class (first conferred by M. Dujardin, XXXIII, in 1835, upon a portion of the animals now included in it, which he ranked only as a family of *Infusoria*) is founded upon the power just referred to, which is possessed by all the members of it in a greater or less degree, of putting forth indefinite extensions of the substance of the body,—sometimes short, broad, and rounded—sometimes longer, slenderer, and gradually tapering to a point—sometimes immensely elongated, and narrowed to threads of extreme tenuity,—which are continually varying both in number, form, and dimensions, and which can be altogether retracted, so as to become incorporated again with the body-substance. These diverging processes, termed *pseudopodia*, are used in some instances merely for the prehension of food; in some cases, again, their primary office is to move the body from place to place in search of aliment; whilst, in another set of cases, they seem to be subservient to both functions: and as they bear some resemblance on the one side to the ramifying roots of a tree, on the other to the feet or locomotive appendages of higher animals, the term RHIZOPODA, or "root-footed," applied to the class of creatures of which their presence is so distinctive a characteristic, is by no means unexpressive.

5. The soft and almost homogeneous substance of which the body of these animals is composed, received from M. Dujardin the designation *sarcode*, or rudimentary flesh; and this designation may be conveniently used, if it be duly kept in mind that "sarcode" is not a substance *sui generis*, but is nothing else than the *protoplasm** in which every form of animal structure has its origin, and from which it is evolved by a process of gradual differentiation. This substance is composed of an albuminoid base, with oil-particles in a state of very fine division diffused through it; it is tenacious, extensible, and contractile; it is diaphanous, reflecting light rather more than water but less than oil; and it is dissolved by alkalies (the aid of heat being necessary if a weak solution be used), rendered perfectly transparent by acetic acid, and dyed brown by iodine. In the midst of this substance are usually to be seen *vacuoles*, or cavities, containing a thinner fluid, which is often coloured; these are extremely variable, both in number and size, and their deficiency in any definite limiting walls is rendered obvious by their not unfrequent coalescence.† There may generally be observed, in the bodies of *Rhizopods*, some differentiation between their central and their peripheral portion; the substance of the latter being the more pellucid, consistent, and motile, whilst

* That the "sarcode" of Dujardin is nothing more nor less than *animal protoplasm* not yet differentiated into cell-wall and cell-contents—a doctrine which has recently been put forth as new by Professor Schultze (XCIX),—was distinctly stated by the Author in 1856 (see his Manual entitled 'The Microscope and its Revelations,' chap. IX).

† These "vacuoles," which commonly form themselves around the particles taken in as food, were mistaken by Professor Ehrenberg under the influence of his "polygastric" hypothesis, for multiple stomachs, each having its own proper wall, and opening into a common alimentary canal, which commences and terminates by a definite orifice. This notion, as will hereafter appear, is altogether ideal, and is utterly inconsistent with the real facts of the case.

that of the former contains a much larger proportion of the granules and vacuoles, and seems less endowed with self-activity, though very easily put into passive motion. This differentiation, which is sometimes scarcely perceptible, in other cases proceeds so far that the coloured, granular, vacuolated sarcode is surrounded by a perfectly transparent envelope; and the two portions thus distinguished may be appropriately designated (after Dr. Strethill Wright) as the *endosarc* and the *ectosarc*.

6. In the cases in which this differentation has proceeded furthest, so that the body of the Rhizopod bears the strongest resemblance to an ordinary "cell" (as is the case with *Amœba* and its allies (¶ 21), a *nucleus* may be distinctly traced; in those, on the other hand, in which the original protoplasmic condition is most completely retained (as seems to be the case with *Gromia*, and with the *Foraminifera* generally), no nucleus can be distinguished. The same appears to be true of the peculiar *contractile vesicle*, which may be regarded as a vacuole with a defined wall; for this seems to be always present in the "ectosarc" of those Rhizopods which have that portion of the body most differentiated from the "endosarc," whilst it cannot be traced in the more homogeneous bodies of such as possess no nucleus. In certain Rhizopods belonging to the former category, the body of each individual contains several nuclei, as well as several contractile vesicles; and thus, as Prof. Schultze has pointed out (XCIX, pp. 315—9), it may be regarded as formed by an aggregation of what would, if still more completely differentiated, have constituted so many distinct cells. In the highest of these composite forms (¶ 20), indeed, it seems probable that complete cells may be developed in the peripheral portion of the body, whilst its interior retains the condition of homogeneous protoplasm.

7. In a large proportion of Rhizopods the body has the power of forming upon its surface a firm, testaceous envelope. This, in some instances, appears to be wholly composed of an organic substance resembling *chitine*: but in general it is either siliceous, as in the *Polycystina*, or calcareous, as in the *Foraminifera*, the mineral constituent in each case being combined with an organic basis-substance. In certain of the last-named group (¶ 60) the calcareous constituent is wanting, and the "test" is composed of foreign particles, so regularly arranged and cemented together as to give it the shape and general aspect of one formed on the ordinary plan. The ordinary "tests" of *Polycystina* and *Foraminifera*, like the *loricæ* of Diatomaceæ, must be regarded as generated by a kind of excretion from the surface of the body; and although the elaborate structure of those of the most highly organized *Foraminifera* might seem, at first sight, to indicate a less simple origin, yet it will be hereafter shown to be readily explicable according to that view (¶ 59). There are Rhizopods, on the other hand, in which the body, instead of being invested with a silicified "test," is strengthened by siliceous spicules diffused through its substance; and as there is evidence that in certain cases (¶ 18) such spicules are formed by an excretion-process around pseudopodial prolongations of the sarcode, it is probable that this is the general fact, more especially as Mr. Bowerbank has shown (VIII, p. 282) that the spicules of Sponges have originally a cavity in their interior, which is occupied by soft animal substance.

8. The subdivision of this Class into Orders seems (in the opinion of the author) to be most satisfactorily accomplished, by taking as a basis those structural characters which are most expressive of physiological differences. Such characters are presented in the form,

proportions, and general arrangement of the pseudopodial extensions; for, notwithstanding their apparently unrestricted *polymorphism*, it will be found that Rhizopods present three very distinct types of pseudopodian conformation, to one or other of which they may all be referred, and that the groups thus formed are eminently natural. How intimately related these diversities are to those fundamental *potentialities* of each type which find so little structural expression in this lowest form of animal life, appears from the circumstance that even a particle of protoplasm detached from the general mass of the body will put forth the pseudopodian extensions characteristic of its type; those of the substance forced out by crushing the "test" of an *Arcella* (Plate I, fig. 19), having the broad, lobated form of those of the *Amœba*, whilst those of the substance forced out in like manner by crushing the shell of a *Polystomella* (Plate IV, fig. 12) have the delicate, thread-like character of those of the Foraminifera generally.

9. In *Actinophrys* and its allies (Plate I, figs. 1—6), which may be considered as constituting the central or typical group of Rhizopods, the *pseudopodia* are very numerous, and, when fully extended, are long, slender processes, that gradually taper from base to point, and issue from the body in a radial direction; they generally remain distinct when they come into mutual contact, never undergoing that complete fusion which is common in those of Foraminifera; and a slow movement of granules may be seen to take place along their margin, when the observation is continued for a sufficient length of time under high magnifying powers. The differentiation between the central and the peripheral portions of the body is such as to mark out the "endosarc" and the "ectosarc" as, on the whole, distinct from each other, though no definite line of demarcation can be drawn between them.—With the family *Actinophryna*, which includes certain forms that possess a firm envelope over a larger or smaller portion of their surface, there seem to be associated, by their more or less complete conformity in the foregoing characters, the *Acanthometrina*, in which the body is supported by a regular framework of radiating siliceous spicules, the *Polycystina*, in which it is more or less completely encased in a siliceous "test," and the *Thalassicollina*, which, whilst apparently sometimes simple, are generally composed of aggregations of more or less fully differentiated cells, supported upon a framework of siliceous spicules. This last family obviously establishes the transition between the typical Rhizopods and Sponges. The four families now enumerated seem to constitute an eminently natural order, to which the designation RADIOLARIA proposed by Müller.* (LXVIII) is very appropriate.

10. In *Amœba* and its allies, which diverge from the typical Rhizopods in the direction of Gregarinida and Infusoria (both of which Classes contain forms that are scarcely distinguishable from it), the pseudopodial expansions are few, short, broad, and rounded (Plate I, figs. 15—20), seeming rather like lobate extensions of the body itself, than appendages pro-

* The *Rhizopoda Radiolaria* of Müller did not include the *Actinophryna*; and he separated them into two sub-orders, according as they are Simple or Composite—a distinction which does not appear to the author at all better founded than that according to which the Foraminifera are primarily divided into *Monothalamous* and *Polythalamous* (see ¶ 52). He is glad to find that the views of MM. Claparède and Lachmann, on this point, seem to be in accordance with his own; no notice being taken, in their classification of Rhizopoda (XXV, p. 434), of the families *Sphærozoa* and *Collosphæræ* established by Müller for the composite forms of *Thalassicollæ*.

ceeding from it. They are not put forth equally from any part of the surface, but only from some particular portion; and this portion, in some of the testaceous forms, is very narrowly restricted. They show no tendency to mutual cohesion; and the smoothness and sharp definition of their outlines makes it obvious that the surface-layer which they derive from the "ectosarc" possesses considerable consistence. No movement of granules is to be seen along their margins; but the larger pseudopodia receive prolongations from the general cavity of the body (formed by the vacuolation of the "endosarc"), into which its granular liquid contents freely pass when propelled by the contraction of the "ectosarc." The differentiation between the "ectosarc" and the "endosarc" here reaches its maximum; the former having almost the solidity of a definite membrane, whilst the particles contained in the latter move so readily upon one another as to show that its consistence is not even that of a viscous liquid. The increased tenacity of the "ectosarc" necessarily opposes the free entrance of alimentary substances through any part of the surface; and it is pretty certain that in some (at least) of the *Amœbina*, possibly in all, there is a special oral aperture.—This group contains testaceous as well as naked forms, which are all so closely related as to constitute but one natural order; and for these Rhizopoda the name Lobosa may be suggested, as expressing the lobe-like character of their pseudopodial extensions.*

11. In the *Foraminifera* and their allies, on the other hand, the characteristic features of the Rhizopod type are (so to speak) exaggerated. The pseudopodial extensions present no approach to definiteness, either in shape, size, or number (Plate II, Plate III, figs. 1, 2, 3). Sometimes they appear cylindrical, and sometimes form broad, flat bands; whilst they are often drawn into threads of such extreme tenuity as to require a high microscopic power for their discernment; they coalesce with each other so readily and completely, that no part of their substance can be regarded as having more than a viscous consistence; their margins are not defined by continuous lines, but are broken by the granules irregularly disposed along them, so that they appear as if torn; and these granules, when the animal is in a state of activity, are in continual movement, passing along the pseudopodia from one extremity to the other, or passing across the connecting threads from one pseudopodium to another, with considerable rapidity. In all these particulars they present, as Professor Schultze has pointed out (xcix, p. 314), a striking analogy to the protoplasmic layer of the interior of certain vegetable cells, such as those of the hairs of *Tradescantia*, which exhibit the aspect of an irregular network formed by the inosculation of threads that spring from the mass immediately surrounding the nucleus, and very closely resembling that which is formed by the pseudopodial extensions of the body of a *Lieberkühnia* (Plate II), or a *Gromia* (Plate III, fig. 2). And as it is along this protoplasmic network in the interior of the cells of *Tradescantia*, that the stream of granules moves which has so long attracted the attention of microscopic observers, there is strong reason to believe that this movement is due in both instances to the same agency—a sort of peristaltic contrac-

* By MM. Claparède and Lachmann (xxv, p. 434), the *Amœbina* and the *Actinophryna* are united into one Order, to which they give the name Proteina. The relationship of the latter, however, to the *Acanthometrina*, &c., seems to the author so intimate, whilst their differentiation from the *Amœbina* appears to him to be so decided, that he cannot hesitate in the belief that the arrangement he has here proposed is much the more natural.

tion in the threads of protoplasm. The low degree of differentiation in the protoplasmic substance of these Rhizopods is manifested, not merely in their pseudopodia, but also in the general mass of their bodies; for although the external portion is less granular and coloured than the internal, and is of somewhat firmer consistence, yet there is nothing like a definite distinction between ectosarc and endosarc, so that the departure from the original homogeneity of the sarcode is here reduced to its minimum. This low grade of differentiation is marked also by the absence of the "nucleus" and of the "contractile vesicle," neither of which organs has been yet detected in any members of this group. By far the larger proportion of the Rhizopods which agree in these general characters are enclosed in calcareous shells, which may be either monothalamous or polythalamous; and such constitute the group of *Foraminifera*. In certain cases, however, the "test" is simply membranous (as in *Gromia*, Plate III, fig. 2), or it may even be reduced to the condition of a very transparent film (as in *Lieberkühnia*, Plate II); and such forms are distinguished as *Gromida*. The physiological condition of all these beings appears to be so closely accordant, as fully to justify their being combined in a single Order, to which the name Reticulosa may be given, indicative of the reticulated character of its pseudopodian extensions. The mode of subdividing this Order will be the subject of discussion in the next Chapter.

According to the foregoing views, the Rhizopoda may be thus arranged:

RHIZOPODA.

Lobosa.	Radiolaria.	Reticulosa.
Amœbina.	*Actinophryna.*	*Gromida.*
	Acanthometrina.	*Foraminifera.*
	Polycystina.	
	Thalassicollina.	
INFUSORIA. GREGARINIDA.	SPONGIADA.	PROTOPHYTA.

Order RADIOLARIA.

12. Actinophryna.*—Commencing our more detailed consideration of these groups with the one which may be regarded as the most characteristic type of the entire series, we find a familiar representative of this in the well-known *Actinophrys* (Pl. I, figs. 1—4), a not uncommon inhabitant of collections of fresh water in which aquatic plants are growing, and sometimes also presenting itself in the sea. The form of its body usually approaches the spherical (fig. 1); but it is liable to modification, on the one hand, from the protrusion of the "contractile vesicle," *v*, when turgid, on the other, from the projection either of newly ingested food (fig. 2), or of particles that are about to be got rid of as indigestible. A still greater departure from the spherical form is seen when the *Actinophrys* is undergoing duplicative subdivision (figs. 3, 4). The average diameter of the body is from 1-1300th to 1-650th of an inch. From every part of its surface radiating *pseudopodia* extend themselves, usually exceeding in length the diameter of the body, and tapering gradually from base to apex, but sometimes swelling again at their extremities into enlargements resembling a pin's head. These pseudopodia, however, vary greatly both in number and in length; sometimes they are partially or almost entirely retracted (a change which may be induced by agitation of the water); and they may even disappear so completely, that the animal cannot be distinguished from an *Amœba* until they are again put forth. The endosarc is distinguished by the presence of granular particles, frequently coloured, which are mostly derived from the matters ingested as food; and by the nearer approach of its substance to the consistence of a viscid fluid, as is indicated by the movements of these granules. It also usually contains numerous "vacuoles," some of which are seen to contain the alimentary matters ingested by the animal, when it is examined soon after feeding. The ectosarc, on the other hand, is more pellucid and of firmer consistence, though not by any means attaining to the tenacity of a proper membranous envelope. There is, however, no definite line of division between the endosarc, and the ectosarc, the one graduating almost insensibly into the other; but it may be remarked, that the pseudopodia seem to be derived from the ectosarc alone, the endosarc not extending itself into them. They possess, moreover, a degree of consistence which usually prevents them from coalescing when they come into contact with one another; and whenever such a coalescence does take place, it is to a much smaller extent than is common among Foraminifera (¶¶ 32, 33). A circulation of granules may be seen by attentive observation to take place along the pseudopodia of *Actinophrys*; but it is far less active than that which constitutes so curious a feature in the life-history of the Foraminifera (¶ 34).

13. Although the existence of a "nucleus" in *Actinophrys* has been denied, its presence (in certain species, at least) must be regarded as a well-established fact.† It presents itself as a flattened vesicular body, with a well-defined margin, usually of circular outline, and very

* On this family, see xi, xxii, xxiv, xxv, xxvii, xxxvi, xxxviii, lvi, lxxxii, lxxxiv, ciii, cv.

† The term "nucleus" was improperly applied by Kölliker (lvi) to the dark granular substance which commonly occupies the central portion of the body. The existence of a true nucleus was

pellucid; and its central portion is occupied by an aggregation of granular particles, less defined at its margin, and less regular in shape. It may be brought into view either by crushing the body of the animalcule, or by the addition of dilute acetic acid. Its diameter bears a considerable proportion to that of the entire body, being (according to Stein,) in *A. oculata* almost one-third.

14. The *Actinophrys* seems to have little or no power of moving spontaneously from place to place: in that respect corresponding with the Foraminifera, but differing (as we shall see) from *Amœba*; and it obtains its food entirely through the instrumentality of its pseudopodia, which, by their peculiar adhesive property, attach themselves to bodies that come into contact with them. Not only motionless particles of Vegetable matter, but actively-moving *Infusoria*, *Rotifera*, and even small *Entomostraca* are thus entrapped. When the prey is large and vigorous enough to struggle to escape from its entanglement, it may usually be observed that the neighbouring pseudopodia bend over and apply themselves to the captive body, so as to assist in retaining it, and that it is slowly drawn by their joint retraction towards the body of the *Actinophrys*. In other cases, however, the captive seems as if it were paralysed by the contact of the pseudopodium, remaining motionless for some seconds, and then, without any visible movement of its captor, gliding either slowly or rapidly in a centripetal direction along the margin of the pseudopodium to which it adheres, until it becomes jammed, as it were, between the base of this and of a neighbouring one. It is usually, in fact, by thus gliding along the margin of the pseudopodium, as if propelled by an invisible peristaltic contraction of its sarcode, rather than by a visible retraction of the pseudopodium, that any small body not capable of offering active resistance is conveyed to its base. Now and then it seems as if the appetite of the *Actinophrys* were sated, or the prey not approved of; for after a few seconds the movements of the latter feebly recommence, and it glides off the pseudopodium without any effort on the part of the *Actinophrys* to retain it. When, on the other hand, the captive is to be used as food, it becomes invested by an expansion of the protoplasmic substance which the body of the *Actinophrys* sends forth on either side of that of the captive, so as to meet and inclose it; and thus a marked prominence is formed (fig. 2), which gradually subsides as the food is drawn more completely into the interior. There can be no doubt whatever that aliment may be thus ingested at any part of the surface, a new mouth, so to speak, being extemporized whenever and wherever there is occasion for it. The struggles of the larger animals, and the ciliary action of *Rotifera* and *Infusoria*, may sometimes be observed to continue even after they have been thus received into the body; but these movements at last cease, and the process of digestion then begins. The body taken-in as food is received into one of the "vacuoles" of the endosarc, where it lies in the first instance surrounded by liquid; and its alimentary portion is gradually converted into an undistinguishable gelatinous mass, which becomes incorporated with the parenchyma, as may be seen by the general diffusion of any colouring particles it may contain. Several vacuoles may be occupied at one time by alimentary morsels; frequently from four to eight are seen thus filled, and occasionally ten or twelve. Ehrenberg in one instance counted as

denied by Claparède in his earlier memoir upon *Actinophrys* (XXIV); but he has since admitted its presence, at least in *A. Eichornii* (XXV, p. 419).

many as sixteen. Whilst the digestive process, which usually occupies some hours, is going on, a sort of slow circulation takes place in the entire mass of the endosarc, with its included vacuoles. If, as often happens, the body taken-in as food possesses some hard indigestible portion (as the shell of an Entomostracan, or the lorica of a Rotifer), this, after the digestion of the soft parts, is gradually pushed towards the surface, and at last escapes by an anal opening in the ectosarc, which extemporises itself for the occasion. Sometimes it may be seen to glide along a pseudopodium from its base towards its apex, after the manner of an animalcule captured as food, but in a reverse direction.

15. When an *Actinophrys* is carefully observed for some little time, a rounded prominence is seen to rise slowly and gradually from a particular point on its surface (fig. 1, *a*), sometimes increasing until it attains in small individuals nearly one-third of the bulk of the entire body, but generally stopping at about one-eighth or one-tenth. The substance of this prominence is so extremely pellucid that it looks almost like a soap-bubble; and its margin is so well defined as to be more clearly distinguishable than that of the body generally. When it has attained its full size, it suddenly contracts and disappears entirely, so that a flattening of the outline is often observable at the point previously occupied by this remarkable elevation; the margin soon becomes rounded again, and gradually rises anew into a projection, which attains its previous highest development, and then suddenly disappears as before. This alternation of quick contraction and slow dilatation, which may be seen to go on with great regularity for many hours continuously, obviously marks this body to be a "contractile vesicle," analogous to that of *Infusoria*; and it is probable that (as may be clearly made out in certain forms of that group) the fluid propelled by its contractions is transmitted through channels in the protoplasma, some of which it distends into "vacuoles," whose contents, by a slow contraction of the substance in which they are excavated, are subsequently propelled back into the contractile vesicle. Sometimes the "vacuoles" approach the surface very closely, and may even form projections from it, so that they have been supposed to be multiple contractile vesicles. The true contractile vesicle, however, is distinguished by the constancy of its position, by its sharper outline, and by the rhythmical regularity of its alternating contractions and dilatations.

16. Of the reproduction of *Actinophrys* so little is at present certainly known, that it will be preferable to bring the observations which have been made upon it into connection with the similarly incomplete fragments of this portion of their life-history, which have been attained by the study of other types of Rhizopod structure (¶¶ 41, 43).

17. The several genera that rank with *Actinophrys* in the family ACTINOPHRYNA present its fundamental type of structure under various special modifications. Thus in *Trichodiscus* the body has the form of a flattened spheroid, and the pseudopodia do not radiate from all parts of its surface, but form a sort of zone round its equatorial region only. In *Plagiophrys*, again, the origin of the pseudopodia is still more limited, for they all pass off in a bundle from one and the same part of the body; and this restriction seems to be related to the investment of the body at other parts by a definite limiting membrane, which is still, however, very flexible. In *P. cylindrica* (Plate I, fig. 6), the body is elongated in form, and the pseudopodia issue

forth from one extremity, which is destitute of any membranous envelope; thus affording a transition towards such genera as *Euglypha* (fig. 5), in which the body is inclosed in a flask-shaped membranous "test," often elegantly sculptured on its surface, and having a wide orifice from which the pseudopodia are put forth.

18. ACANTHOMETRINA.*—The siliceous skeletons of the *Acathometrina*, which are all marine,† consist of a number of elongated spines, which meet in a common centre, and radiate from this with great regularity (Pl. I, fig. 7). These spines are hollow, and the canal by which each is traversed opens-out near its base into a furrow, by which a pseudopodian process of the body of the animal gains access to its interior, to issue forth again at its apex. There are, however, many pseudopodia not thus inclosed, which strongly resemble those of *Actinophrys* in their appearance and their action. The body is spherical in form, and occupies the spaces left between the bases of the spines, which in some species widen-out so much as to join each other by their edges at some distance from the centre (fig. 8), thus dividing the interior of the sphere of sarcode into pyramidal segments. The ectosarc seems to have a more definitely-membranous consistence than in *Actinophrys;* but it is pierced by the pseudopodia, whose convergence may be traced from without inwards, after passing through it, and it is itself enveloped in a layer of less tenacious protoplasm resembling that of which the pseudopodia are composed. The endosarc contains a number of yellow cell-like globules, resembling those of *Thalassicollæ*, having a thick peripheral layer and a central cavity. These are rendered brown by tincture of iodine, and are blackened by the subsequent action of sulphuric acid, whilst the rest of the body assumes a deep yellow colour; on the other hand, they are turned green by hydrochloric acid.

19. POLYCYSTINA.‡—The very numerous group of *Polycystina*, whose skeletons furnish to the microscopist so many objects of the highest interest for their varied beauty, is also entirely marine;§ and is distinguished from the foregoing in having the body itself more or less completely inclosed in a siliceous envelope, fenestrated or perforated with numerous

* On this family, see especially XI, XXV, LXVIII.

† The *Acanthometra echinoides* is described by MM. Claparède and Lachmann (XXV, p. 460) as extremely common on some parts of the coast of Norway; being brought in abundance by westerly winds into the fiord of Bergen, from which it disappears when the wind changes; but being always to be found at Glesnætholm, which is nearer the open sea. To the naked eye, it presents itself as a crimson-red point, the diameter of its body (not including the spicules or pseudopodia) being 0·15 millim., or 0·006 inch. This colour is seen under the microscope to depend upon the presence, in the central part of the body, of a mass of pigment, which, when viewed by transmitted light, is no longer crimson, but reddish purple. *Acanthometræ* do not seem to have yet been discovered near our own shores. As they are undoubtedly inhabitants of the North Sea, they should be looked-for on our eastern coast when the wind blows towards the shore.

‡ On this family, see especially XI, XXV, XLI, XLII, LXVIII.

§ They are best known as the "Fossil Infusoria of Barbadoes;" a large proportion of a Sandstone that prevails through an extensive district of that island, being composed of the siliceous skeletons of *Polycystina*, more or less firmly united together by a calcareous cement.

apertures for the passage of pseudopodia, and often furnished with radiating elongations (fig. 9). The sarcode body is altogether of an olive-brown colour, but contains yellow globules, like those of *Acanthometræ*. It does not always entirely fill the shell, especially when this does not form a complete casing; as in the *Eucyrtidium*, only the upper part of whose bell-shaped "test" is occupied by the body, which is divided into four equal lobes. The pseudopodia of the *Polycystina* bear a close resemblance to those of *Actinophrys*, alike in their gradually tapering form, their isolation from each other, their radiating direction, their indisposition to fusion, and the slow movement of granules along their borders.

20. THALASSICOLLINA.*—Certain forms of *Polycystina*, in which the fenestrations of the siliceous shell are so large and in such close proximity that the solid portion constitutes nothing more than an open network (as is the case with the *Dictyosoma* of Müller), serve to connect that group with the *Thalassicollina*. Of these bodies, which are found passively floating on or near the surface of the ocean, very few forms are yet known, and they are distinguished by Prof. Müller into the simple and the composite. Of the former we may take as an illustration his *Thalassicolla morum* (Pl. I, fig. 12), which seems very closely to resemble an *Actinophrys*, but presents on its surface, partly imbedded in its ectosarc, a number of composite siliceous spicules (fig. 13), much resembling those of some species of *Tethya*. In the *Th. nucleata* of Huxley, the dark spheroidal body is described by him as surrounded by a transparent gelatinous investment, resembling that which incloses the cells of many Protophytes. The former consists of a spherical vesicle, 1-65th of an inch in diameter, the wall of which is formed by a strong, resisting, and elastic membrane, whilst the interior is composed of fluid, holding in suspension granules of various sizes, with a pale, delicate, nuclear body. In the gelatinous investment many vacuoles are observable, varying in size from 1-62d to 1-2500th of an inch, the smallest being innermost; and scattered among the vacuoles of the inner portion, immediately surrounding the vesicular body, are many yellow, bright spheres (cells?), about 1-1600th of an inch in diameter, with a multitude of minute granules. From the surface of the vesicular body delicate branching fibrils are seen to radiate through the gelatinous envelope, passing between the vacuoles; and these are beset with excessively minute dark granules, which are continually circulating among the fibres, but without any definite direction. In the complex type, which is represented by the *Thalassicolla punctata* of Huxley (the *Sphærozoum punctatum* of Müller), the aggregate mass—which may be either spherical, spheroidal, or hour-glass shaped—is composed of a number of spheroidal bodies, nearly allied to the preceding, imbedded (like the cells of a *Palmella*) in a common gelatinous investment (fig. 10). Each spheroid is a cell of from 1-200th to 1-250th of an inch in diameter, having a thin but dense membranous wall, and containing a distinct nucleus surrounded by a mass of granules (fig. 11); and it is surrounded by a zone of siliceous spicules, each consisting of a short cylinder, from either end of which radiate three or four pointed spines, themselves beset with pointed processes, closely resembling the spicules of *Halichondria*. Round each of these spheroidal vesicles, moreover, is seen an aggregation of the before-mentioned small bright yellow spheres; which are also diffused, though more sparingly, through the substance of the common gelatinous investment. And through that substance also there are

* On this family, see especially XI, XXV, LII, LXVIII, XCIV.

seen to extend themselves from the surface of each vesicle (fig. 10) radiating fibres, resembling those of the simple *Thalassicolla nucleata.* The central part of the mass is hollowed out by numerous vacuoles of considerable size, closely pressed together; and these sometimes coalesce into a single cavity, so that the aggregate body (which sometimes attains the diameter of an inch) is in the condition of a hollow sphere. In another form of the same group, distinguished by Müller as *Collosphæra Huxleyi,* the aggregate body (which seems to correspond in all essential particulars with the preceding) is included within a clear, transparent, brittle, siliceous envelope, fenestrated by numerous rounded apertures (fig. 14). In this type (which seems to approximate to the *Polycystina*) there are no spicules, but each spheroidal vesicle contains a few prismatic crystals.

Order LOBOSA.

21. Amœbina.*—Returning now to our starting-point—the most generalized type of Rhizopods—we find in the *Amœba* and its allies (some of which are inhabitants of almost every pond that is tenanted by aquatic plants, whilst others are marine) a condition which, as in some respects transitional towards the *Infusoria,* has caused Prof. Müller to distinguish them as "Infusorial Rhizopods." The body of the *Amœba,* which may vary in diameter from 1-2800th to 1-70th of an inch, cannot be said to possess any definite shape, its outline being determined by the form and number of its pseudopodian prolongations, which are processes of the body itself, into which the endosarc often passes as well as the ectosarc, and not merely extensions of the latter, as in *Actinophrys.* Both in form and number these are continually undergoing change; sometimes they are all retracted, so that the shape of the body is simply spheroidal (Pl. I, figs. 16, 17, A); sometimes it puts forth a few broad, short, lobated expansions (fig. 16, B, C); sometimes these are more numerous, slender, and elongated, assuming a radial direction (fig. 15, A, B, C, D); and occasionally they are so greatly multiplied, radiate with such regularity, and taper so uniformly from base to apex, as strongly to resemble the pseudopodia of *Actinophrys* (fig. 18). The varieties thus presented have been designated under different specific names; but, as MM. Claparède and Lachmann have justly observed, the grounds of such distinction will appear far from sufficient, when the remarkable *polymorphism* characteristic of this type has been duly allowed for.

22. The distinction between the endosarc and the ectosarc is far more clearly marked in *Amœba* than in *Actinophrys;* the former being much more fluid, whilst the consistence of the latter is much firmer. It is through the endosarc alone that those coloured and granular particles are diffused, on which the hue and opacity of the body depend; the ectosarc, which forms a layer of greater or less thickness around it, being perfectly pellucid. The surface layer of the ectosarc in some forms of *Amœba* (as *A. bilimbosa*) seems almost to attain a membranous consistence, a distinct double contour being visible all round the body when at rest (fig. 17, A). Still, it cannot be said that even in such cases the body is

* On this family, see especially II, XI, XXII, XXIII, XXV, XXVII, XXXIII, XXXVI, XXXVIII, LXXXII, LXXXIV, XCIII, XCVII.

inclosed in a proper membranous envelope; for this investment seems ready to yield at any point, so as to give exit to the pseudopodial projections put forth by the softer contractile ectosarc (fig. 17, B). And in ordinary *Amœbæ*, which have no double contour line (figs. 15, 16), it seems most likely that alimentary and other substances can be introduced through any part of the ectosarc into the interior, as in *Actinophrys*, and that indigestible bodies can be extruded in like manner, though previously to their escape they may often be seen to push the ectosarc before them, so as to form considerable projections from the surface of the body. The central portion of the endosarc seems to have an almost aqueous consistence, the granular particles diffused through it (which are, for the most part, derived directly from without) being seen to move very freely upon one another with every change in the shape of the body. There is not, however, a definite limitation between the wall and the contents of this cavity; for the peripheral portion of the endosarc is much more tenacious than the central, and seems to graduate insensibly into the firmer substance of the ectosarc. In the typical forms of *Amœba* (as *A. princeps*, fig. 16, and *A. radiosa*, fig. 15), the endosarc passes into the interior of the pseudopodial extensions. But in *A. bilimbosa* (fig. 17) and some other forms, in which the differentiation of the endosarc and the ectosarc is unusually great, these extensions are derived from the latter only. In *A. porrecta* (fig. 18), on the other hand, the differentiation is far less complete, and the pseudopodia seem to be as much formed by the endosarc as by the ectosarc; in this and other particulars presenting a link of transition to the shell-less Reticulosa.

23. A "nucleus" (*n*, figs. 15, C, 17, A) is always distinctly visible in *Amœba*, having, when most perfectly seen, the aspect of a clear, flattened vesicle surrounding a solid and usually spherical nucleolus; it is adherent to the inner portion of the ectosarc, and projects from it into the general cavity.—A "contractile vesicle" seems also to be uniformly present; though it does not usually make itself so obvious by its external prominence as it does in *Actinophrys*.

24. The more advanced differentiation of the central and peripheral portions of the protoplasmic body of *Amœba* is made evident by the effects of reagents. If an *A. radiosa* (fig. 15) be treated with a dilute alkaline solution, the granular and molecular endosarc shrinks together and retreats towards the centre, leaving the radiating extensions of the ectosarc in the condition of cæcal tubes, of which the walls are not soluble, at the ordinary temperature, either in acetic or mineral acids, or in dilute alkaline solutions, thus agreeing with the envelope noticed by Cohn as possessed by *Paramecium* and other ciliated *Infusoria*, and with the membrane of ordinary animal cells. The nucleus and nucleolus are readily soluble in alkalies, whilst they are rendered darker and more distinct by dilute acetic or sulphuric acid, in consequence of the precipitation of a finely granular substance in the clear vesicular space that surrounds the nucleolus. When treated with more concentrated acids, the nucleus and nucleolus first expand and then dissolve.

25. The *Amœba* and its allies are distinguished in a very marked manner from all other Rhizopods by the comparative activity of their locomotion; instead of remaining fixed to one spot (except when made to change their place by external agency), and entrapping their food

by their elongated radiating pseudopodia, they are continually moving over the field of the microscope, and receiving into their bodies any small substances which they may happen to encounter in their progress. This movement is effected by the protrusion of some part of the periphery of the body into a pseudopodian process of greater or less elongation: towards this process, and usually for some way into it, there is a current of the internal granular substance; at the same time there is a retraction of any processes of the like nature which might have been previously put forth from the other side of the body, and a reflux of the granular substance from these towards the centre; and by a continuance of this change the entire body is gradually advanced in the direction of the new extension. The kind of motion thus executed by an *Amœba* is described by most observers as a "rolling" action, this being certainly the aspect which it commonly seems to present; but it is maintained by MM. Claparède and Lachmann, as the result of a very careful observation of certain forms of *Amœba* that present peculiarities in the disposition of their parts which render them (so to speak) "test objects" as to this point (such as the *A. quadrilineata* of Carter, and the *A. limax* of Auerbach), that the appearance of rolling is an optical illusion, for that the nucleus and contractile vesicle always maintain the same position relatively to the rest of the body, and that "creeping" or *reptation* would be a more true description of their mode of movement. On this view, these animals have their ventral surface constantly differentiated from their dorsal, it being from the former alone that the pseudopodian extensions proceed; and thus a transition would seem to be indicated towards the testaceous *Amœbinæ*, in which the dorsal surface is invested by a shell, and the pseudopodia are strictly limited to the ventral.

26. When the body of an *Amœba*, or one of its extensions, comes into contact with any small particle, the movement of the former very commonly presses it against the latter with sufficient force to cause it to make its way through the ectosarc into the cavity of the endosarc;* and thus the latter may often be seen to contain *Diatomaceæ*, *Desmidiaceæ*, fragments of larger *Algæ*, *Infusoria*, *Rotifera*, and even *Entomostraca*, with an occasional intermixture of inorganic particles. These undergo a kind of circulation in the general cavity of the interior, which is maintained, as just shown, by the movements of the surrounding contractile substance; and this circulation (like the movement of the contents of the stomach in higher animals) doubtless promotes the digestive process. The larger masses that are available for nutriment are gradually broken up into finer particles; and these seem to constitute the granules which are always to be seen diffused in greater or less abundance through the liquid interior of the endosarc, the colour of those granules being pretty obviously the same as that of the matters ingested, and the effects of chemical reagents upon them being identical. Insoluble bodies appear to be rejected from time to time, by making their way towards the surface, and then penetrating the ectosarc at the point which happens to be nearest, just as they are in *Actinophrys*.

* Whilst admitting that there is no evidence of the existence of a constant definite oral aperture in *Amœba*, MM. Claparède and Lachmann think it conceivable that there may be such an aperture, of which the lips might be exactly applied to one another, as in *Amphileptus*, so as only to open at the moment of deglutition. They express themselves as certain, that in their *Podostoma filigerum* (¶ 28) such a definite oral aperture exists (xxv, p. 118).

27. The "contractile vesicle" does not usually project much from the surface; though in a form of *Amœba* allied to *A. princeps*, in which it has been carefully studied by MM. Claparède and Lachmann (xxv, p. 427), it bore a very close resemblance, when in its state of greatest turgescence, to that of *Actinophrys sol.* When fully contracted, it disappeared entirely, but soon presented itself anew as a minute vesicle in the substance of the ectosarc, which enlarged little by little until it acquired its original dimensions. On its contraction, from four to eight vacuoles were seen to project on different parts of the body, often at a considerable distance from the contractile vesicle;* and when these had attained a certain dimension they seemed to put themselves in motion towards it, and to discharge their contents into it,—an operation which is probably performed by a sort of peristaltic movement along a system of canals excavated in the sarcode-substance, portions of which are distended into larger cavities by the contractions of the principal vesicle, and gradually recover their original dimensions by propelling back to it the fluid which it injected into them. This kind of circulation is not maintained in *Amœba* with the regularity that is elsewhere seen; for MM. Claparède and Lachmann observed that whilst only from half a minute to three minutes sometimes intervened between the contractions, an interval of as much as five minutes might elapse between the contractions,—a circumstance which shows how necessary it is to watch a Rhizopod for a sufficiently long time, before coming to a conclusion as to the absence of a contractile vesicle. It is not likely, however, that the movement of fluid which it seems to be the action of the contractile vesicle to sustain, is completely suspended during so long an interval; and as the contractile vesicle was observed to be undergoing a continual change of bulk, it seems probable that it was executing partial contractions during this period, and was refilled in the intervals of these.

28. A singular modification of the ordinary Amœban type is described by MM. Claparède and Lachmann (xxv, p. 441) under the name *Podostoma.* This creature (which was found by M. Lachmann in great abundance at Berlin, in a vessel containing Algæ and Infusoria) may be readily mistaken for an *Amœba* until it exhibits the appendages which are peculiar to it; each of these resembles at its base a short broad pseudopodium, but from the extremity of this there is put forth an elongated whip-like filament, which is in continual motion like the *flagellum* of certain Infusoria, and which lashes the surrounding water in every direction. Any foreign particle which may come into contact with this filament is retained by adhesion to it, and the filament then contracts into a spiral, disappearing at last in the substance of its pseudopodium, with which it becomes re-incorporated, and drawing into it the attached particle, which is at first brought to the rounded extremity of the pseudopodium, is then received into a spoon-shaped depression that forms itself on this, and then, by a gradual deepening of this depression, finds its way into the interior of the pseudopodian expansion, and thence into the soft endosarc which constitutes a sort of "general cavity of the body."

* These distensible vacuoles seem to have been mistaken by some observers for multiple contractile vesicles; they have not, however, the well-defined boundary of that organ; and they do not undergo the well-marked contractions which it presents at intervals.

29. From the simple naked *Amœba* a transition is presented to those testaceous forms which accord with it in general structure, by the genus *Pseudochlamys*, in which the dorsal surface is protected by a buckler or carapace (somewhat resembling the shell of a *Patella*), whose substance, however, is not dense enough to prevent its changing its form with that of the body. In the *P. patella* described by MM. Claparède and Lachmann (xxv, p. 443), which is common in ponds in the neighbourhood of Berlin, from six to ten "contractile vesicles" are seen along its margin, but only a single "nucleus" can be distinguished.

30. Of the testaceous *Amœbina* there are two principal types; the *Arcellæ*, which form a membranous "test," possessing considerable firmness in itself; and the *Difflugiæ*, in which firmness is imparted to the "test" by the adhesion of foreign particles (such as grains of sand or fragments of shell) to its external surface. Both are inhabitants of fresh water, and are pretty generally diffused. They have been divided into many species, according to supposed differences of the most trivial character, which extended observation proves to be altogether valueless.

31. The "test" of *Arcella* is ordinarily of nearly hemispherical form, the circular plane which closes it in being perforated by a large aperture, from which the pseudopodia are put forth (Pl. I, fig. 19); sometimes, however, it is deepened into the form of a vase or pitcher, whilst in other instances it is flattened or depressed. Its surface is usually marked with hexagonal facets, which are due to the thinning of the membrane at those parts; and sometimes it presents a larger pattern formed by bands or depressions passing round it in various directions. The animal creeps with the mouth of the shell downwards; its pseudopodia, which resemble those of *Amœba*, being extended between the flattened side of the shell and the surface over which it moves. According to MM. Claparède and Lachmann (xxv, p. 444); the number of "contractile vesicles" in *Arcella* is very variable, and may increase with the bulk of the animal; they are always disposed around the periphery of the hemisphere. Although individuals are sometimes observed to possess only a single "nucleus," yet this body is generally repeated several times; and these multiple nuclei may be seen to form a ring interior to the contractile vesicles, which they may equal in number, as many as from ten to fifteen having been observed. The *Arcella* may be observed to change its "test" many times during the course of its life, not having any power of enlarging it. When the sarcode-body has become too bulky for its envelope, it projects from the aperture of the test, from the cavity of which it almost entirely withdraws itself; and on the surface of this projecting portion a new test is formed, which often differs from the old one in those characters which have been considered to differentiate species. At first, the new test is thin, transparent, and colourless; but it gradually becomes thicker, more opaque, and of a light yellowish-brown colour. The old and the new tests are applied to one another, aperture to aperture (a condition which seems to have been mistaken for an act of "conjugation"); and the sarcode-body passes alternately from one to the other, until at last, when the new test has acquired sufficient consistence, the *Arcella* entirely quits the old one, which very commonly splits under the violence that seems involved in the final separation (xxv, pp. 445, 446). The "test" of *Difflugia* (fig. 20) is usually more or less of a spherical or ovoidal shape, but is sometimes more elongated into the form of a pitcher or a flask: its aperture is generally somewhat notched. When

freed from adhering particles, its membranous base is thin, transparent, and colourless; sometimes it extends into spine-like processes, by which the test adheres to a fixed point of attachment. The animal of *Difflugia* appears closely to resemble that of *Arcella*, but has not been so carefully studied.

Order RETICULARIA.

32. As each of the preceding Orders contains both naked and testaceous forms, so do we find that with the proper *Foraminifera* furnished with calcareous shells, there must be associated (in virtue of the close conformity in the nature and actions of their sarcode-bodies) animals which only form a membranous "test," and some even which seem as destitute of any protective envelope as an *Amœba* or an *Actinophrys*.* An example of this last kind, which affords an admirable illustration of the essential features that distinguish this group (¶ 11), is presented by the *Lieberkühnia*, a very remarkable Rhizopod, which has been found in the neighbourhood of Berlin, by MM. Claparède, Lachmann, and Lieberkükn (xxv, pp. 464-466).† The body of this animal (Pl. II), which measured about 1-16th millim. (1-400th inch) in its longest diameter, was formed of a mass of granular protoplasm not presenting any distinct differentiation of "endosarc" and "ectosarc," and destitute alike of "nucleus" and "contractile vesicle," but including a large number of "vacuoles" filled with a homogeneous liquid. From one portion of this mass there issued a sort of stem, from which all the pseudopodia diverged; and this stem was enveloped in a transparent sheath, which might be traced, as a thin pellicle, over the whole surface of the body. From this stem the granular protoplasm extended itself into branches, which ramified with extreme minuteness and to an extraordinary distance, their length in proportion to the diameter of the body being nearly three times that which is represented in the plate. Wherever these ramifying pseudopodia came into contact with each other, the substance underwent a complete fusion or coalescence; and thus a network was formed, which might be described as a sort of animated spider's web, and which was admirably fitted for the acquisition of food. Any small particles that come into contact with these pseudopodia were held to their surface by adhesion, and then partook of the general movement of the granules included in the protoplasm to be presently described. But when larger bodies were thus entrapped, they became enclosed in a sort of sheath of protoplasm formed by the blending of the neighbouring pseudopodia which applied themselves to its surface; and by the progressive contraction of this they were drawn towards the body, as in the *Actinophrys* (¶ 14). In one instance a large *Stentor* thus captured was seen to make its escape, carrying with it a portion of the pseudopodial expansion of the *Lieberkühnia*. The granules so abundantly distributed through the protoplasm of the body and its extensions were obviously for the most part of external origin; many of them being particles of chlorophyll derived from vegetable organisms that had been

* On this group see especially IV, XXV, XXXIII, XXXV, XXXVI, LXXXIV, XCVII.

† The animal described by Professor Bailey (IV) under the name of *Pamphagus mutabilis* seems to have been nearly allied to this, if not identical with it.

taken-in as food, whilst the introduction of others, that happened to lie on the surface of the glass, took place under actual observation. These granules were in a state of continual movement, passing from the interior of the body and along the stem and branches of the pseudopodial expansions towards the extremities of these, and then back again into the interior of the body, in the manner that will be more particularly described in *Gromia*. The current was rapid, and seemed to attain its maximum of intensity at the surface of the pseudopodia. It was noticed in this interesting animal, which was kept for several days under observation, that the pseudopodia were always most expanded in the absence of light, being splendidly displayed when the slip of glass was first brought out of darkness and placed upon the stage of the microscope; but that after a few moments they began to retract themselves, their viscid substance flowing rapidly towards the body with a wave-like motion; and in a short time it became impossible to recognise a Rhizopod in the dark motionless mass beneath the microscope.

33. In the *Gromiæ*, some forms of which inhabit fresh water, whilst others are marine, the sarcode-body, which is of essentially the same character with that of *Lieberkühnia*, is enclosed in a yellowish-brown membranous "test" of ovoidal shape, with a single round orifice of moderate size, through which the protoplasmic substance extends itself from the interior through the surrounding medium (Pl. III, fig. 2). When the animal is in a state of rest, the whole of this is drawn within the test; and when its activity recommences, single fine processes are first put forth, which move about in a sort of groping manner until they find some surface to which they may attach themselves. When this attachment has taken place, new sarcode flows into them, so that they speedily increase in size; and they then elongate themselves by sending out finer ramifying processes, which, in diverging from each other, come into contact with those proceeding from other stems, and, by mutual fusion, form a set of inosculations or connecting bridges between the different systems of ramifications, so that the whole becomes a complicated network extending to a distance of six or eight times the length of the body. This network continues to undergo incessant changes, new filaments being put forth in different directions, sometimes from its margin, sometimes from the midst of its ramifications, whilst others are retracted. Not unfrequently it happens that at a spot where two or more filaments meet and fuse together, a lamina is formed by an expansion of the viscous protoplasm that flows towards this point; and from such an expansion a new set of thread-like processes is given off, as from the central body, of which several examples are shown in the figure. It is not only, however, in the protoplasmic substance directly as it issues from the mouth that the pseudopodia originate; for this substance is seen to extend itself over the surface of the test, and may put forth pseudopodia from any part of it. The greater development of these at the posterior extremity of the shell would seem to indicate that they are employed for fixing it, and thereby enabling the animal to put forth more power when seizing and drawing into itself as food living creatures that can struggle against its ensnaring action. (The greater part of the *Foraminifera* are firmly fixed by the adhesion of their shells to the surfaces of Algæ, Zoophytes, Mollusks, &c.) Any minute particle which may chance to come into contact with a pseudopodium, and which is retained in adhesion to its viscid surface, soon becomes imbedded in its protoplasm, and is subjected to the general movement to be presently described. But when a larger body is thus

entrapped, a number of pseudopodia apply themselves to its surface, and a sort of flux of their viscid protoplasm takes place towards it, until it becomes ensheathed with this substance, as shown in the case of the Diatom entangled amongst the pseudopodia on the right side of the figure. A reflux of the protoplasm of the pseudopodia then takes place, and the body entrapped by them is gradually received into the mass of sarcode lying outside the mouth of the test, through which it passes into its interior if not too large to find admission. The *loricæ* of *Diatoms*, portions of *Confervæ*, and other similar bodies, bearing a considerable proportion in length to the whole diameter of the test, may often be distinguished in its interior, as shown in fig. 2.—As the form of the test of *Gromia* does not admit of any addition being made to its capacity, so as to accommodate it to the growth of the contained body, it appears probable that the latter (like *Arcella*, ¶ 31) quits it, and forms a new test whenever it has outgrown the old one; and it does not seem unlikely that an accumulation of indigestible substances may be got rid of at the same time, as the enclosure of the body in a firm envelope must prevent these from being ejected from time to time through an extemporised anus, with the facility which we have seen to characterise the process of defecation in the naked Rhizopods.

34. Through the whole of the protoplasmic network, a movement of granules is continually taking place, chiefly in two directions—from the body towards the extremities of the pseudopodia, and from these extremities back to the body again. This movement may be seen in every one of the processes; but it is only in the broader filaments containing numerous granules, that two streams can be seen passing at the same time in opposite directions. In the finest filaments, whose diameter is less than that of the granules, the latter glide along their surface at distant intervals, each passing up as far as the termination of the filament, and then returning, sometimes meeting and carrying back with it a granule advancing in the opposite direction. Even in the broader processes, granules are sometimes observed to come to a stand, to oscillate for a time, and then to take a retrograde course, as if they had been entangled in the opposing current—just as is often to be seen in *Chara*. When a granule arrives at a point where a filament bifurcates, it is often arrested for a time until drawn into one or the other current: and when carried across one of the bridge-like connections into a different band, it not unfrequently meets a current proceeding in the opposite direction, and is thus carried back to the body without having proceeded very far from it. This curious circulation, as already pointed out (¶ 11), so nearly resembles the *cyclosis* that takes place within the cells of Plants, as to leave no reasonable doubt that the conditions of the two sets of phenomena are essentially the same.

35. In one large section of the *Foraminifera*, of which *Miliola* may be taken as the type, the calcareous "shell," whether monothalamous or polythalamous, is formed upon the same plan as the "test" of *Gromia*;* the wall of each chamber being perforated by no other openings

* Although the author has here followed the example of other Systematists in separating *Gromia* and its naked allies from the true *Foraminifera*, he is by no means certain that such separation, however convenient in practice, is scientifically justifiable; since the difference in the composition between the membranous "test" of *Gromia* and the calcareous "shell" of *Miliola* scarcely seems to him a character

than those which communicate with the adjacent chambers, and the last-formed chambers having only a single orifice* of communication with the exterior, from which alone pseudopodia are put forth (Pl. III, fig. 3). But all these openings are usually so free, that no obstacle can exist to a transmission of nutrient materials obtained by the pseudopodia put forth on the exterior, to the segments of sarcode-body that are furthest removed by it, by a circulation of granules through the entire mass analogous to that which has just been described; and thus the physiological condition of the animal of *Miliola* and its allies may be considered to be in all essential respects the same as it is in *Gromia*. This will still be the case, even when the number of such segments is immensely multiplied by the subdivision of the principal sections, as in the animal of *Orbitolites* (Pl. IV, fig. 14), *Orbiculina*, and *Alveolina;* and the evidence which the author has been fortunate enough to obtain in regard to the first of these types is sufficient to show that there is no indication of deficient vitality in the portion of the sarcode body which occupies the centre of the largest disk, the character of its substance being precisely the same throughout.

36. A very different condition presents itself, however, with the two great groups (together constituting by far the largest proportion of the entire series), of which *Rotalia* and *Operculina* may be regarded as the types. For in these the apertures in the septal planes by which the chambers communicate with each other, and by which the special communication is established between the last chamber and the exterior, are so much narrowed that they are sometimes not easy to be discovered; but, on the other hand, the lateral walls of the chambers are everywhere perforated, more or less closely, with pores for the exit of pseudopodia. Hence when a living *Rotalia* is under observation, its pseudopodia are seen to extend themselves from every part of its surface (Plate III, fig. 1), and not to proceed only from the orifice of the last chamber, as in *Miliola*. When the pseudopodia have been entirely retracted, however, it is generally observable that those first put forth proceed from the orifice (or orifices) of the septal plane of the last chamber; and frequently a considerable time elapses before the pores of the lateral walls give exit to protoplasmic filaments. Often, again, these filaments are put forth only from the two or three last-formed chambers. Still, when such an animal has remained long undisturbed, its pseudopodia may be seen to extend themselves from all the pores on its surface. If these are used for the introduction of alimentary materials into the body, it is obvious that such materials only can thus enter, as are in a state of sufficiently fine division to pass through these pores. No difficulty need be felt on this score in the case of the *Rotaline* group, in which the diameter of the pores, being commonly as much as 1-3000th of an inch, allows the passage of pseudopodia of by no means the smallest

of sufficient importance to differentiate groups which are so intimately allied in their general physiological conditions, especially when it is borne in mind that some of the *Milolida* form their shells, after the manner of *Difflugia*, by the agglomeration of particles derived from without, instead of by an exudation from within. Moreover, if *Gromia* be regarded as the monothalamous type of the *Milioline* series, it naturally fills a place exactly parallel in rank to that of *Orbulina* in the *Rotaline*.

* The single large mouth is sometimes replaced, as in *Peneroplis* and *Orbitolites*, by a series of pores; but these, being limited to the "septal plane," have no relation whatever to those which allow the passage of pseudopodia through the lateral walls of the chambers of *Rotalia* and *Operculina*.

size. But in the *Operculinæ* the diameter of the pores is so much smaller,—being commonly no more than 1-10,000th of an inch, and often less,—that only the very finest pseudopodian threads can issue from them, and only the minutest granules can be received into them. Certain facts in the structure of the shell, to be hereafter detailed (Chap. II), render it almost certain that the protoplasmic substance extends itself at certain times, if not constantly, over the whole exterior of the shell, as in *Gromia* (¶ 33); and hence it is by no means impossible that the digestive process may really be performed in this external layer, so that only the products of digestion may have to pass into the portion of the sarcode-body occupying the cavity of the shell.

37. The sarcode-body of such *Foraminifera* as have been observed in the living state, is observed to be more or less deeply coloured; its tint being in some instances a yellowish-brown, in other cases a crimson-red. This colour seems in some instances to be uniformly diffused through the whole mass of the sarcode, probably owing to the fine state of division of the particles which possess it; but in the larger forms it occurs in much larger and more scattered masses, which appear sometimes to be collections of granules, and in other cases to be vacuoles filled with a coloured liquid. In the polythalamous *Foraminifera* it is nearly always to be observed that the colour is deepest in the segments of the body which occupy the oldest chambers, and that it fades progressively in the segments which intervene between these and the one that occupies the last-formed chamber, which is often nearly colourless. There is strong reason to believe that the colouring material is directly derived from external sources, though modified in some cases by the agency of the animal itself. It was found by Schultze, that he could increase the intensity of the colour, and cause even the last-formed segment to be dyed with it, by feeding the animals with substances fitted to impart it; whilst, on the other hand, by depriving them of food that would furnish colour, he could reduce the older segments to almost the same state of deficiency in this respect as is usually presented by the last segment alone. It is stated by Schultze that the colouring matter of *Foraminifera*, when treated with dilute sulphuric or hydrochloric acid, is changed to an intense verdigris green; and by dilute nitric acid, first to green and then to yellow. Concentrated sulphuric acid destroys the colouring substance, but when combined with sugar renders it green. By concentrated solutions of potass and soda, the coloured granules are dissipated without change; and in ether and alcohol they are readily and completely dissolved. In these reactions the colouring matter agrees with that of the *Diatomaceæ*, from which tribe the greatest part of the food of the *Foraminifera* is probably derived.

REPRODUCTION OF RHIZOPODA.

38. So little is at present known of the manner in which Rhizopods belonging to any of the foregoing types propagate their kind, that it seems preferable to bring together the principal facts hitherto recorded respecting the mode of reproduction in all these groups; more especially as they will be found to bear a very close resemblance to one another.

39. The deficiency of structural differentiation, either morphological or histological, which

is so remarkable a characteristic of this group, would lead us to infer that, as every part of the homogeneous sarcode seems possessed of the same attributes in regard to the physiological activity of the individual, so it should be equally able to participate in that modification of the ordinary processes of nutrition which gives origin to new and independent beings by continuous growth. There is evidence that this is actually the case: for not only do portions of the sarcode-body detached from the principal mass forthwith comport themselves after the manner of that from which they have been separated,—the sarcode forced out by crushing the shell of a living *Arcella*, for example, putting forth lobose extensions on the Amœban type, whilst that forced out by crushing the shell of a living *Polystomella* puts forth the slender branching pseudopodia of the Reticularian (Plate I, fig. 12),—but there is every reason to believe that such detached portions can continue to maintain an independent existence. Thus it is not unfrequently seen in *Amœba* that when a pseudopodial process or lobe of the body has been put forth to a considerable length, and has become enlarged and fixed at its extremity, the subsequent contraction of the connecting portion, instead of either drawing the body towards the fixed point, or retracting the pseudopodial lobe into the body, causes the connecting band itself to become more and more attenuated until it gives way, leaving the terminal enlargement altogether detached; and this portion speedily shoots out pseudopodial processes of its own, and behaves itself in all respects as an independent *Amœba*. Still more satisfactory evidence to the same effect has been obtained by myself in my detailed study of *Orbitolites*; for not only have I met with numerous specimens in which the loss of any portion of the disk was repaired by a new growth taking place in every respect upon the regular type (Plate IV, fig. 26), but I have been fortunate enough to obtain a specimen (fig. 27) in which a new disk has been formed from what was obviously nothing else than a fragment broken away from the margin of a much larger one.—Since, therefore, in the more as in the less specialised types of Rhizopod conformation, any portion of the sarcode-body can thus comport itself as an independent organism, it may be reasonably inferred that this is true of the entire group, and that the detachment of such portions, after the manner of the gemmation of higher plants and animals, is one mode in which Rhizopods are ordinarily multiplied. And such would seem to be the most probable explanation of the appearances seen by Schneider (XCIII) in *Difflugia*; which indicate that a whole colony may be formed by gemmation from the pseudopodial lobe of one individual.

40. Inferential evidence to this effect is abundantly afforded by the study of the polythalamous types of *Foraminifera*; for in every case in which it has been hitherto possible to examine the sarcode-body of these animals, its character has been found to be uniformly the same throughout, every segment precisely repeating every other, save in the difference of colour already noticed, and in certain appearances occasionally presented by the outer segments (¶ 48), which are probably indicative of a more special kind of reproductive action. The entire sarcode-body of an *Orbitolites* (Plate IV, fig. 14), for example, is made up of an aggregation of segments that have been successively put forth, by a process essentially resembling gemmation, from the primordial segment which continues to occupy the central chamber; and it affords one of the best examples which the Animal Kingdom can present, of that "vegetative" or "irrelative" repetition which is an essential feature of all low grades of organization. Every one of these segments, there is strong reason to believe, could maintain

an independent existence: and yet so long as it remains in connection with the rest, it shares a common life with them, the nutrient materials being introduced in the first instance through the marginal segments, and being transmitted by protoplasmic circulation (¶¶ 32—34) through the entire mass. But in a large proportion of the polythalamous *Foraminifera*, the segments thus successively formed are much more completely isolated from each other than are those of *Orbitolites*: and there are several in which the chambers of the shell that envelope these segments have so little connection with those that precede and follow them, as to be easily detached from them and from each other. This is the case, for example, with *Globigerinæ*, and with many of the *Nodosariæ*: and there is reason to believe that the separation of their parts, which can be produced by very slight external violence, may be a means of their multiplication and diffusion.

41. Besides this, which may be considered the *most general* method of reproduction among Rhizopoda, other more special forms of that process are indicated by observed facts. In those types which exhibit, in the differentiation of "ectosarc" and "endosarc," and in the presence of a nucleus, the nearest approach to the condition of cells, multiplication takes place, as in growing cells generally, by a process of binary subdivision. This may often be witnessed in *Actinophrys*, round whose spherical body an annular constriction forms itself, which gradually deepens so as to separate its two halves by a sort of hour-glass contraction (Plate I, fig. 4); and the connecting band becomes more and more slender (fig. 5), until a complete separation of the two halves occurs. The process of fission, which may be completed within half an hour from its commencement, seems to take place first in the contractile vesicle; for each segment very early shows itself to be provided with its own (Fig. 4, *v*, *v*), and the two vesicles are commonly removed to a considerable distance from one another. The segments thus divided are not always equal, and sometimes their difference in size is very considerable.—The like process of duplicative subdivision has been witnessed also in *Amœba*. Whether in either case this subdivision commences in the nucleus, or extends through it subsequently, has not yet been ascertained.

42. It is affirmed by Schneider (XCIII *a*) that *Amœba* sometimes passes into an encysted condition. He observed it first to become globular, and then to form a firm membrane on one side, whilst the other portion maintained its peculiar character and actions. (In this state it seems to have resembled the *A. bilimbosa* of Auerbach, Plate I, fig. 17.) By degrees the membrane extended itself over the whole body, the moveable portion constantly becoming smaller, until at last a completely closed cyst was produced, in the clear interior of which a round nucleus, with a reddish halo, exactly like that of *Polytoma* and other *Monadina*, might be distinctly observed. To what this encysting stage leads, there is at present nothing to show.—A change which seems to be of the same nature has also been observed by Schneider (XCIII) in *Difflugia*, and by Schultze (XCVII, p. 25) in *Lagynis Baltica* (Plate I, fig. 21, B).

43. On the other hand, a junction of two individuals has been seen to take place in *Actinophrys*, which has been supposed to correspond with the "conjugation" of certain Protophytes. It is very doubtful, however, if this junction or "zygosis" involves a complete fusion of the substance of the bodies which take part in it; and there is not sufficient evidence

that it has any relation to the act of reproduction. Certain it is that such a "zygosis" may occur, not between two only, but between several individuals at once, their number being recognised by that of their contractile vesicles; and that after remaining thus coherent for several hours, they may separate again without having undergone any discoverable change. Whether, by any process of a sexual character, germs are developed within the body, and are then set free, must at present be regarded as quite uncertain; the only reliable evidence on this point being that which is afforded by the observation of Professor Kölliker, that very small individuals of *Actinophrys* sometimes present themselves, measuring no more than ·01 or ·02 millim. (1-2560th or 1-1280th inch), and presenting very few and inconspicuous granules. But these may be gemmæ or small segments separated by the process of subdivision, and not sexual products. And it must for the present be held to be quite uncertain, whether the body which we know as *Actinophrys* does not go through some entirely different phase, before the completion of its life-history.—A like process of conjugation has been seen to take place also in several *Amœbinæ*, testaceous as well as naked; and the same doubt exists whether this "conjugation" has any import at all corresponding to that of sexual union among the higher animals, and whether the being which is known as *Amœba* is anything more than one form of an organism, which would present itself to us under other very diverse aspects if the whole of its life-history were known to us.*

44. Certain appearances, however, have been observed by Mr. H. J. Carter (XXII, pp. 223-233) among *Amœbina* and *Actinophryna*, which may be provisionally accepted as indicating that true sexual products are formed in the interior of their bodies, and are afterwards set free by their disintegration. In *Amœba* the formation of the male apparatus appears to commence by an increase of size in the vesicular portion of the nucleus, which also becomes more or less globular (Plate IV, fig. 6, *a*); and its contained aggregation of granules then augments so as to occupy a third of the interior of the animalcule, and undergoes successive binary subdivisions, by which it is broken up into numerous segments. These segments assume a circular compressed or globular form, and continue entire until the granules (spermatozoids?) of which they are composed become fully developed, when the latter acquire the power of locomotion, and then separate from each other, the original containing vesicle in the meanwhile disappearing. In this way some individuals out of a group of *Amœba radiosa* bearing such granules were seen moving about, even when so reduced that hardly anything but their external pellicle and the one or two spherical segments of the granulated nucleus that remained in their interior were left. Sometimes these segments are evidently held together by a soft mucous envelope, which, being polymorphic, assumes the form of *Actinophrys* (fig. 7), and exhibits locomotive power; while in other instances this capsule becomes firm, transparent, and spherical; and the granules do not leave it until they become endowed with independent activity. When the latter is the case, the sperma-

* The Author considers that it would be foreign to the purpose of the present work, were he here to enter upon a discussion of the curious observations of Hartig, Carter, and others, who maintain that *Amœba* and *Actinophrys*, or organisms undistinguishable from them, are formed as individualised segments of protoplasm within Vegetable cells, entering upon their independent Animal life when set free from these.

tozoids (?) may be seen, if fully developed, to be bounding about in the interior of their capsules, while the capsules themselves are still rolled on in the sarcode of the *Amœba* under progression. At other times, the whole mass of the spermatozoids (?), all separated and freed from their capsules, may be seen to be diffused through the body of the *Amœba* whilst still in active polymorphism and locomotion. Lastly, the parent sometimes dies in this state; and then the mass of spermatozoids (?) may be seen to undergo gradual disintegration, as the granules, by twos or threes or more, disentangle themselves from the sarcode, and bound off into their new element.—The development of granular spermatozoids (?) has been observed by Mr. Carter to take place after almost exactly the same fashion in *Euglypha alveolata* (fig. 9), in which their diameter averages from 1-16,000th to 1-12,000th of an inch; and similar bodies have been seen by Schneider (XCIII) to develope themselves from the nucleus of *Difflugia*.

45. Again, not only *Amœbæ*, but *Euglyphæ*, *Difflugiæ*, and *Arcellinæ*, have been frequently observed by Mr. Carter to contain in the midst of their sarcode a number of discoid or globular bodies having the appearance of ova (Plate IV, figs. 8, 10, 11). At an early stage of their formation each of these bodies consists of a transparent capsule, lined with a faint-yellow film of semitransparent matter, which, subsequently becoming more opaque and yellowish, also becomes more marginated and distinct.* They are very commonly accompanied by active molecular granules. Their number is sometimes so great, that, as in the specimen of *Amœba verrucosa* represented in fig. 8, the entire body comes to resemble an ovisac filled with granuliferous germ-cells. In *Euglypha alveolata* they are first seen, to the number of from four to fifty, congregated round the nuclear vesicle, though afterwards they become diffused through the sarcode-body generally (fig. 10); their diameter averages from 1-4000th to 1-3000th of an inch, or something less than that of a human blood-corpuscle.

46. Although the development of spermatozoids (?), and of ovules (?) takes place more profusely in distinct individuals than in the same, yet it is by no means uncommon to see individuals of *Euglypha alveolata* containing both kinds of bodies (fig. 11): there is no such gradation between them, however, either in size or aspect, as would suggest the inference that the one form originates from the other.

47. Of the subsequent history of these bodies very little has been yet ascertained, and it cannot be stated with any approach to probability in what way their development and actions are related to the "conjugation" already mentioned as not unfrequently to be seen between two or more *Amœbina* or *Actinophrynа*. It is stated by Mr. Carter that the granular spermatozoid (?) development does not take place until after conjugation; and that after *Euglyphæ* have united themselves, not only in pairs but triply and quadruply, it is common to see only ovules developed in all the individuals of one group, and spermatozoids in those of another. In *Euglyphæ* (fig. 11) which contained both ovules (?) and spermatozoids (?), the former were often observed to be surrounded by actively-moving swarms of the latter: and the same is

* The "seed-like bodies" of *Spongilla* have been found by Mr. Carter to contain numerous transparent, globular sacs, each of which includes a greater or less number of ovules (?) resembling those described above. Thus, each of these sacs may be considered as the representative of an *Amœba*.

also observable in *Spongilla*, in which Mr. Carter thinks that he has seen the incorporation of one of the spermatozoids (?) with an ovule (?), in a manner that indicates the act to be one of fecundation. He has been able to watch the ovules from their first appearance until they acquire the aspect of simple Rhizopods with a power of putting forth pseudopodia; and he believes that when they have attained this condition they are set free by the death of the parent, and, escaping from the cavity of its test, soon form new tests for themselves. By his subsequent observations upon *Amœba verrucosa* (XXIII, p. 37), Mr. Carter was led to believe that each ovule in that species gives origin to a number of independent "polymorphic" cells, resembling those which he had previously described as constituting the first product of the ovum of *Spongilla*; and that these pass several months in their immature condition, before taking-on the characteristic aspect of the parent.

48. Of the special modes in which Reproduction is effected in FORAMINIFERA, scarcely anything is yet known. It was observed by Dujardin that the protoplasmic contents of the chambers of *Truncatulina* sometimes group themselves together as spherical masses; and I have met with the same kind of aggregation in the sarcode of the superficial chambers of *Orbitolites* (Plate IV, fig. 1), the spherules averaging about 1-3200th of an inch in diameter. Lying in the midst of the sarcode of the same animal, I have occasionally found other bodies (fig. 2, *a*—*g*), sometimes resembling simple cells, sometimes like cells undergoing binary subdivision, having a firm envelope, and retaining the crimson hue of the animal substance even in spirit-specimens; their diameters varied between 1-650th and 1-300th of an inch. These seem analogous to the dark spherules observed by Schultze (XCVII, p. 27) in certain *Rotaliæ*, sometimes occupying all the chambers (fig. 3), in other instances confined to the last one or two; the ordinary sarcode co-existing in the same shells, but not putting forth pseudopodia. These spherules were composed of a collection of dark molecular matter, not enclosed in a distinct membrane, but held together by some uniting medium; and they were especially remarkable for their resistance to reagents, not being acted on by sulphuric, nitric, or hydrochloric acids, or by boiling alkalies. The *Rotaliæ* containing these dark spherules were isolated by Schulze, and kept for many weeks, but no change could be observed in them; and it must at present be regarded as quite uncertain whether the foregoing phenomena have any relation to the reproductive process.

49. More satisfactory information was subsequently obtained by the same excellent observer (XCVIII) in regard to the production of the young of *Miliola*. Having obtained some large living specimens of the *triloculine* form of Miliola, he kept them for some time under inspection, and found that some of them, after remaining adherent to the sides of the glass vessel during from eight to fourteen days, became invested with a brownish, slimy matter, which more or less completely obscured the view of the external characters of their shells. After the lapse of some days longer, minute, sharply-defined granules could be seen in this substance with the aid of a lens (Plate IV, fig. 4, A), and these gradually loosened themselves from the soft enveloping mass, and separated further and further from the shell which it surrounded. Microscopic examination of these corpuscles, of which as many as forty were counted round a single progenitor, proved that they were young *Miliolæ*. When viewed by transmitted light, they presented a pale, yellowish-brown, calcareous shell, consisting of the

central globular primordial chamber in which all *Foraminifera* seem normally to commence, partly surrounded by a closely applied tubular part, not separated from the preceding by any distinct septum (fig. 4, B). In a short time, the young animals put forth their pseudopodia from the aperture of the shell, and crawled about upon the surface of the glass. The shell was sufficiently transparent to enable the contained sarcode-body to be examined with high magnifying powers; and it was seen to consist throughout of the ordinary protoplasmic substance, without any vestige either of nucleus or of contractile vesicle. The latter half of the tubular volution of the young shells was observed not to be completely occupied by the animal substance, whilst the central portion was densely filled, the oil-particles especially accumulating in the latter position. When the calcareous shell of the parent *Miliola* was carefully broken up, it was found to contain only trifling remains of fine granular sarcode, which did not put forth any pseudopodia, and in which no vestige could be traced of anything resembling a young animal in progress of development. Hence it would appear as if the principal part of the body of the parent had been transformed into the bodies of the brood of young, which seem to quit the parent in an advanced condition, probably acquiring their shelly envelope before leaving that of their progenitor.—Prof. Schultze has since (XCIX, p. 320) had the opportunity of observing a like phenomenon in the case of a small *Rotalia*, about 1-100th of an inch in diameter, which was living attached to the interior of a glass bottle. The yellowish-brown contents, especially of the larger chambers, exhibited a peculiar coarsely granular consistence, observable even with a strong lens; and on breaking up the shell, which contained ten chambers, twenty or thirty small Polythalamia were found in its interior. These were all of equal or nearly equal size, and consisted of three mutually adherent, nearly globular chambers, of which the first and innermost was the largest, and was filled with large pigment-vesicles, resembling fat-globules, while the other two were colourless. The shell was very thin and brittle, and corresponded in the dimensions of its chambers with the first-formed portion of that of the parent. On watching other individuals which presented the same coarsely granular appearance, it was observed that a multitude of granules suddenly appeared in their neighbourhood, which proved, on examination, to be young Polythalamia, of the same size and form as those artificially freed from their parent, and only differing from them in showing the yellow colour in the second as well as in the first chamber. Whether they made their escape by the rupture of the shell of the parent, Prof. Schultze did not succeed in determining with certainty, but appearances favoured the belief that such was their mode of exit.—Dr. T. Strethill Wright has lately (CXII, p. 362) confirmed an observation formerly made by Ehrenberg, as to the presence of the young of *Spirillina vivipara* in the interior of the shell of the parent.—I may add that I have in my possession a number of very young specimens of *Orbitolites*, consisting simply of the primordial chamber and the one immediately surrounding it (Plate IV, fig. 22), which were removed by Mr. W. K. Parker from the deeply-channeled margin of one of these large plicated forms of *Orbitolites* that present themselves in certain localities of the Polynesian Archipelago. In that specimen they occurred in considerable numbers.

50. Whether the transformation of the sarcode-body of the parent into the substance of the young occurs in the foregoing cases as the result of anything like a sexual act, or is effected (like the formation of zoospores among Protophytes) simply by the breaking up of the original

protoplasmic mass, is a question as to which there is not at present the slightest evidence on either side; and it is much to be desired that observers who have facilities for the study of the reproduction of the *Foraminifera* should systematically and perseveringly investigate it. The only observations yet recorded, that indicate the existence of a sexual process in *Foraminifera*, are those of Dr. T. Strethill Wright (CXII), who states that on examining a great number of specimens of *Gromia*, *Cornuspira*, *Miliola*, *Rotalia*, and *Orbulina*, he has repeatedly discovered bodies which correspond to the "primitive ovum" of *Acalephæ*. They consist of transparent spheres or ovoids, formed of a finely molecular substance, in which, however, the molecules are masked or rendered indistinct by the highly refractive matter in which they are imbedded. He was never able to detect either germinal vesicle or germinal spot in the living specimens; but in a specimen of *Truncatulina* which had been hardened in spirit, decalcified by dilute nitric acid, and then mounted with strong heat in Canada balsam (Pl. IV, fig. 5), four of the segments (*c*, *c*, *c*, *c*) each contain an ovum, which shows a germinal vesicle and spot with the utmost distinctness, whilst the rest (*d*, *d*) present the usual appearance of granular, low-refracting sarcode. The ova of *Gromia* are small enough to escape by the aperture of the "test:" and as young *Gromiæ* are met with slightly larger than these ova, it seems probable that the ovum is at once transformed into the body of the offspring, and that it directly acquires an envelope. But in *Orbulina* and *Truncatulina* the ova are of much larger proportionate size, having in the latter case as much as ten times the diameter of the primitive segment, and being far too large to escape by the aperture of the chambers which contain them. Hence it is considered probable by Dr. Wright that the ova of these genera undergo a polymorphic development of many months' duration, similar to that supposed by Carter to occur in *Amœba verrucosa* (¶ 47); and that each ovum becomes transformed by fission (of which process he detected indications) into numerous amœboid zooids, which escape through the openings of the shell and form the primordial segments of future Rhizopods. The observations of Prof. Schultze upon *Rotalia*, however, would rather lead to the inference that the segments into which the ovum breaks up remain in connexion with each other, and constitute, not the primordial segment only, but the segments immediately succeeding it, in each of the young, and that these escape by the rupture of the shell of the parent.—Specimens occasionally present themselves which indicate that a partial binary fission of the germ may take place at a period anterior to the calcification of the wall of the primordial segment. Thus Prof. Williamson (CX) has described a twin monstrosity of *Entosolenia* (fig. 32, *a*), and a similar example of *Dentalina* (fig. 49), which have obviously originated in an incomplete subdivision of the primordial segment: and he states (p. xi) that "whenever such specimens occur, it invariably happens that the two halves of the twin organism belong to the same variety or type,"—a fact of some importance as indicating that the *transmission* of varieties is effected, as in Plants, by those processes of subdivision which take place under the form of fission or gemmation, whilst the *origination* of varieties is rather to be looked for in sexual generation. Some curious examples of the same kind of "monstrosity by excess," occurring in *Orbitolites*, have been described and figured by myself (XIII); and in those cases also Prof. Williamson's general statement was fully borne out.

CHAPTER III.

OF THE FORAMINIFERA GENERALLY; THEIR CHIEF TYPES OF STRUCTURE AND MODES OF GROWTH, AND THE PRINCIPLES TO BE FOLLOWED IN THEIR CLASSIFICATION.

51. THE group of Rhizopods which is known under the designation FORAMINIFERA has been shown in the preceding Chapter to be distinguished from the other great divisions of its class, not only by that investment of the sarcode-body with a calcareous shell which constitutes its most easily recognised feature, but by such a peculiarity in the condition of the sarcode-body itself, as seems to justify a marked separation of the animals which exhibit it from those formed upon the type either of the *Amœba* or the *Actinophrys*. That peculiarity (it may be well to repeat) essentially consists in the absence of differentiation in the semi-fluid protoplasmic substance of which the body is composed; its homogeneousness being especially manifested in the freedom and minuteness with which its pseudopodial extensions subdivide, and in the readiness and completeness of their coalescence wherever they come into contact with each other, so as by their ramification and mutual inosculation to form a living network, along the threads of which a circulation of granular particles is continually taking place. Of the Order RETICULARIA thus constituted so few other forms exist, that it may be almost said to be synonymous with the group of FORAMINIFERA; and it may indeed be questioned whether in a classification based on physiological principles there is any adequate ground for separating from the calcareous-shelled *Miliola* (¶ 35) either *Gromia* (¶ 33) whose "test" is membranous (probably chitinous), or *Lieberkuhnia* (¶ 32) which has no firm covering at all. So far as we yet know, there is no difference whatever between the animals of these three types; and to class them separately, still more to arrange *Gromia* and *Lagynis* (as Schultze has done, XCVII, p. 52) with *Arcella* and *Difflugia*, on account of the unilocular condition of the "test," would seem just as unnatural as it is now admitted to have been to separate *Hydra* from the compound HYDROIDA, and *Actinia* from the compound HELIANTHOIDA, and to group together *Hydra* and *Actinia* as naked solitary polypes, whilst their composite representatives were classified according as they form horny or calcareous skeletons. Until, therefore, some more adequate ground of differentiation shall have been established than any at present known, the group of FORAMINIFERA may be considered as really coextensive with the Order RHIZOPODA RETICULARIA; and there

seems the more reason for including *Gromida* and even *Lieberkühnia* within its limits, when it is borne in mind that in the limitation of the origin of the pseudopodia to one part of the body these forms bear a closer relationship to the Foraminifera of the *Milioline* series, than the latter do to those of the *Rotaline*, in which the pseudopodia seem to extend themselves equally from any part of the sarcode-body.

52. Before enlarging upon the value of the differential characters just alluded to—which will be shown to have such an important relation to certain peculiarities in the structure of the Shell, as to justify the employment of these as characteristics of the fundamental divisions of the group—we must stop to inquire how far the separation of the *Monothalamous* or *Unilocular* Foraminifera, as an order distinct from the *Polythalamous* or *Multilocular* (a separation which has been adopted by D'Orbigny, Schultze, and Bronn), is to be regarded as based on a right appreciation of their mutual affinities. It has been seen that, in common with all the lower forms of animal and vegetable life, the Rhizopoda tend to multiply by a separation of continuously growing parts of their bodies, which may take the form either of *fission* or of *gemmation*, according as the original body undergoes subdivision, or as it puts forth an extension which eventually detaches itself. Among the Foraminifera proper, whose bodies are enclosed in unyielding shells, multiplication by fission cannot take place, except in that early stage of existence in which the shell is not as yet consolidated (¶ 50); but extension by gemmation may go on without limit. The progressive growth of the sarcode-substance causes a portion of it to project beyond the aperture of the shell; and this projecting portion possesses all the attributes of the body of which it is an extension, and can maintain its existence with equal readiness either in a separate state (¶ 39) or in continuity with the stock of which it is an offset. Although, therefore, there are certain types of Foraminifera in which such offsets appear invariably to separate themselves before the consolidation of their shell, so that the original body never adds to the number of its segments and the shell remains "monothalamous,"—whilst there are others in which they ordinarily remain in connexion with the original stock, so as progressively to augment the number of its segments and of the chambers of its "polythalamous shell," often to an indefinite extent,—there is no such essential difference between the physiological conditions of the newly formed segment in the two cases, as would be required to justify the erection of the *Monothalamia* into a distinct order.* Moreover, we find that between these two groups there are gradational affinities of such a kind as to render it impossible to separate them by a decided line of demarcation. For, on the one hand, there are certain Monothalamous Foraminifera which may be regarded as *potentially* Polythalamous, the body and shell having the power of indefinite extension, but not exhibiting any distinct segmentation; as is the case with *Cornuspira* and *Spirillina*, of which the former is intimately related to the least specialised forms of *Miliola* (¶ 104), whilst the latter is scarcely less closely related to certain *Rotaliæ*. On the other hand, since there are certain Polythalamia (¶ 40), the successive chambers of whose shells are so slightly connected

* No botanist would think of separating from their natural allies, and ranking together as a distinct order, those Plants which habitually propagate themselves by detached *gemmæ*, such as *Lunularia vulgaris* and *Lemna gibba* (which are only known to reproduce themselves after this fashion), or *Dentaria bulbifera*, *Globba amarantina*, and *Lilium bulbiferum*.

as to be easily separable from each other by accidental violence, and of which the animals can maintain their lives just as well when they are thus broken up into distinct segments as when retaining their original connexion, such may be regarded as *potentially* Monothalamous; and the fact that the segments of sarcode, as they were successively budded forth from the stock, formed their shelly investments before instead of after their detachment from it, can scarcely be admitted by the physiologist as alone justifying an ordinal differentiation which is not borne out by other structural or physiological diversities.

53. It was not unnatural that, in seeking for a basis on which to found an arrangement of the multitudinous forms of Foraminifera which he for the first time brought together under one distinct category, M. D'Orbigny should have attached primary importance to characters so easily recognised as those which are produced by diversities in the plan on which the successive segments are added one to another. For the varieties of form thus produced seem at first sight easily capable of being reduced to a small number of primary types; and it is only by such a laborious and conscientious comparison of *osculant forms* as formed no part of M. D'Orbigny's method of study, that the essential conformity in plan of growth is discovered which often exists between organisms arranged by him under different orders; whilst it is only by an equally painstaking examination of the internal structure of the shell, such as seems never to have been even thought of by M. D'Orbigny, that those very marked characters are brought to light, which often separate by the widest interval organisms grouped by him under the same order, and which bring these respectively into intimate relationship with others whose place in his series is very remote. Thus, when we come to speak of the genus *Cristellaria*, we shall find that it comprehends a series of straight, curved, and spiral forms, agreeing with each other in all essential particulars save the direction of their axis of growth, and presenting such a continuity in the gradation from the straight to the curved, and from the curved to the spiral, as prevents any decided line of demarcation from being anywhere drawn among them. So, again, we shall find that although, on the ground of conformity in their plan of growth, *Orbitolites* and *Cycloclypeus* would be grouped together by M. D'Orbigny in his order *Cyclostègues*, whilst *Orbiculina*, *Peneroplis*, and *Operculina* are placed in his order *Hélicostègues*, and *Heterostegina* in his order *Entomostègues*, a careful comparison of the essential features of their structure shows that not only have *Orbitolites* and *Cycloclypeus* nothing in common but their cyclical mode of growth, but that *Orbitolites* is most intimately related to *Orbiculina* (which often takes-on the cyclical mode of growth), and through it to *Peneroplis*, whilst *Cycloclypeus* is scarcely less intimately related to *Heterostegina* and through it to *Operculina*. It may, in fact, be most safely asserted, that *plan of growth* is no more to be regarded as an exponent of the really natural affinities of the several generic types of Foraminifera, than the number of stamens and pistils is of the natural affinities of Phanerogamous plants. The system founded upon each of these bases will doubtless, in many instances, bring together types which have a real affinity to each other, simply because the characters in question sometimes coincide with those of more essential value; but such coincidence is (so to speak) accidental; and it much more frequently happens in the one as in the other of these artificial systems, that they separate by a wide interval types which in reality are closely related, whilst those which they bring into nearest proximity are essentially diverse in organization.

54. The foregoing remarks are scarcely less applicable to the classifications of Professors Schultze (XCVII) and Bronn (XI) than they are to that of M. D'Orbigny; since by them, as by him, the *plan of growth* is regarded as the fundamental basis of systematic arrangement, so that their primary divisions are eminently *artificial*. They have been guided, however, in their subdivision of Orders into Families by a higher appreciation of the characters furnished by variations in the *texture of the shell*, than was entertained by M. D'Orbigny; and they have thus been led to a more natural grouping of generic forms than his classification usually presents.—As neither of their systems, however, has yet found its way to general acceptance, it scarcely appears necessary here to enlarge upon their defects; these being necessary results of the imperfect method of study which their authors have followed; and the object of the present work being to substitute a classification, which, however incomplete, shall, at any rate, present an approximation to a *natural* system, as being based on the whole aggregate of the ascertainable characters of the several types, instead of on a single feature which affords no reliable indication of their real affinities.

55. It is now universally admitted by Philosophical Zoologists, that the importance of the characters furnished by the *skeleton*, whether internal or external, of any animal, depends entirely upon the relations which they bear to its general organization; and that hence the adoption of any such characters as a basis for classification can only be justified, when their accordances and differences can be shown to be indicative of corresponding accordances and differences in those parts of the organism which are of higher physiological import. Thus the possession of a *bivalve* shell is universally admitted as differentiating the Mollusks which bear it from those whose shell is *univalve*, the whole plan of structure of the animals in the two cases being obviously different. But among "bivalve" Mollusks there are two very distinct types of structure (the Lamellibranchiate and the Palliobranchiate), whose essential dissimilarity, being only revealed by anatomical inquiry, would never have been recognised by the mere Conchologist; although, when he has once made himself acquainted with these types, he finds no difficulty in distinguishing the shells they respectively include by the special characters which they severally present. So among "univalve" Mollusks there is not less diversity of type, shells composed of a single piece being found among Gasteropods, Pteropods, and Cephalopods; and the conformation of the shell is here so much less intimately related to that of the animal by which it is constructed, that it is not always possible to refer a shell with certainty to its proper place while the nature of its animal inhabitant is unknown. Further, "univalve" shells are formed also by *Annelida*, and there are no well-defined characters by which the tubes of a *Serpula* (Annelid) and these of a *Vermetus* (Gasteropod Mollusk) can be distinguished one from the other; so that in a system of classification founded upon the shell alone they would be placed side by side, as would also the Crustacean *Cirrhipedes* and the Gasteropod *Chitons*, because both these tribes of animals have their bodies protected by *multivalve* shells. Among Zoophytes, again, whilst the "lamelliform" structure of the stony Corals is so uniformly related to the *Actiniform* type of organization, that the existence of that structure in the oldest fossil affords a sure key to the nature of the animal which formed it, the polyparies which constitute the skeletons of animals of the *Alcyonian* type are so diverse in their composition and arrangement, that it only becomes safe to predicate the

animal from the polypary, when each type of skeleton has been examined in connection with the soft body it supports. On the other hand, we not unfrequently find that a close resemblance in the structure of the polypary masks an essential diversity in the organization of the animal; certain horny skeletons of *Hydrozoa* being scarcely distinguishable from those of *Polyzoa*, although the former belong to true Zoophytes, whilst the latter are members of the Molluscous sub-kingdom.

56. It seems obvious, then, that no classification of FORAMINIFERA can be thoroughly satisfactory, which is based rather on the characters of their shells than on those of the animals by which those shells are formed; and it is unfortunate that our knowledge of the latter is as yet so imperfect, as to afford us but a very slight foundation for a natural arrangement of the group. It may be questioned, indeed, whether the extreme *indifferentism* of structure which seems to be a general characteristic of the Rhizopod type and to reach its *acmé* in the Foraminifera, will not always prevent the systematist from finding the study of the animal of much avail to him; and whether he will ever be relieved from the necessity of placing his chief reliance on those features in the structure of the shell, which may be regarded as most surely indicating the *potentialities* of the apparently homogeneous jelly-like mass which it encloses. Such, at any rate, must be his method of procedure under existing circumstances; and as there is at present nothing to be added to the general account already given of the structure and life-history of the sarcode-bodies of the Foraminifera, our attention will be now directed to the characters furnished by the investments which they form, with a view to determine what are those on which the primary and secondary subdivisions of the group may be most satisfactorily based.

57. *Texture of the Shell.*—In the shells of Foraminifera, as was correctly pointed out by Prof. Williamson (cx, p. xi), three very distinct varieties of texture are easily recognisable: the *porcellanous*, the *hyaline* or *vitreous*, and the *arenaceous*.—In the first of these varieties the shell, when viewed by reflected light, presents an opaque-white aspect, which bears a strong resemblance to that of porcelain, especially when (as in *Peneroplis*) its surface is highly polished. When thin natural or artificial laminæ of it, however, are viewed with transmitted light, the opacity gives place to a rich brown or amber colour, which seems to be imparted by the animal matter that is united with the calcifying deposit, the colour of the sarcode-body being usually the same as that of the shell. In a few instances both the shell and the animal body have a rich crimson hue. No structure of any kind can be detected in this kind of shell-substance, which is apparently homogeneous throughout. When shells of this character are decalcified by dilute acid, a delicate, gelatinous-looking substratum of animal matter is left, very distinct in its aspect from the sarcode-body which the shell included (Plate IV, fig. 14). This, in fact, seems to bear the same relation to the protoplasmic substance, that the cellulose wall of the vegetable cell bears to the "endoplast" from the surface of which it is excreted; and just as in *Diatomaceæ* the consolidation of that exudation by silex forms the beautiful *loricæ* characteristic of that group, so here does the consolidation of an analogous excretion-layer by alcareous deposit form the shelly wall of each segment of the animal. Although the shells of the porcellanous type often present the appearance of being perforated with foramina, yet this appearance is illusory, being due to a mere "pitting" of the external surface, which pitting

though often very deep, never extends through the whole thickness of the shell. Some kind of inequality of that surface, indeed, is extremely common in the shells of the porcellanous Foraminifera. Very frequently it presents an alternation of ridges and furrows, such as distinguishes certain varieties of *Miliola* (Plate VI, figs. 3, 4); and this alternation is so regular and constant in *Peneroplis* (Plate VII, fig. 18), and in the first-formed segments of *Vertebralina* (Plate V, figs. 17—25), as to be peculiarly characteristic of those types. In other instances, especially among the *Miliolæ*, we find the surface marked by depressions which may vary greatly in size and in arrangement (Plate VI, figs. 13, 14), being sometimes minute punctations, in other cases being large areolæ; being sometimes scattered with no apparent regularity, in other instances disposed with the most exact symmetry. But no difference of texture accompanies any of these inequalities of the surface, the raised and depressed portions being alike homogeneous.

58. In the shells of the *vitreous* or *hyaline* type, on the other hand, the proper shell-substance has an almost glassy transparency; which is shown by it alike in the thin natural laminæ of young specimens, and in artificially-prepared sections of such as are thicker and older. It is usually colourless, even when (as is often the case with *Rotaliæ*) the substance of the animal is deeply coloured. In certain aberrant forms of the Rotaline type, however, we shall see that the shell is commonly, like the animal body, of a rich crimson hue. But notwithstanding the transparence of their substance, these shells derive an adventitious opacity from being channeled out more or less minutely by tubular perforations, which, when occupied either by air or by any substance having a refractive power different from that of the surrounding shell, interfere with its power of transmitting light, and cause it to reflect a large part of that which falls upon it. Their effect varies, however, according to their degree of minuteness and the closeness of their arrangement. Thus, in *Rotalia*, in which they are commonly almost 1-3000th of an inch in diameter and somewhat more than that apart from one another (Plate XIII, fig. 1, A), the hyaline transparence of the thin shell makes itself apparent between them, and imparts to its entire surface a vitreous aspect. In *Operculina* and *Cycloclypeus*, on the other hand, in which the average diameter of the tubuli does not exceed 1-10,000th of an inch, and their distance from each other is not much greater, every part of the shell that is traversed by them presents a semi-opacity, which only disappears when extremely thin sections are made in a direction exactly transverse to the axis of the tubes, so as to enable the transparence of the intervening substance to display itself without interruption (Plate XIX, fig. 4). It often happens, however, that certain parts of the shell are left unchanneled by these tubuli; and such are at once distinguished, even under a low magnifying power, by the readiness with which they allow transmitted light to pass through them (Plate XVII, figs. 12, 13, *aa*, *a′a′*, *bb*), and by the peculiar vitreous lustre they exhibit when light is made to fall obliquely upon their surface. In shells formed upon this type we frequently find that the surface presents either bands or spots which are thus distinguished; the non-tubular bands usually marking the positions of the septa (Plate XVII, fig. 1), and being sometimes raised into ridges, though in other instances they are either level or somewhat depressed, whilst the non-tubular spots may occur on any part of the surface, and are most commonly raised into tubercles (Plate XV, fig. 5, and Plate XIX, fig. 5), which sometimes attain a size and number sufficient to give a very distinctive character to the

shells that bear them. In shells of this type, however, which have been long dead and exposed to the action of sea-water, the vitreous transparence often gives place to a lustrous white opacity, that is particularly striking in the prominent tubercles; as is remarkably shown in the tuberculated variety of *Planorbulina vulgaris* (Plate XIII, fig. 15). The texture of the shells of this type is much firmer than that of the porcellanous shells; approaching closely to that of the inferior forms of dentine, or to that of the terminal portion of the crab's claw.

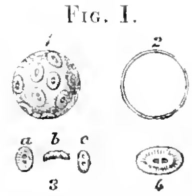
59. Between the comparatively large apertures which are common in the *Rotaline* type, and the minute tubuli of the *Operculine*, there is such a continuous gradation as indicates that their mode of formation, and probably their uses, are essentially the same. In the former it has been demonstrated by actual observation that they allow the passage of pseudopodial extensions of the sarcode-body through every part of the external wall of the chambers occupied by it; and there is nothing to oppose the idea that they answer the same purpose in the latter, since, minute as they are, their diameter is not too small to enable them to be traversed by the finest of the threads into which the branching pseudopodia of Foraminifera are known to subdivide themselves. And it seems the more likely that they answer this purpose, when attention is given to the remarkable continuity which they exhibit through a considerable thickness of shell, formed of numerous lamellæ that seem to have been added at successive periods of growth (Plate XIX, fig. 3). Now, if this be the case, it is not difficult to account for the production of a texture closely resembling that of dentine, without having recourse to the hypothesis (xxv, p. 421) of a higher organization in the bodies of these animals than that which we have other grounds for admitting. For if the shell-substance be, as there seems reason to believe, an excretion from the protoplasmic mass of which the body itself is composed, each new lamella, as it is added to the preceding, will mould itself upon the pseudopodia that issue from the orifices of the subjacent surface; either some difference in their composition, or the activity of the changes continually taking place in their substance (¶ 34), preventing them from being involved in the consolidation which takes place around them. We have an illustration of the same kind on a larger scale, in the extension of the straight branches of the canal-system which pass through the solid masses of shell-substance that occupy the umbilical regions in the shells of *Calcarina* and *Polystomella* (Plate XIV, fig. 3, and Plate XVI, fig. 3): the successive accretions of vitreous material being so disposed around the extensions of the sarcode-body which occupy these passages, as to preserve their continuity throughout, and thus to maintain the most direct relation between the parts of the canal-system most deeply buried beneath these accretions, and the external surface from which they become further and further removed. If this should prove to be the true account of the formation of the dentine-like tissue produced by the higher type of *Foraminifera*, it will deserve consideration whether a like explanation may not be applicable to the formation of analogous calcified tubular tissues in animals much more elevated in the scale; especially since there is increasing reason to believe that the development of such tissues takes place after a far simpler fashion than has been commonly supposed, and that their foundation is laid in a homogeneous blastema, rather than in a matrix possessing distinct organization.

60. Besides these two principal types of shell-structure, another is met with in certain groups of *Foraminifera*, which is designated as the *arenaceous*; the shells being formed, either

partially or wholly, not of a calcareous exudation from the sarcode-body, but of particles of sand obtained from without, the cement with which they are attached together being all that is furnished by the animal. The aspect of such "arenaceous" shells necessarily varies considerably with the kind of material of which they are composed: and the same type, inhabiting several different localities, may thus present as many diverse *facies*. Thus, the *Textularia* dredged off the Canary Islands have their shells entirely composed of fine particles of a black sand, apparently formed by the disintegration of volcanic rocks; whilst those of the Red Sea have shells of a grayish-yellow colour, the arenaceous particles of which vary much more in their nature and origin. In some instances the particles are very uniform in size, and are very methodically disposed (like those of which the tube of *Pectinaria* is made up); so that the surface of the shell has almost the appearance, when sufficiently magnified, of a tesselated pavement (Plate VI, fig. 41). This regularity—alike in size, form, and arrangement,—is sometimes so remarkable as to have given rise to the supposition that the siliceous particles are not derived from external sources, but are formed by exudation from the surface of the contained body. As, however, there is no siliceous "test" at present known to be formed by an animal of this group, which is not obviously made up of an aggregation of distinct particles, instead of possessing the structural homogeneousness proper to the shells which are undoubtedly formed by calcareous or siliceous consolidation, it would probably be correct to say that the true "shell" of *Foraminifera* is uniformly *calcareous*, and that when this is replaced by a siliceous "test" the materials of such test have been drawn together from external sources. There are certain cases, on the other hand, in which the sandy particles are less uniform in size and less regular in disposition, and are imbedded in a calcareous cement which forms the essential constituent of the shell; in these the arenaceous texture, being superficial only, and to a certain extent accidental, has not that importance as a differential character which it bears when extending throughout the thickness of the shell.*

* The surface of certain Foraminiferous shells (especially *Globigerinæ*) is not unfrequently studded with the minute rounded or oval bodies to which the name "coccoliths" was first given by Professor Huxley. (See his Appendix to the 'Report on Deep-Sea Soundings in the North Atlantic Ocean, between Ireland and Newfoundland, made in H.M. "Cyclops," Lieut.-Com. Dayman, in June and July, 1857.") These bodies have been since observed by Dr. Wallich (CIV *b*), not only in the free state, but adherent to the surface of minute spherical cells which seem to constitute a rudimentary type of *Foraminifera*; the uniformity of this adhesion being such as to lead almost necessarily to the conclusion that it is a normal condition. These "coccoliths" are described by Dr. Wallich as of an oblong form, concave on their internal aspect, and convex externally (Fig. I, 3, 4), their average length being about 1-2700th of an inch; in some specimens there is but a single aperture in the centre; in others the aperture is double, the two portions being separated by a delicate transverse band; and the external marginal surface, which constitutes a quoit-like oblong ring round the central perforated portion, is marked with radiating striæ. The spheres, to the surface of which the coccoliths are found adherent at nearly regular intervals, are stated by Dr. Wallich to have a diameter from 1-1250th to 1-1600th of an inch, and to be composed of a sarcode-like substance enclosed in a delicate limitary wall, apparently consolidated by calcareous deposit (Fig. I, 1, 2). These bodies, to which he has given the name of "coccospheres," are

Fig. I.

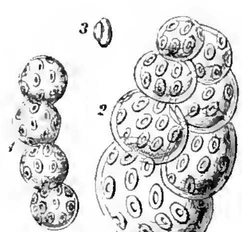


1, 2, Coccospheres. 3, 4, Coccoliths.

61. To separate all the *Foraminifera* that form "arenaceous" shells from those of the "porcellanous" and "hyaline" types, to which many of them obviously bear the closest affinity, would be a violation of the first principles of a natural arrangement; and yet we shall find that there are certain generic types in which the sandy texture is a character of great systematic importance. Thus, on the one hand, in the low "porcellanous" type *Nubecularia*, and in the "triloculine" and "quinqueloculine" forms of the more elevated type *Miliola*, individuals frequently present themselves whose surface is rendered arenaceous by the imbedding of sandy particles in their ordinary calcareous shell-substance; but for being thus "rough-cast," such individuals would present the ordinary aspect of their respective types, to which they are entirely conformable in every other character; and it would be manifestly improper to rank them apart on account of this trifling variation. So even when we find truly arenaceous shells presenting the characteristic forms of the "hyaline" genera *Bulimina* and *Textularia*, since we find at the same time that not only do they correspond in general structure to the calcareous shells respectively peculiar to those genera, but are perforated like them by regular pores for the passage of pseudopodia, we feel that we have no right to dissociate what are manifestly nothing else than varieties of a common type. But when, on the other hand, we find that certain assemblages of forms, constituting well-marked generic types, can be uniformly characterised by the possession of "arenaceous" shells,—as is the case with *Trochammina*, *Valvulina*, and *Lituola*,—it becomes obvious that this peculiarity is to be regarded as a distinctive feature of higher value, since it marks a fixed and decided physiological condition, the occurrence of which elsewhere is only occasional or incomplete. The absence of any pseudopodial pores in the walls of the chambers of the shells of this group shows their affinity to be rather with the porcellanous than with the hyaline series, notwithstanding the very close resemblance in form which some of them present to particular types of the latter,—*Valvulina*, for example, to *Bulimina*, certain *Lituolæ* to *Nonionina*, and *Trochammina* to *Spirillina*.

62. Turning now from the ultimate texture of the shell to its conformation, we have to inquire whether there are any fundamental and essential diversities in its *mode of increase*, which can be advantageously used as differential characters. It may be stated as an unquestionable fact, that the shelly casing, once formed to any portion of the sarcode-body, cannot be enlarged by interstitial growth; and hence it can only be adapted to the augmenting dimensions of that body, by addition to the part already formed. In the greater part of the

Fig. II.



Coccospheres, with attached coccoliths, growing (1) on the *Nodosarian*, (2) on the *Textularian* type.

sometimes united in series, after the manner of certain forms of *Foraminifera*; thus in Fig. II, 1, is shown a *Nodosarian* series of four equal cells; whilst at 2 is seen a *Textularian* series of seven cells, which increase regularly in diameter from 1-1250th to 1-450th of an inch. The "coccoliths" do not appear to be attached to the wall of the "coccosphere" in any other way than by gelatinous adhesion; and hence they are very easily detached, so as to form a considerable proportion of many deep-sea deposits. Similar bodies have been found in Chalk by Mr. H. C. Sorby.

"monothalamous" Foraminifera, the contraction of the aperture entirely forbids the enlargement of the cavity by any such addition, but those spiral forms in which there is no such contraction are capable, like the tubular shells of Annelids and certain Mollusks, of being indefinitely extended; and it is simply because of its absence, that they present no indication of the segmental division which would otherwise be marked by a transverse septum every time that a longitudinal addition is made. This is the case with the genera *Cornuspira*, *Trochammina*, and *Spirillina*, which are respectively the porcellanous, arenaceous, and hyaline representatives of the simply spiral plan of conformation; and it is obvious that, although structurally "monothalamous," these genera are in reality more nearly allied in their capability of unlimited growth to the "polythalamous" series. The "polythalamous" shells are formed, as already explained, by the repeated gemmation of the sarcode-body; and it usually (though by no means constantly) happens that the successive gemmæ increase in size, so that each chamber is larger than the one which preceded it. The simplest types of *Polythalamia* are those in which the segments of the shell have only an external adhesion, the cavities of their chambers having no communication with each other; as is the case in the *imperforate* series with *Dactylopora* and *Acicularia*, and in the *perforated* with *Globigerina*. Save in these types, however, the cavity of each segment always communicates with that of the segment from which it is budded off; and this it may do merely by the apertural neck of the older segment, which dilates into the globular cavity of the newer, so that the succession of segments is united into the semblance of a string of beads, as we see in some forms of *Nodosaria* (Plate XII, fig. 2). More generally, however, the apertural portion of one segment is completely embraced by the walls of the next chamber, in the manner diagrammatically represented in Fig. III, where the primordial chamber is seen at 0 and its aperture at *a*; this aperture is received into the second chamber, 1, the lateral wall of which joins the anterior wall of the preceding at *b*; in like manner, the aperture a^1 of the second chamber is received into the third chamber 2, the aperture of this, a^2, into the next chamber 3, and so on, the aperture a^4 of the last chamber opening externally.—A great alteration in external shape may be produced, without any departure from the rectilineal plan of growth, by the still more complete reception of the anterior portion of the older chamber into the posterior portion of the newer; as is shown in Fig. IV, which diagrammatically represents the "frondicularian" form of *Nodosarina*.—

FIG. III.

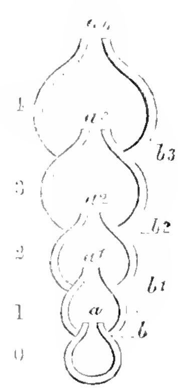
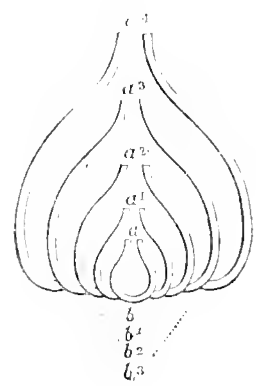


FIG. IV.



On the other hand, a complete alteration in external configuration may be produced by the substitution of a *curvilinear* for a *rectilinear* axis of growth; the most ordinary type of the former being a *spiral*, which may be either flat, like that of a *Nautilus*, or may coil around a longitudinal axis, like that of a *Trochus*. Between the rectilineal and the spiral forms of axes of growth a complete gradation is presented in the *Nodosarine* series. In Fig. VII we see that the relations of the chambers may be essentially the same in the spiral as in the rectilineal type; the septal plane that divides each chamber from its successor being formed solely by the anterior wall of the older, which serves as the posterior wall of the newer.

This is the case throughout the *porcellanous* series and with the lower forms of the *vitreous* series. But in the highest types of the latter we find that each chamber of the spire has a

Fig. V.

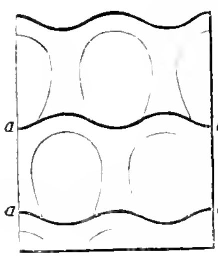


Fig. VI.

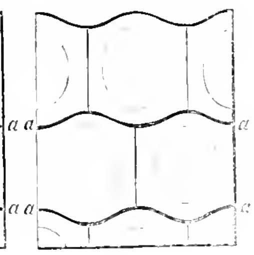


Fig. VII.

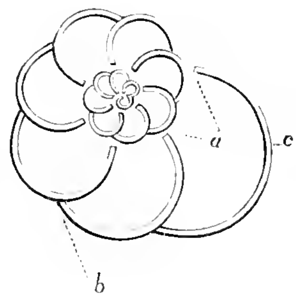
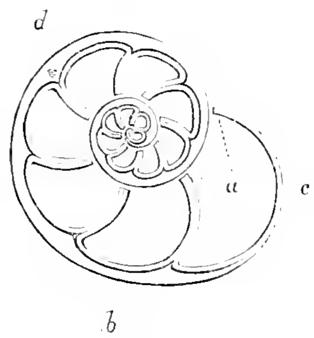


Fig. VIII.



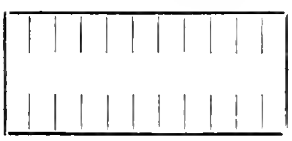
complete shelly envelope of its own, the new segment forming a posterior wall, which applies itself to the anterior wall of the preceding segment, so that each septal plane (except that of the last chamber) is composed of two lamellæ, as is shown in Fig. VIII. —The same difference exists among the *Polythalamia* formed upon the *cyclical* plan of growth, which is ordinarily the result of the gemmation of the primordial segment not on one side only, but from every part of its circumference, and the subsequent repetition of the same mode of increase (see Fig. XXIV, p. 108). For in the cyclical forms of the *porcellanous* series the successive annuli are joined, each to its predecessor, in such a manner that the external wall of the latter serves as the internal wall of the former, as is seen along the lines *a a*, *a a*, Fig. V; and the septa dividing the adjacent chamberlets of the same annuli are also single. In the cyclical forms of the *vitreous* series, on the other hand, each chamberlet has its own proper wall, as is shown in Fig. VI: so that not merely the annular but the radial septa are all double.

63. But this is by no means all: for in the higher types of the hyaline or vitreous series we frequently meet with an "intermediate" or "supplemental" skeleton, formed by a secondary or exogenous deposit upon the outer walls of the chambers, by which they receive a great accession of strength. This deposit not only fills up what would otherwise be superficial hollows at the junctions of the chambers, or (as in *Polystomella*) at the umbilical depression, but often forms a layer of considerable thickness over the whole surface, thus separating each whorl from that which encloses it (Fig. VIII, *d*); and it is sometimes prolonged into outgrowths that give a very peculiar variety to the ordinary contour, as in some varieties of *Rotalia* and *Polystomella*, but most characteristically in *Calcarina* (Plate XIV, figs. 1, 2, 8) and the stellate form of *Tinoporus* (Plate XV, figs. 5—9). This intermediate or supplemental skeleton, wherever developed to any considerable extent, is traversed by a set of "canals," which are usually arranged upon a systematic plan, and are sometimes distributed with considerable minuteness. The passages which make up this "system" are not true *vessels*, but are mere *sinuses*, left in some cases by the incomplete adhesion of the two contiguous walls which separate the adjacent chambers, and in other cases apparently originating in the incomplete calcification of the sarcode which forms the basis of the solid skeleton; certain

portions of that substance remaining in their original condition, so as to maintain a communication between the contents of the chambers and the parts of the calcareous skeleton most removed from them, analogous to that which the Haversian canals afford in the case of laminæ of bone not in the immediate vicinity of a vascular surface. As, therefore, the development of the Haversian system is related to the thickness of the bone-substance to be nourished, so does that of the canal-system in Foraminifera seem to be related to the amount of the consolidating substance which constitutes the supplemental skeleton. There is good reason to believe that these canals are occupied in the living state by prolongations of the sarcode-body, which pass from the chambers into the portions of the system in nearest relation to them, and proceed to its peripheral extensions; and they are largest and most numerous where nutriment has thus to be conveyed to parts of the supplemental skeleton, which (like the outgrowths of *Calcarina*) are very far removed from the segments of the ordinary sarcode-body. Now, although it is only in the largest and most developed types of the hyaline series, that we meet either with a distinct "canal-system" or with any considerable amount of that intermediate deposit which it nourishes, yet the presence of these two peculiar features most strongly differentiates those types from such of the porcellanous series as most nearly resemble them in general plan of growth, and to which, according to any classification essentially founded on that character, they would be most nearly approximated,—as, for example, the hyaline *Operculina* from the porcellanous *Peneroplis*, the hyaline *Cycloclypeus* from the porcellanous *Orbitolites*.

64. Another strongly marked difference, that seems no less obviously related to the physiological condition of the animal than the perforation or non-perforation of the shell, is observable in the degree of separation that exists between the segments of the sarcode-body in the two series respectively; this body even in the most complex types of the imperforate shells being an aggregate of mutually related parts, whilst even in the simplest types of the perforated these parts acquire a much higher degree of independence, so as to live much more *for* and *by* themselves alone. The key to this difference is furnished by the relative size of the aperture, which indicates in the unilocular types the degree of readiness with which the animal can extend itself into the medium it inhabits, whilst in the multilocular it indicates not only this, but also the relative amount of connection between the several segments of the composite structure. Thus, when we compare the unilocular *Gromia* (which, though possessing only a membranous "test," may be considered as physiologically representing the unilocular type of the imperforate Foraminifera) with the unilocular *Lagena*, we are at once struck with the extreme narrowness of the aperture of the latter, as compared with the wide, open mouth of the former (Plate II, fig. 2); and this difference will be readily understood, when it is borne in mind that in one case the principal aperture is supplemented (so to speak) by the pores distributed through the whole of the globular casing that encloses the body of the animal, every one of which allows the passage of a pseudopodium, whilst in the other the sarcode-body, shut up within its "test," has no other means of communication with the external world than that afforded by its single orifice. So, if we compare the apertures of *Nubecularia*, *Vertebralina*, and *Miliola* with those of the *Nodosarian* series, we find a no less striking contrast between the mere constrictions that mark out the segmentation of the sarcode-body in the former, and the almost complete separation that exists between the successive chambers in the latter. In *Peneroplis*, again, although the apertural pores are

individually small (Plate VII, fig. 18), yet their multiplication (which takes place proportionally to the size of the chambers) renders the aggregate communication very free, as we see in the *dendritine* variety, in which the pores are all gathered together, as it were, into one aperture (Plate VII, fig. 1); and the contrast is very marked between the large size of this, and the extreme narrowness of the fissure which forms the only constant communication between the chambers of *Operculina*. The like contrast, in regard to the connection of the successive segments, exists between *Orbiculina*, the spiral type of which may be described as a *Peneroplis* whose principal chambers are partially subdivided by transverse partitions, and *Heterostegina*, which bears the like relation to *Operculina*. And a no less striking difference exists, in this respect, between *Orbitolites*, which is the most developed type of the imperforate series, and *Cycloclypeus*, which holds a like position in the perforated; the communications between the successive annuli in the former, and between the outermost annulus and the exterior, being so numerous and free, as to amount in the aggregate to a large apertural area, whilst in the latter they are so much more restricted as to be not readily discoverable. This tendency to a more complete separation of the segments shows itself yet more strongly in regard to the transverse subdivision of the principal chambers in *Orbiculina* as compared with *Heterostegina*, and in *Orbitolites* as compared with *Cycloclypeus*; for in the two imperforate types we find this transverse subdivision so far from complete, that it resembles that of a long dormitory in which the beds (arranged in rows on the two sides) are separated from each other by partitions that extend from the walls towards the central line of the apartment, but stop short of it, so as to leave a free passage from one end of it to the other; whilst in the two perforated types the chamberlets of each row are entirely cut off from each other laterally, communicating only with those of the rows behind and in front of them. Thus we see that, whereas in the imperforate shells the nutrition of the entire body is derived from the alimentary materials obtained by the last segment alone, every segment in the perforated shells is capable of obtaining, at any rate, a portion of its supply for itself; and hence a much greater degree of individualization of the segments is possible in the latter case than in the former. We shall find this contrast most strongly marked when we come to compare the calcareous skeleton of *Orbitolites* with that of *Cycloclypeus*; the former being, as it were, a concretionary framework, which grows up in the midst of and around the sarcode-body for its support and protection, isolating its parts from each other no more than is required for that purpose; whilst in the latter each segment and sub-segment has its own distinct and complete envelope, which seems (as it were) to be moulded upon its shape, any interspaces being filled in by the intermediate skeleton, whose intervention between the two layers of the double partitions renders the isolation of the chambers yet more complete.



65. Thus, then, we find that, alike in the intimate structure of the shell, in the presence or absence of an "intermediate skeleton" and of a "canal-system" for its nutrition, in the completeness with which each chamber is surrounded by its own proper wall, and in the degree of its separation from adjacent chambers—all which features are as characteristic of every individual portion of the shell as they are of the shell as a whole, and are evidently in intimate relation with the physiological condition of the animal that inhabits it,—a very decided differentiation may be established between the two series of *imperforate* and *perforated*

FORAMINIFERA; and this primary differentiation will be found so constantly to harmonize with the grouping which would be based on the principle of continuity of gradation, that I cannot entertain a doubt of its being the one on which (in our present state of ignorance respecting the physiology of this tribe) our classification may be most securely based. For it will be found that the several types of "porcellanous" Foraminifera, however diversified in form, constitute a series connected throughout by the closest links of mutual affinity; whilst the proper "arenaceous" types form a parallel series, of which the members are not less closely related to each other. In like manner we shall find that the far more numerous forms of the "hyaline" Foraminifera may be ranked together into a small number of assemblages, the members of each of which are so gradationally united that the groups thus composed are obviously in the highest degree natural; whilst these series are at the same time connected with each other, not only by their mutual approximation to certain fundamental types, but also by intermediate forms which serve to link together even their more divergent portions, the whole being thus united into a compact aggregate, of which there is no part that is not held (as it were) to the rest by firmly cohesive attraction.—It must not, however, be supposed that every member of the one series is differentiated by the characters just enumerated from every member of the other. The non-perforation of the walls of the chambers, the singleness of the septal partitions, and the freedom of the apertural communications between the chambers, seem invariably to characterize the shells of the porcellanous type; whilst the perforation of the walls of the chambers, the duplication of the septal partitions, and the straitness of the apertural communications, appear to be no less constant characteristics of the shells of the hyaline type. The "intermediate" or "supplemental" skeleton, on the other hand, presents itself to an extent that makes it readily distinguishable, only in the most developed forms of the hyaline series; and it is not a little remarkable that within the limits of one and the same generic type (*Tinoporus*) we meet with certain forms in which this portion of the fabric is evolved to an extraordinary degree, whilst in others its presence is not to be traced at all. And the same may be said of the "canal-system," which presents its most extensive and symmetrical distribution in the highest examples of certain generic types, whose less elevated specimens show scarcely any traces of it. Hence, whilst the presence of an "intermediate skeleton" and of a "canal-system" in one Foraminiferous shell serves to mark it as belonging to the higher section of the hyaline series, their absence in another must not be regarded as indicating its porcellanous characters, seeing that such absence prevails equally through the lower section of the hyaline series also. And it is chiefly because their presence, in connection with other characters, serves to mark a *nisus* or tendency in the one series, of which no trace whatever is presented by the other, that it has been here included among the features of distinction between the two.

66. On the other hand, there is an entire absence of any other special relation between the members of the "porcellanous" and those of the "hyaline" series, than that which arises out of the configuration of their respective shells; which configuration is determined by their *plans of growth*, that is, by the direction in which new chambers are successively added. Thus, in both series we have rectilineal, spiral, cyclical, and acervuline forms, with every gradation between these; and it is true that such a striking *isomorphism* displays itself between certain types of these two series respectively, as would not unnaturally lead any systematist whose views of classification of Foraminifera might be founded on their supposed Molluscous

affinities to a belief in their mutual affinity. A most complete isomorphism presents itself, for example, in the simple spiral which constitutes one of the lowest forms of the porcellanous, the arenaceous, and the hyaline series respectively; and by such as have not traced out the affinities of this spiral in each series, it might readily be supposed that such a conformity in the plan of growth of the shell must be indicative of conformity in the physiological condition of the animal.* But the porcellanous *Cornuspira* and the hyaline *Spirillina* differ not merely in the texture of their shells, but in what we have seen to be the fundamental character of non-perforation in the one and perforation in the other; and whilst the former graduates almost continuously into the spiroloculine form of *Miliola*, the latter is in like manner related to *Rotalia* through the vermiculate varieties of the latter genus. So the arenaceous, simply spiral *Trochammina*, which agrees with *Cornuspira* in its non-perforation, not only differs from it in the almost purely arenaceous composition of the shell, but also in the varietal forms into which it passes; and by some of these it is brought into relation with the other types of the arenaceous series.—Passing now to the higher forms, we meet with so remarkable an isomorphism between the nautiloid forms of *Peneroplis* and *Operculina* (the septa of the latter genus, besides their regular aperture at the inner margin, being perforated here and there by secondary pores that remind us of the former), between the subdivided spirals of *Orbiculina* and *Heterostegina*, and between the discoidal *Orbitolites* and *Cycloclypeus*, that, in any classification founded mainly upon plan of growth, the genera of each pair must be placed in near proximity to each other; yet they are really separated by *all* those characters which have been shown to possess the highest physiological value, and can only be regarded as "representing" each other in the series to which they respectively belong. A like "representation" will be shown to exist among the higher forms of the arenaceous series; certain varieties of *Lituola*, for example, bearing a close resemblance to *Nonionina*, and others to the spiroline variety of *Peneroplis*; whilst *Valvulina* may take on the forms of *Rotalia*, *Bulimina*, and other hyaline Foraminifera.

67. It seems obvious, from the foregoing considerations, that the importance of *plan of growth*, as a character available in the classification of Foraminifera, is far below that of the aggregate of other characters which stand in more intimate relation to the physiological condition of the animal; and the low value which ought to be attached to it is further indicated by its frequent tendency to variation within the limits of what are shown by the evidence of gradational affinity to be well-marked natural groups. Such a tendency seems greatest in the lower types of each series; "polymorphism" being the rule among them, rather than the exception. Thus we shall find that *Nubecularia*, one of the simplest of the porcellanous Foraminifera, presents itself under such a variety of forms, that the attempt to classify these in any system based on the geometrical arrangement of the successive segments, would lead to nothing but a most absurd separation of what are clearly but varietal modifications of one and the same type. In *Vertebralina* we find, with a closer general conformity to a common type, a range of variation which is still very remarkable; and even when we rise as

* Thus, by Professor Schultze (XCVII, pp. 40, 41), the porcellanous and the hyaline spirals have been ranked as *Cornuspira planorbis* and *C. perforata*; whilst by Prof. Williamson (CX, pp. 92, 93), the porcellanous, arenaceous, and hyaline spirals are designated respectively *Spirillina foliacea*, *S. arenacea*, and *S. perforata*.

high as *Peneroplis*, we very commonly observe a change in the direction of growth from the spiral to the rectilineal with the advance of life. The spiral growth of *Orbiculina*, again, often gives place to a cyclical plan exactly resembling that which is typical of *Orbitolites*; whilst at the commencement of the development of *Orbitolites*, which is typically cyclical, the chambers are sometimes added according to a spiral arrangement. In the same manner, when we enter upon the "hyaline" series, we shall find ourselves compelled by the like continuity of affinities to rank as varietal modifications of the single generic type *Nodosaria* a long list of reputed genera, separated by D'Orbigny under his three orders, *Stichostègues*, *Hélicostègues*, and *Enallostègues*: and marked changes in the plan of growth frequently present themselves among the higher genera of that series in the life of one and the same individual; the early arrangement of the chambers of *Planorbulina* and *Tinoporus*, for example, being as typically spiral as that which prevails in *Rotalia*, but the additions being subsequently made in such a manner as to convert the spiral, in the first instance, into a circular disk, which may then increase at its periphery so irregularly that all definiteness of contour vanishes, whilst the chambers may also be piled one upon another in an irregular "acervuline" manner, so as entirely to mask either their original spiral or their secondary cyclical arrangement.

68. The foregoing examples serve to show, not only that neither *plan of growth* nor *resultant form* can be rightly taken as a character for separating the great primary divisions of FORAMINIFERA, but also that they are so often liable to variation within the limits of genera, that no constant reliance can be placed on them as means of differentiating even these subordinate groups from each other. It will be usually found much safer, in fact, to place our chief reliance on those characters which can be stated in terms of each individual segment, than on those which can only be predicated of the aggregate. And no characters are, in general, so free from the fallacy resulting from tendency to variation, as those which are drawn from the nature and position of the *septal apertures*. Even these, however, in certain exceptional cases, share in the general tendency to variation: and in estimating the value which should be attached to such diversities, it is important to bear in mind the remark already made (p. 8) as to the purpose which is served by these apertures. It must obviously be a matter of no great physiological importance, whether a number of those fine threads of sarcode, which act as stolons connecting the successive segments of the body, and are put forth as pseudopodia from the last, pass out in one undivided bundle, or be separated by the interposition of minute processes of shell, which convert a narrow fissure into a row of pores, or a wide orifice into a cribriform plate. Such a difference exists between the aperture of *Rotalia* and that of *Calcarina*, and between that of *Miliola* and that of *Hauerina*; and it could not be regarded as even of sub-generic value in those two cases, if it were not accompanied by other distinctions. A far greater dissimilarity exists between the aperture of *Peneroplis* and that of *Dendritina*, the former consisting of a linear series of separate pores, whilst the latter is a single, large, dendritic orifice: and yet, as I have elsewhere shown (XV), the former of these conditions graduates into the latter so continuously as to render it impossible to draw any definite line of demarcation between them; and each is related to the shape of the septal plane, which may vary no less gradationally from that of a long, narrow band (Plate VII. fig. 16, *a*), to a cordate or sagittate form (figs. 6, *a*, 14, *b*, *c*), according to the compression or turgidity of the spire. Hence, as there is a most remarkable accordance between these two

types in all other respects, and their differences are such as occasionally present themselves to a certain degree between the successively formed portions of one and the same organism, they cannot be generically separated; and, notwithstanding the extraordinary contrast presented by their extreme forms, both in the shape of their septal plane and in that of their aperture, the one must be regarded as merely a varietal modification of the other.

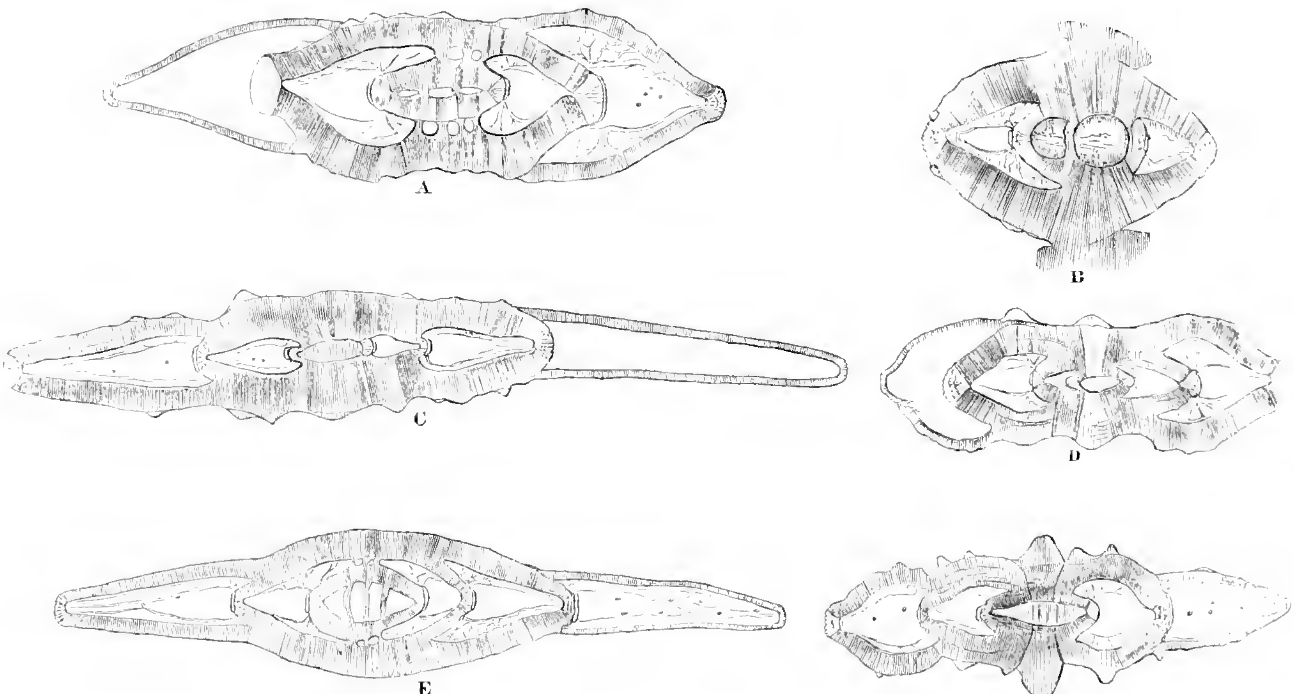
69. Since, then, even the characters which in some groups of FORAMINIFERA are most stable, are in others so inconstant as to be quite valueless for the purposes of the systematist, the inquiry naturally arises whether any definite method of generic and specific differentiation can be laid down; and to this inquiry I have to answer—not for myself alone, but for Messrs. Parker and Rupert Jones, whose views on this point are in complete harmony with my own—that in the present state of our knowledge such a methodization is impossible. Whether it will ever be practicable to arrange the multitudinous forms of this group in natural assemblages whose boundaries shall be capable of strict limitation, is to us by no means certain; since the tendency of every extension of our researches is to enlarge our idea of the range through which these forms may vary. And all that it seems to us at present feasible to attempt, is to group them around certain generic types, each marked by some combination of characters which impresses on it (so to speak) a distinctive physiognomy, and to trace out the principal modifications to which these types are subject through the separate or combined variation of their characters. Among these modifications there will generally be found some which indicate an affinity towards other types, so as to diminish the intervals between each type and those to which it is related. Wherever such a gradation can be shown to exist with anything like complete continuity, its presence will be accounted a sufficient reason for including the whole series (however diversified in its extreme forms) under one and the same generic designation; where, again, it seems likely to be established by further research (which is sometimes especially the case in regard to extinct types), the modification thus related will be ranked as a *sub-genus*; while the existence of such a decided break between any two types, as enables any specimen at present known to be referred without hesitation (after a sufficient examination of its structure and affinities) to one or to the other, will be held to justify their *generic* separation.

70. The impracticability of applying the ordinary method of definition to the *genera* of FORAMINIFERA becomes an absolute impossibility in regard to *species*. For whether or not there really exist in this group generic assemblages capable of being strictly limited by well-marked boundaries, it may be affirmed with certainty that among the forms of which such assemblages are composed, it is the exception, not the rule, to find one which is so isolated from the rest by any constant and definite peculiarity, as to have the least claim to rank as a *natural* species. Nothing is more easy, however, than to make *artificial* species in this group; for the variation to which every one of its generic forms is liable, gives rise to a multitude of dissimilar forms most inviting to those systematists who consider that credit is to be gained by adding new names to the already enormous list; and accordingly we find that a vast mass of such specific names and definitions has been accumulated, of which but a very few really express the facts they are designed to record. For it is the habit of such systematists to pick out only what they consider the well-characterized types, and to disregard the intermediate or osculant forms that establish the gradation between these, neglecting altogether

the fact that the existence of such a gradational series entirely does away with the fundamental assumption on which the idea of a natural species (as ordinarily understood) is based. When a large collection of individuals of one generic type is brought together (such as that placed in my hands by Mr. Cumming of the *Operculina* of the Philippine Seas), it very commonly happens that by selecting the most divergent forms, a considerable number of specific types—say six, eight, twelve, or even twenty—might be readily established, and a considerable part of the collection might be arranged around these as centres; but after all the specimens have being thus separated, which present a sufficiently close conformity to those types to admit of been referred to one or other of them without hesitation, there will remain a considerable proportion in which the characters of two or more are combined with such equality as to render it impossible to assign to them any other than an intermediate position, whilst there will be others which present such departures from any of them as themselves to have an equal claim to rank as distinct species; so that there is no middle course between that of grouping the whole series as varieties of one species, and that of erecting into a distinct species every varietal modification presented by individuals,—a course which would be the *reductio ad absurdum* of the ordinary system of species-making in its application to this group.

71. Two sets of characters may be especially named, on which it has been customary to found specific distinctions; these are the *form of the septal plane*, and external *sculpture* or *surface-marking*. Now, in regard to the first of these, it may be affirmed most positively that wherever any marked variation exists, that variation will be found, on comparison of a sufficient number of specimens, to be so gradational as to defy all attempts to use it as a basis of specific differentiation. Of this we have a marked example in *Operculina*, six vertical sections of which are shown in Fig. IX. Further, no dissimilarity between the form of the

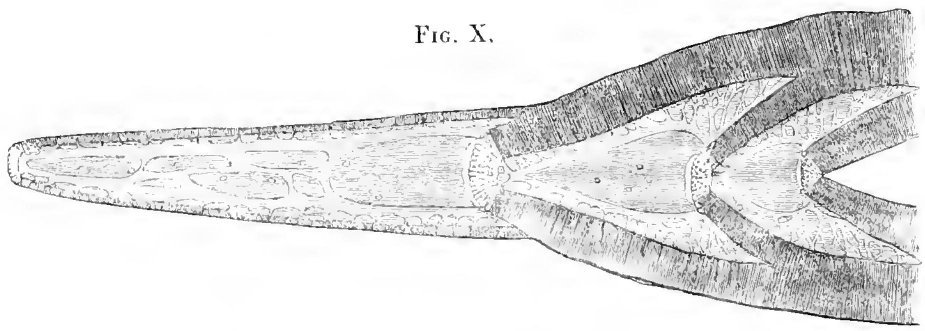
Fig. IX.



Vertical sections of six specimens of *Operculina*; showing a remarkable diversity in the forms and proportions of the chambers.

septal plane in different individuals can be greater than that which often presents itself at different periods of the life of one and the same individual. Thus, among the *nautiloid* Foraminifera, there is very commonly to be noticed a remarkable tendency to flattening-out in the latest whorl; the breadth of the spire being rapidly augmented, whilst its thickness (or the space between its two lateral surfaces) is proportionally diminished. Of this, again, we find a striking illustration in *Operculina*; in which the attenuation of the last convolution

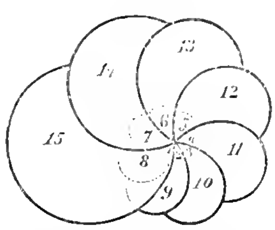
Fig. X.



Vertical section of the three outer convolutions of an *Operculina*, showing a complete change in the form and proportions of the last convolution.

often proceeds to a far greater extent than in the example represented in the accompanying figure, the septal plane being thus converted in one turn of the spire from the form of a broad arrow-head to that of a band so narrow as to be little else than a line, whilst it is lengthened in the same proportion. The form of the septal plane, moreover, is in direct relation, not merely with the general contour of the shell, alike in its lateral and in its antero-posterior aspects, but also with certain of its surface-markings. For if each chamber be merely applied to the extremity of that from which it is budded forth, the whole of the previously formed shell remains visible externally; and thus, in the case of a nautiloid spiral, all the whorls are traceable from its commencement to its termination. But it most commonly happens that the earlier whorls are either partially or completely invested by the later: where such investment is complete, nothing but the last whorl is visible externally (Fig. XI); where, on the other hand, it is partial, the earlier whorls may be more or less clearly distinguished. Now, the degree of this investment is determined by the degree in which the successive segments of the sarcode-body of the animal send out lateral lobes that extend themselves over the previously formed portion of the shell; and this is manifested in the shell by the development of what may be termed the *alar prolongations* of the chambers, which are the portions formed to include those lobes. Thus, in Fig. XII, we have an anterior view of a nautiloid shell, in which the last whorl so little encroaches on the preceding, that the septal plane *s.p.* terminates at the angles *b*, *b*, which are but little nearer to the centre of the spire than the aperture *a*, which lies against the margin of the preceding convolution. On the other hand, in Fig. XIII, we have a like view of another nautiloid shell, in which the last whorl completely invests the preceding,

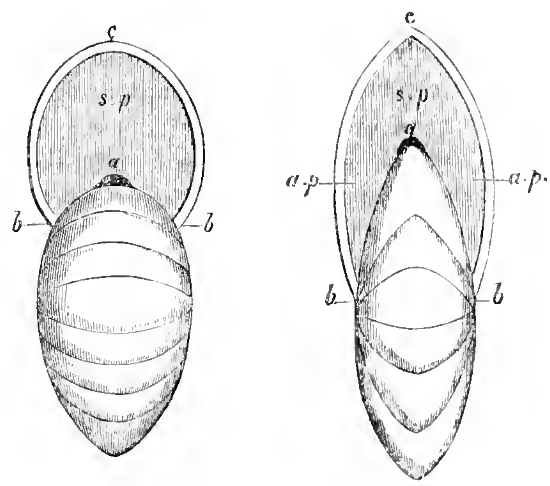
Fig. XI.



Lateral view of a nautiloid shell, of which each convolution completely invests the preceding, so that the chambers 1-8 are hidden by 9-15.

and the septal plane *s. p.* is here extended on either side into the "alar prolongations" *a. p.*, *a. p.*, until its angles *b*, *b* reach the umbilicus or centre of the spire. Now a difference of this kind not unfrequently presents itself, not only between different individuals whose specific identity is demonstrated by the gradational series that connects them, but also between the different parts of one and the same individual; the latest whorl often disengaging itself more or less completely, whilst each of the earlier whorls was successively invested by that which succeeded it. Hence it is obvious that no such difference can be justly regarded as a basis for specific distinction, until it shall have been shown to be both constant in its occurrence and uniform in its degree; the presumption being decidedly in favour of its variability, until the contrary shall have been established. It is in the genus *Nummulites* that the peculiarities in the disposition of the *alar prolongations* of the chambers, and of their intervening septa, seem to have the greatest importance as differential characters, and have been most used for the discrimination of species; but we shall find reason to question whether even there such peculiarities have the uniformity and definiteness which are required to justify such an employment of them.

FIG. XII. FIG. XIII.



72. Of *surface-marking* there are two principal kinds, which are for the most part related to the "porcellanous" and the "hyaline" types of shell-structure respectively. The surface of the porcellanous shells, as already stated (¶ 57), is not unfrequently marked by striations or by pittings, more or less conspicuous and regular in their arrangement; and the value to be attached to these must depend entirely upon the degree of constancy with which they present themselves in each particular type. Thus in *Vertebralina* we shall find that the presence of coarse striations, passing transversely between the septal bands (Plate V, figs. 17—25), is so far constant in the first-formed portion of the shell (though very commonly wanting in the later segments) as to afford important evidence in the determination of forms that might otherwise be doubtful. So, again, the more delicate striation of *Peneroplis* (Plate VII, figs. 16, 18, 20) is so constant and characteristic, that the exact similarity it presents in the "dendritine" and "spiroline" forms (Plate VII, figs. 1, 4, 12, 13, 21) becomes an important element in the determination of their merely *varietal* nature; even its occasional obsolescence (figs. 2, 3) strengthening rather than weakening this conclusion, such obsolescence occurring after the same manner in all these types. In *Miliola*, on the other hand, nothing can be less constant than the sculpture which so remarkably distinguishes certain individuals (Plate VI, figs. 3, 5, 13, 14) as apparently to justify their being ranked as well-characterised species; for wherever a sufficient number of individuals thus distinguished is brought together, there will be found some in which it is far less conspicuous than usual, and others in which it is wholly wanting either on some part of

the external surface or at some period of growth; so that, a continuous gradation being thus established between the most regularly sculptured and the perfectly smooth forms, it becomes obvious that no valid specific distinction can be erected on such a basis in this type.

73. Among the "hyaline" shells, on the other hand, variety is given to the surface marking chiefly by the interposition of bands or spots of non-tubular substance in the midst of the tubular; such portions being distinguished by their vitreous lustre from the general surface, even when they do not project above it. Most commonly, however, they are raised into ridges or tubercles; and these are sometimes arranged with great regularity, whilst in other instances they are extremely variable. Generally speaking, we find that when either continuous bands or rows of spots of non-tubular substance repeat themselves with anything like regularity in a direction *transverse* to that of growth, these mark the position of subjacent septa: and, by the elevation of these septal bands, we have septal ridges or rows of tubercles, such as are often strongly marked in the "cristellarian" type of *Nodosaria* (cx, Pl. II, fig. 54), in *Operculina* (Plate XVII, fig. 1), and in *Cycloclypeus* (Plate XIX, fig. 2). But, between these septal ridges, we often find a multitude of tubercular elevations; sometimes arranged in regular transverse rows, as in certain varieties of *Operculina*: more commonly, however, without any such symmetry, as in many *Rotaliæ* and *Planorbulinæ*. These, instead of the vitreous lustre, sometimes exhibit an opaque porcellanous whiteness (Plate XIII, fig. 15). In cases in which the original walls of the shell are overlaid by subsequent deposits, we very commonly find that the size and prominence of these tubercles increase with every addition to its thickness; so that in section they present the appearance of cones whose base is at the surface of the shell, whilst their apex points to its interior. This is often strikingly displayed in the umbilical region of *Operculina* (Plate XVII, fig. 1), and in the central regions of *Cycloclypeus* (Plate XIX, figs. 2, 5) and of *Orbitoides* (Plate XX, fig. 2). The variability of any such ridges or tubercles, however, is such as altogether to destroy their value as specific characters; individuals in which they present themselves under so pronounced and peculiar an aspect as to seem definitely differentiated by their presence from the ordinary type, being found to be connected with it by a continuously gradational series; whilst even on different parts of the very same shell, the size, disposition, and aspect of the tubercles are found to vary so much as to render exactness of definition altogether impossible.

74. Another kind of surface-marking in the "hyaline" series is given by ridges which project from the shell, not transversely, but *longitudinally*, that is, in the direction of growth; these are very common in the genus *Lagena* (cx, Pl. i, figs. 8-14), and in the protean forms of the *Nodosarian* type (cx, Pl. ii, figs. 36-48); but they are of no more value to the systematist than those already noticed, since they vary greatly in the degree in which they are developed in different individuals, and are frequently wanting on portions of shells which elsewhere present them very strongly marked. The most remarkable modification of this kind of surface-marking with which I am acquainted is the hexagonal areolation presented by certain "entosolenian" varieties of *Lagena* (see cx, Pl. i, figs. 29-32); this, however, is not more constant than the similar areolation of certain varieties of *Miliola*, although it would at first seem to have more value as a differential character on account of the difference of texture between the shell substance of the ridges and that which forms the general surface. One other variety of

surface remains to be mentioned; namely, that hispid character which is given by the projection of conical spines from every part of it. Of this we have numerous examples among the straight and slightly curved *Nodosariæ* (Plate XII, fig. 2); whilst among spiral shells we meet with it in the most pronounced degree in a varietal form frequently presented by the young of *Calcarina* (Plate XIV, figs. 6, 7). The careful study which I have made of this last type enables me to affirm with confidence, that these conical spines are formed by an excessive growth of the tubercles of non-tubular shell-substance already described, and that they usually disappear with the advance of age, by an increase in the thickness of the ordinary shell substance which fills up the spaces that intervene between them. And among the *Nodosariæ* they certainly have no more value as differential characters than the ridges already noticed.

75. Taking our stand, then, upon the characters by which the Order RETICULARIA is differentiated from other Rhizopods,—viz., the minute subdivision and the free inosculation of the pseudopodia, the imperfect differentiation of the endosarc and the ectosarc, and the absence both of nucleus and contractile vesicle,—we have finally to inquire how the group thus constituted can be most naturally subdivided in accordance with the principles that have now been laid down. At first sight, it would appear as if the groups of GROMIDA and FORAMINIFERA were so strongly differentiated by the deficiency in the former of that calcareous envelope which is the special characteristic of the latter, that they should constitute two sections or sub-orders of corresponding rank; and such a view has been adopted by MM. Claparède and Lachmann (XXV, p. 34). If, however, we attach a greater value to the characters furnished by the animal than to those afforded by the material of its envelope (and this appears to me the more natural method), we find that the affinity of the Gromida to those Foraminifera whose shells, being imperforate, do not give passage to pseudopodia, is even closer than is that of the Foraminifera having imperforate shells to those of which the shells are perforated; whilst the systematic value of the difference in the material of the envelope is lowered by the circumstance, that among the true Foraminifera we occasionally meet with instances in which the only part of the shell that is really formed by an exudation from the animal is the cement that holds together the particles of sand from which it derives its solidity. Following out this principle, the whole Order Reticularia may be subdivided into two primary groups, according as the envelope (whether membranous or shelly) is *imperforate* or is *perforated;* the pseudopodia in the former case issuing only from the single or multiple aperture, whilst in the latter they proceed from the general surface of the body. The *imperforate* sub-order may be divided into three very natural groups, according as the nature of the envelope is *membranous, porcellanous*, or *arenaceous;* and thus we have the families GROMIDA, MILIOLIDA, and LITUOLIDA. Throughout the *perforated* sub-order, on the other hand, the texture of the shell is *hyaline* or *vitreous*, save in the few instances in which the ordinary shell-substance is partially replaced by particles of sand; and there seems no other basis for a division of that sub-order into families, than that which is afforded by the mutual affinities of its generic types.

The results of our inquiry up to this point, therefore, may be summed up as follows:*—

* The nearest approach to the above principle of classification which I find among preceding systematists, is that hinted at, though not actually adopted, by M. Dujardin (XXXVI). As the original

Class RHIZOPODA, *Order* Reticularia.

Sub-order, IMPERFORATA.

Test membranous	Family *Gromida.*
Shell porcellanous	,, *Miliolida.*
Shell arenaceous	,, *Lituolida.*

outline of the system in which the Foraminifera first had their true place assigned to them, the classification of M. Dujardin will always have an historical value, although its incompleteness has been made apparent by subsequent researches. The *Amibiens* constitute the second, the *Rhizopodes* the third, and the *Actinophryens* the fourth family of his Infusoria; but as he distinctly states (p. 240) that the structure of the animals is essentially the same in the first two cases, it is rather to be wondered at that he should have limited the name Rhizopods to such as have the body enclosed in a testaceous envelope. This envelope, he says, varies in consistence from a simple flexible membrane to a thick calcareous shell, either solid or porous. But he does not regard these differences as equal in importance to those presented by the form of the pseudopodial extensions of the sarcode-body, according to which the group may be divided into two sections; of which the first (corresponding to Ehrenberg's family *Arcellina*) includes only the *Arcellæ* and *Difflugiæ*, whose pseudopodia are short, thick, and rounded at their extremities, whilst the second comprehends all those whose pseudopodia are filiform and much attenuated towards their extremities. This second section he subdivides into three tribes; the first composed of the genera *Trinema, Euglypha,* and *Gromia* (all discovered by himself), which are distinguished from *Difflugia* only by the attenuation of their pseudopodia; the second is composed of the single genus *Miliola,* which agrees with the ordinary Foraminifera in the possession of a calcareous shell, whilst in having but a single large aperture from which the pseudopodia extend themselves it corresponds with *Gromia*; and the third includes the *Foraminifera* proper, which he supposed to be all furnished with porous shells for the passage of pseudopodia from the general surface of the body. It is remarkable how little change is required (and this rather in the application of terms than in re-arrangement) to bring this outline into conformity with the more complete system which subsequent research enables us now to frame. For if we extend the application of M. Dujardin's term *Rhizopodes* not only to the *Amibiens* which precede them but to the *Actinophryens* which follow them in his classification, and transfer to the former from the central group the genera *Arcella* and *Difflugia* whose animals are of the Amœban type, and to the latter the genera *Trinema* and *Euglypha* which are Actinophryan, we find the central group thus restricted to correspond exactly with our Order Reticularia; and the limitation or non-limitation of the pseudopodia to the single or multiple aperture would probably have been adopted by M. Dujardin as the basis of his primary divisions of that group, if he had been aware that *Miliola,* so far from being exceptional among Foraminifera in this respect, is in reality the type of an extensive series.—Whilst this sheet is passing through the press, I find that Prof. Reuss has recently propounded to the Imperial Academy at Vienna (xci *a*) a scheme of classification of which the principles are almost identical with my own. He considers the *composition* and *intimate structure* of the shell to be characters of primary importance, and attaches but little value in comparison to *plan of growth.* He still retains the distinction into *Monothalamia* and *Polythalamia* (which he terms *Monomera* and *Polymera*), but expresses himself doubtfully as to its value.

CHAPTER IV.

OF THE FAMILY GROMIDA.

76. The members of the Family *Gromida* accord with the imperforate *Foraminifera* in the characters furnished by their sarcode-body, which puts forth its pseudopodial extensions only from a single aperture; but differ from them in having that body enclosed only in a membranous test, which may be reduced to such tenuity as to be scarcely distinguishable. By M. D'Orbigny this family was altogether ignored, no member of it having been known when he first applied himself to the systematic study of the Foraminifera, and no mention having been made in his subsequent writings even of its typical genus *Gromia* discovered by M. Dujardin in 1835 (xxxv), notwithstanding the clear demonstration given by that admirable observer of its close relationship to *Miliola* (xxxvi). Not less completely was this type excluded by Professor Ehrenberg from his systematic arrangement of Bryozoa (xl); the genus *Gromia* being apparently regarded by him as allied to *Arcella* and *Difflugia*, which he ranked as Infusoria. It was by Professor Schultze (xcvii) that *Gromia* and its allies were first introduced into a complete systematic arrangement of the Foraminifera; but he placed so much higher a value on the unilocularity of the "test" than on any other character, as to associate them with *Arcella* and *Difflugia*, whose animals are of the Amœban type, with *Trinema* and *Euglypha*, whose animals are Actinophryan in character, with *Squamulina*, which has an imperforate calcareous shell of the Milioline type, and with *Ovulina*, whose shell is perforated and hyaline, in the Family *Lagynidæ* of his Monothalamia Testacea,—an association which must be altogether incorrect if there be any truth in the principles laid down in the preceding Chapter, as being those on which alone can any approach to a natural classification of Foraminifera be founded. Between the "test" of *Gromia* and that of *Arcella*, indeed, there is but little difference; but between the animals which form and inhabit these "tests" respectively, the difference is as wide as any that is known to exist in the whole Rhizopod series; and this difference has been clearly recognized by MM. Claparède and Lachmann (xxv).

Genus I.—Lieberkuhnia (Plate II).

77. This genus is the one of the whole Order *Reticularia* in which the envelope of the sarcode-body is reduced to its minimum; so that it approaches most nearly to the absolutely naked condition, and may in consequence be most advantageously studied as a type of the group, holding the same position in the Reticulose series that *Amœba* does in the Lobose, and

Actinophrys in the Radiolarian. A detailed account of its very simple organization and of its mode of life (so far as at present known) having been already given (¶ 32), there is no occasion here to repeat the description; but it may be advantageous to point out that the origin of the whole ramification of pseudopodial expansions from a single stem which is limited by a definite envelope, shows *Lieberkühnia* to be strictly conformable to the imperforate type. From no other part of the body are pseudopodia given off, as would be the case if it had any affinity to the perforated series.

Genus II.—GROMIA (Plate III, fig. 2).

78. The genus *Gromia* was first constituted by M. Dujardin in 1835 (XXXV) for the reception of a group of Rhizopods characterised by the possession of a brownish-yellow, soft, membranous, ovoidal or spheroidal "test," having a small round orifice, whence issue very long pseudopodia, which ramify and become much attenuated towards their extremities. In the membranous nature of its "test" *Gromia* resembles *Arcella* and *Euglypha*, but the character of the animal entirely differentiates it; and it thus holds in the Reticulose series a rank exactly parallel to that of *Arcella* in the Lobose, and of *Euglypha* in the Radiolarian. This genus has since been especially studied by Schlumberger (XCIX *a*); and still more recently by Professor Schultze (XCVII), whose account of it is in some respects more complete than that of Dujardin, but corresponds with his in all essential points.

79. The smooth, coloured "test" of *Gromia*, which commonly attains a diameter of from 1-10th to 1-12th of an inch, looks to the naked eye very much like the egg of a Zoophyte or the seed of some aquatic Plant; and its real nature would not be suspected until, after an interval of rest, the animal begins to creep about by means of its pseudopodia, and to mount along the sides of the glass vessel that contains it. Some *Gromiæ* are marine, and are found among tufts of Corallines, Ceramiaciæ, and other Algæ; whilst others inhabit fresh water, and adhere to Ceratophylla, Confervæ, and other plants of running streams. Various species have been described, differing slightly in the size, form, and colour of the "test," and in the proportional length of the pseudopodia; but, with the evidence we have of the variability of all such characters in other instances, these specific distinctions cannot be regarded as having any valid claim to acceptance. The composition of the "test" has been studied by Schultze (XCVII, p. 21), who states that it resists the action of boiling solutions of the caustic alkalies, and that of the concentrated mineral acids, even sulphuric. With sugar and sulphuric acid it gives a red colour; whilst by iodine and sulphuric acid it is turned to a blackish hue, with a tinge of violet. The organic substance which it seems most to resemble in these reactions is *cellulose*, but it differs from cellulose in not being dissolved by sulphuric acid; and it would seem to have some relation to *chitine* and the substance of the *horny* tissues. Of the animal of *Gromia*, and of its mode of obtaining its food, a sufficient account has already been given (¶¶ 33, 34); and it has only to be here stated in addition, that the shell has no permanent attachment, but that the animal moves slowly from place to place by the alternate extension and contraction of the pseudopodia which

it projects in advance, those which it leaves behind it (so to speak) being retracted into the general mass of the body, from which new ones are put forth in front.

Genus III.—Lagynis (Plate I, fig. 21).

79. It may be doubted whether this genus, first discovered by Prof. Schultze (xcvii, p. 56) in the Baltic sea in the year 1849, should be ranked as an aberrant type of the family *Gromida*, or should be removed to the *Actinophryan* group; the intermediate character of its pseudopodian extensions, and the strong resemblance of its "test" to that of *Euglypha*, being such as to justify either position. This "test," which seldom exceeds 1-240th of an inch in length, is unattached, membranous, transparent, and elastic, and has somewhat the form of a retort with a prolonged neck and a large aperture. The sarcode-body rarely fills its cavity, the posterior part of which is generally unoccupied save by four tapering prolongations, that come off from the hinder part of the sarcode-mass which occupies the central part of the cavity, and extend themselves backwards so as nearly to meet each other at the posterior extremity of the "test" (Plate I, fig. 21, a). These processes, with the part of the sarcode-body from which they proceed, are composed of a granular sarcode more opaque than the rest; and this is disposed, in the middle portion of the cavity of the test, around a bright globular centre. The anterior portion of the cavity, on the other hand, is occupied by sarcode of peculiarly pellucid character; and it is this which extends itself into the pseudopodia that issue from the orifice. These pseudopodia, like those of the *Reticularia* generally, are very slender, in this respect contrasting very strongly with those of the typical *Amœbans* (though not unlike those of *A. porrecta*, fig. 18), but more resembling those of certain *Actinophryans*. They diverge and occasionally subdivide; but do not extend to more than two or three times the length of the shell; and they show little or no tendency to reunite (as in *Gromia*), so as either to form a network or to establish fresh centres of ramification. The sarcode-substance has not been seen to extend itself (as in *Gromia*) backwards from the orifice over the surface of the test, so as to give off pseudopodia laterally and posteriorly. Occasionally the sarcode-body is found to occupy only the posterior part of the cavity of the test, and to present the form of a sphere without any prolongations, its bright pellucid centre being still distinguishable in the midst of the darker substance (fig. 21, b). Whether this retracted condition has any relation to the "encysted" state of Infusoria, is a point still to be determined. It is pointed out by Prof. Schultze that the "test" of *Lagynis* bears a close resemblance to one described by Perty (lxxxii, Plate viii, fig. 21), under the name of *Euglypha curvata*, as having been found empty on the Simplon, at a height of from 4000 to 5000 feet.

CHAPTER V.

OF THE FAMILY MILIOLIDA.

80. THE series of generic types which is marked out by the porcellanous texture of the shell (¶ 57), and by those other structural characters which are associated with that distinctive feature (¶¶ 62—65), includes so great a variety both of modes of conformation and of grades of development, that at first sight the association of all these into a single family would seem altogether unnatural. As we proceed in our study of them, however, we shall find that from the lowest to the highest of these forms each is most remarkably connected with other parts of the series by links of affinity so strong as to forbid their dissociation; so that, starting from the humblest or simplest types, we are gradually conducted, with scarcely any decided interruption, to the highest or most specialised. Thus in *Squamulina* (Plate I, fig. 22) we have a monothalamous shell, of which the shape, although not very definite, seems to preclude any extension or super-addition. In *Cornuspira* (Plate V, fig. 16) we find that the shell, although still remaining monothalamous or undivided, is indefinite in its mode of increase, receiving a succession of increments which foreshadows the successional addition of new chambers in the Polythalamia. From this undivided spiral to the regular, scarcely divided spiral of certain "spiroloculine" forms of *Miliola*, the transition is almost insensible; from the "spiroloculine" we pass by easy steps to all the other forms of the Milioline type; and certain of the most aberrant of these establish the transition to *Hauerina* and *Fabularia*, in which last the Milioline type seems to reach its most complex phase, the cavity of the shell being minutely subdivided, as in *Orbiculina* and *Alveolina*, and the single large orifice into being replaced by multiple pores. Returning to our starting point, we shall find in the proteiform *Nubecularia* (which seems as much related to *Squamulina* as to *Cornuspira*) a sort of primitive sketching out of the various plans of growth which are more perfectly evolved in higher parts of the series; all its forms, however, being obviously but varieties of one type, of which the most definite positive character is afforded by the incompleteness of the separation between the successive chambers. The substitution of the rectilineal for the spiral is more definitely manifested (though still under a great variety of aspects) in *Vertebralina*, and the division of the chambers is more complete. From this we pass almost insensibly to *Peneroplis*, which also presents itself under the form of a spiral giving place to a straight line, and in which the elongated fissure that constitutes the aperture in Vertebralina is broken up into a row of separate pores. The subdivision of the chambers of Peneroplis by secondary partitions con-

verts it into an *Orbiculina;* and this, in the later stage of its existence, usually takes on the cyclical mode of growth, whereby it is linked on to *Orbitolites* which ordinarily follows that plan from the commencement; whilst, on the other hand, the mere lengthening of its axis of growth carries us from the discoidal *Orbiculina* to the fusiform *Alveolina.* The most peculiar types at present known to belong to this series are *Dactylopora* and *Acicularia,* which seem to be formed upon somewhat the same plan as *Orbitolites,* though separated from it by a wider interval than exists elsewhere.—Hence we seem fully justified in bringing together all these forms into a single Family, and in giving to this family a designation derived from that one of its genera which seems *most widely diffused* both in space and in time, there being none which can be regarded as typical in regard to *form.* The following tabular arrangement of this family may assist in the appreciation of the relationships of its members.

FAMILY MILIOLIDA.

```
              Squamulina.
                |      |
         Nubecularia—Cornuspira.
             |            |
         Vertebralina . . Miliola.
             |            |
         Peneroplis . . . Hauerina.
             |            |
         Orbiculina . . . .Fabularia.
          |       |
   Alveolina  Orbitolites.
                  |
            Dactylopora.
                  |
              Acicularia.
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Genus I.—SQUAMULINA (Plate I. fig. 22).

81. The genus *Squamulina* was instituted by Prof. Schultze (XCVII, p. 56) for a minute monothalamion of which he found several specimens at Ancona, adhering to the surface of Algæ and to the side of a glass vessel in which sea-water had been long kept. The shell, whose largest diameter is about 1-300th of an inch, has the form of an irregular plano-convex lens, being usually flat, or nearly so, on its attached side (which accommodates itself to the surface whereon it grows), and convex on its free side, on some part of which—usually about half way between the centre and the periphery—is a wide orifice from which the pseudopodia issue. The shell is calcareous and opaque, and is destitute of pores; its adherent layer is very thin, and is with difficulty detached from the surface to which it is attached. The substance of the animal is of a brownish-yellow colour, as in *Gromia;* its pseudopodia, however, seem fewer and less disposed to subdivide and inosculate.

Genus II.—CORNUSPIRA (Plate V, fig. 16).

82. *History.*—The genus *Cornuspira* was instituted by Prof. Schultze (XCVII, p. 40), for those calcareous-shelled Foraminifera which form a flat spire like that of a Planorbis, and have their cavity simple and undivided; and two species were distinguished by him, one of them, *C. planorbis*, having the shell solid, the other, *C. perforata*, having it finely porous. Prof. Williamson (CX, p. 91), whilst recognising both these forms, and describing another in which the shell is arenaceous, reverted to the generic name *Spirillina*, which had been previously given by Ehrenberg to a shell resembling Schultze's *C. perforata*, and included all three forms under that designation; at the same time changing the specific name of Schultze's *C. planorbis* to adopt that of *foliacea*, which had been previously bestowed by Philippi upon a more advanced form of the same organism. Soldani (by whom this shell seems to have been first figured), Philippi, Williamson, and Messrs. Parker and Rupert Jones, have all recognised in its opaque-white porcellanous character a close resemblance to that of the *Miliolinæ*. This resemblance is unquestionable; and if there be any truth in the principles enunciated in the two preceding chapters, it is obvious that the imperforate porcellanous spirals and the perforated hyaline spirals must be regarded, in spite of their almost exact resemblance in external form, as belonging to two fundamentally different types. Reserving, therefore, the name *Spirillina* as the generic designation of the latter, I concur with Messrs. Parker and Rupert Jones in thinking it expedient to make use of the name *Cornuspira* as the distinctive appellation of the former.

83. *External Characters.*—The shell of *Cornuspira* is a simple flat spire, the successive turns of which at first increase but slowly in width, but which at last opens out rather suddenly, like that of many other Foraminifera growing upon the same type (Plate V, fig. 16). The successive convolutions are in contact at their edges, but the later do not extend themselves over the earlier, so that the whole of the spire remains visible externally on each lateral surface. Not the least appearance of septal bands or constrictions presents itself at any part of the spire; except that a slight depression may sometimes be detected, which marks off the primordial chamber from the spire that proceeds from it. In the young form of this shell the tube is cylindrical or nearly so, and its aperture is round; but as it advances in age and flattens itself out, whilst the spire undergoes a rapid increase in width, its two surfaces become so closely approximated that the form of the aperture changes from a circle to a long, straight-sided fissure (fig. 16, *a*). The compressed whorls of the adult often show a series of irregularly alternating ridges and depressions, which cross the course of the convolutions with a convexity directed forwards, and these seem to mark the successive additions which the shell has received. Occasionally, as in many higher types, an abrupt narrowing of the spire takes place, so that the convolution is continued on the smaller scale of some previous portion of the whorl, as is shown in fig. 16.

84. *Internal Structure.*—The entire absence of septal divisions, indicated by the external aspect of this type, is proved by an examination of its internal structure, which shows that the cavity occupied by the sarcode-body of the animal is perfectly uninterrupted, except

where (as already mentioned) a slight constriction marks off the primordial chamber at the commencement of the spire. Hence the body will present no appearance of segmentation except at that point, and the large size of the external aperture will enable it to extend its pseudopodia most freely into the surrounding medium.—The *Cornuspira foliacea,* which is at present the only known form of this type, attains the diameter of 1-8th of an inch.

85. *Affinities.*—In *Cornuspira* we have a sort of rough sketch of the higher type of helicine Foraminifera, which it greatly resembles in external form, but from which it differs in the simplification of its structure resulting from the absence of segmentation in its sarcode-body. Its growth, like theirs, is unlimited; and thus, although *actually* monothalamous, it may be considered as *potentially* polythalamous (¶ 62).

86. *Geographical and Geological Distribution.*—This type is at present very generally diffused through various seas, its shells growing attached by one of their lateral surfaces to Algæ and Zoophytes, usually at no great depth. It has not been met with in any formation of older date than the Eocene; but it abounds in the "calcaire grossier," and presents itself at every subsequent epoch.

Genus III.—Nubecularia (Plate V, figs. 1—15).

87. *History.*—The genus *Nubecularia* was first established by Defrance (xxix) for the reception of an assemblage of small calcareous bodies of variable form and extremely indefinite characters, which he found within univalve shells of the "calcaire grossier." He expressed himself as altogether undecided in regard to the place to be assigned to them in the animal series; but in figuring them he grouped them with Zoophytes (xxix, Zooph., Pl. xliv, fig. 3). A comparison of the figures given by him (imperfect as these are) with the figures previously given by Soldani (ci) of certain of the bodies to which he gave the general designation *Serpula,* serves to show that this type had been previously recognised by that painstaking observer. The indefiniteness of Defrance's characterisation of the genus seems to have prevented its adoption by subsequent authors; thus we find that even Blainville did not accept it (vi *a*), though retaining Defrance's figures and the name appended to them on the plate; and Lamarck makes no mention of it. The genus was entirely ignored by M. D'Orbigny, though one of its multiform varieties was described and figured by him under the name *Webbina rugosa* (v, Pl. i, figs. 16—18, and lxxiii, p. 74, Pl. xxi, figs. 11, 12). It has, however, been noticed by M. Dujardin (xxxviii), who remarks of it that its proper place is probably rather among Foraminifera than among Polypifera. The firm establishment and true characterisation of the genus, however, can only be fairly attributed to Messrs. Parker and Rupert Jones, by whom it has been especially studied in its recent as well as in its fossil forms (lv, p. 455), and who have kindly furnished me with the materials on which the following account of it is based.

88. *External Characters.*—No Foraminiferous shells are more protean in shape than those of *Nubecularia,* for we find them presenting almost every plan of growth that is to be found among Foraminifera. It is one of their distinctive characters that they attach themselves to other bodies, the surfaces of which they use as part of the walls of their own cavities; and

thus it happens that they mould themselves to the shape of the bodies to which they are adherent, and that the plan of their own conformation varies accordingly. It is when growing on flat surfaces, such as those afforded by shells or sea-weeds, that *Nubeculariæ* best exhibit their characters (Plate V, figs. 6, 13); when, on the other hand, they extend themselves over the projections of foliated shells, or ensheath the stems and branches of Zoophytes, Corallines, &c., they often lose all external traces of definiteness of plan (figs. 8, 9), and even their internal structure would be unintelligible if the simpler forms did not supply the means of interpreting it. It is difficult to say what ought to be accounted the typical plan of conformation in this genus; but as it usually (though not always) commences in a *spiral*, which subsequently gives place to other modes of growth, this may be conveniently adopted as the starting-point. The spiral shell of *Nubecularia* differs from that of *Cornuspira* in several very important particulars. In the first place, it is frequently deficient altogether on the attached side (figs. 1—3), so that the cavity of the tube is there bounded only by the surface to which its edges are adherent, and the form of its section is not circular, but semicircular. Sometimes, however, a layer of shell is deposited on that surface, so as to close-in the tube (figs. 4, 11, 14); but this layer is so thin as to require the support afforded to it by the surface to which it is adherent. On the other hand, the shelly substance of which the unattached side of the tube is composed is deposited in unusual abundance, so as not only to form a very thick wall on the exposed surface, but to fill up the grooves which would otherwise be left between the successive coils of the spire. Thus it often comes to pass that the distinction between the coils is altogether obliterated, and only from the general outline of the entire shell could it be supposed that a spire is concealed beneath. This deficiency of shell on the attached side, with such an exuberant thickness on its exposed side as masks its characteristic form, is observable not merely in the spiral *Nubeculariæ*, but also in those curved, straight, zigzag, ramifying, and acervuline varieties through which this generic type will be shown to range (fig. 9).

89. *Internal Structure.*—In those forms of *Nubecularia* which spread themselves over plane surfaces, the internal structure is readily disclosed by detaching the shell from its adhesion, and looking at it from the under or attached side; for its cavity is then either laid open altogether (fig. 1), or becomes visible through the thin pellicle of shell which covers it (fig. 4). In the most regular spiral forms the spire commences in a spheroidal chamber, from which it is separated by a slight constriction, and it then rapidly opens itself out, especially in the second or third whorl. Its cavity is partially divided at irregular intervals by imperfect septa, formed by inflections of the walls of the tube, which curve inwards with a convexity directed forwards, but stop far short of meeting at the axis of the tube, so that a wide aperture of communication is left between the adjacent chambers. When the spire enlarges, a dilatation is seen beyond every one of these constrictions, the narrowed aperture of one chamber being received, as it were, into the dilated base of that which succeeds it (fig. 5). This is for the most part better seen, however, in the *straight* growth (fig. 10), to which the spiral convolution very commonly gives place after having made two or three turns; the axis of growth alone being changed, and the structure of the tube and its partitions remaining the same. This straight mode of growth may prevail from the commencement, individuals sometimes presenting themselves in which the spire is altogether wanting. Sometimes the new chamber is formed at the side instead of in the axial line of the preceding, so that the direction of growth is suddenly altered.

Sometimes, again, a new chamber is formed at the side as well as at the end of the preceding, and thus a branch may pass off at a considerable angle from the main axis (fig. 12). More commonly, however, when such a lateral gemmation takes place, the new series of chambers which thus originates advances along the side of the preceding (fig. 7); and by further offsets of the same kind these parallel series may multiply to any extent, the new chambers sometimes arching over those from which they are derived, so as even in these flat spreading forms to mark the tendency to an acervuline aggregation. Further, the axis of growth may be neither straight nor spiral, but may bend or twist in any direction; the chambers still succeeding one another, either in a single linear series, or in ramifying extensions, or in multiple rows; and nothing then marks the generic type save the texture of the shell, its attachment by one of its surfaces, and the narrowing of the chambers behind the constrictions, followed by a dilatation in front of them.

90. Instead, however, of extending itself in length, the shell not unfrequently widens itself out so much, that the distance across the chambers is far greater than that which intervenes between the successive septa; and it is then to be observed that, between each chamber and the next, there are two or more apertures in the septum that divides them (fig. 15). This plan of growth is carried to an extraordinary extent in the specimen represented in fig. 13, in which the enormous increase in the transverse dimensions of the chambers is accompanied by a great multiplication of these septal communications (fig. 14), so that a *Nubecularia* formed upon this type becomes a sort of rude sketch of *Peneroplis*. In not a few cases, again, the growth takes place almost from the commencement on the *cyclical* plan (fig. 11), the first-formed chambers extending themselves around that which is occupied by the primordial segment, and budding off new chambers in all directions; the successive chambers communicate with each other laterally, as well as in a radial direction; and thus a sort of sketch is presented of the plan of growth characteristic of *Orbitolites* and *Planorbulina*, to the lower forms of which last, indeed, this type of *Nubecularia* (the chambers of which I have always found to be much smaller than the average) often presents a decided analogy.

91. Either of the foregoing modes of growth may give place to one in which no regularity whatever can be traced, the successive chambers being no longer added on the original plane alone, but piling themselves upon one another, without any discoverable system, so as to imitate the *acervuline* growth which *Planorbulina* sometimes takes on. This is especially liable to happen with *Nubecularia* that cluster around the stems and branches of Corallines, Zoophytes, &c.; and thus it comes to pass that, as already remarked, not only does their external configuration become altogether amorphous, but their internal structure seems to be entirely destitute of arrangement. By a careful comparison of the intermediate forms, however, the true nature of these amorphous acervuline growths, as derivations from the simpler and more regular types, is unmistakeably demonstrated. In the larger and coarser acervuline specimens, it is not unfrequently to be observed that the surface is roughened by the inclusion of fine particles of sand (which seem to be composed of comminuted shell) in the proper calcareous substance of their shells; but this substance is never *replaced* by sand, as in the truly *arenaceous* types.

92. *Affinities.*—The type which has now been described is of no common interest, as displaying the first *nisus* of a Rhizopod towards the production of a multilocular shell, and as marking out, though in a rude and indefinite form, the principal plans which are evolved with much greater completeness and regularity in the higher types. *Nubecularia* is obviously allied to *Cornuspira* on the one hand, and to *Vertebralina* on the other; it cannot, however, be said to be truly intermediate between those genera (though some of its forms approximate to each), because it differs from both of them in the deficiency of the shelly wall on one side, as well as in the rude and almost amorphous aspect of its free surface.

93. *Geographical Distribution.*—The shells of this genus are, for the most part, inhabitants of the warmer seas, being especially large and abundant in the Laminarian zone, in which they sometimes attain the size of hemp-seeds, or even of split peas; whilst, when brought up from deeper water, attached to the shells of large Mollusks, they are much more minute. They also occur in a detached condition, associated with other *Foraminifera*, in many recent sea-sands from shallowish water.

94. *Geological Distribution.*—*Nubeculariæ* are abundant in some of the French Tertiaries, have been met with attached to *Gryphææ*, &c., in many Oolitic Clays, and have been recognised in abundance (though the examples were very minute) in the Triassic Clay of Chellaston.

Genus IV.—VERTEBRALINA (Plate V, figs. 17—25).

95. *History.*—The genus *Vertebralina* was first characterised by D'Orbigny (LXIX) in 1826; the name which he has assigned to it having been apparently suggested by the resemblance presented by some of its forms (Plate V, fig. 22) to the vertebral column of a Shark. On account of its spiral commencement he placed it among his nautiloid *Hélicostègues*, though admitting that its position there is anomalous (LXIII, p. 120). Its relationship to the Milioline type was first clearly indicated by Professor Williamson (CX, p. 89), who has given an excellent description of its characteristic form, and has very properly reunited with *Vertebralina striata*, the *V. cassis* and *V. mucronata*, of D'Orbigny, the differential characters of which are too slight and inconstant for their separation. He was not aware, however, of the extraordinary *polymorphism* which this type is found to display when the comparison is extended through a sufficiently wide geographical and geological range.

96. *External Characters.*—The aspect of the shell in *Vertebralina* is generally opalescent and brightly polished, and its surface is usually marked by delicate, longitudinal striations, which have the strength of ribs in the thick-walled and more strongly characterised specimens, such as D'Orbigny's *V. mucronata* (XCII, Pl. vii, figs. 16—19), but which become obsolete, or even disappear entirely, on the later portions of the more delicate and more aberrant specimens. More rarely the surface is pitted. The shell is complete on both sides, and is usually a symmetrically flattened tube; it has no other attachment to the surface on which it grows, than

that afforded by the sarcode-body of the animal itself, or by the gelatinous investment of the sea-weed to which it adheres. Its growth nearly always commences either in a regular spiral or in a Milioline modification of it, each turn of the spire being commonly formed as in *Hauerina*, ¶ 112) by three chambers, or more rarely (as in the ordinary *Miliolæ*, ¶ 104) by two; and it was on certain forms which are at first strongly milioloid and afterwards uniserial, that D'Orbigny founded his genus *Articulina*. The earlier whorls of the spire are generally inclosed by those which succeed them; but sometimes they are merely surrounded by them, so that the whole of the spire remains apparent. The septa are marked externally by depressed bands, which are not crossed by striations. After making from two to four turns, the shell continues to grow in a straight line; the successive chambers (usually to the number of five or six) being sometimes of extremely uniform size, subcylindrical in shape, and disposed with great regularity (fig. 22); whilst in other cases they are progressively compressed, so that the shell becomes flatter and wider (fig. 25); and they are sometimes disposed in a zigzag manner. In either of these cases, however, the type is very easily recognised by the form of the aperture, which is a simple fissure with lips slightly everted, extending along the whole breadth of the septal plane; and it is further to be noticed that behind each septal plane there is a more or less well-marked constriction, after which the walls of the chambers open out again. These constrictions are sometimes marked in an unusual degree by the very sudden enlargement of the new chamber formed beyond, as in the specimen represented in fig. 23. Sometimes, on the other hand, the tendency to increase appears suddenly checked, the new chamber being considerably smaller than that which preceded it (fig. 21), the dimensions of which are only again attained after a progressive increase continued through several chambers. A similar temporary dwarfing has been already noticed in *Cornuspira*, and seems liable to occur in any type of polythalamous Foraminifera.

97. *Internal Structure.*—On laying open the shell of *Vertebralina*, its cavity is found to correspond very closely with its external contour, the walls of its chambers being everywhere of very uniform thinness. The septal divisions are disposed at much more regular intervals than in *Nubecularia*, but still have rather the character of constrictions formed by an inflection of the walls, than of regular partitions; and the wide aperture in each septal plane can scarcely be differentiated from that of *Nubecularia*, except in the somewhat patulous character which it derives from the slight eversion of its lips

98. *Varieties.*—The typical form just described is liable to a great modification in either of two principal directions. On the one hand the chambers may become nearly cylindrical in form, and at the same time narrowed and elongated, so that the straight portion of the shell is drawn out into the form of a rod (fig. 19), though still presenting its characteristic contraction and subsequent opening-out at each septum; whilst the aperture from a narrow fissure becomes circular, or nearly so. This rectilineal elongation of the chambers may extend even to the first-formed portion of the shell, the primordial chamber and its immediate successors being uncoiled (as it were) into a series of long cylinders laid end to end in a straight line, the striated and pitted surface of which, together with the occurrence of intermediate modifications of form, mark their derivation from the ordinary type. On the other

hand, the progressive widening-out of the chambers may go on to such an extent as still more to disguise the fundamental type, especially when they not only become extremely elongated transversely, but even wind themselves round the edges of those previously formed, so as almost to meet on the opposite side of the original spire (fig. 18). Even such an extremely aberrant form of the one here represented, which was distinguished by Lamarck (LIX and LX) under the names *Renulina* and *Renulites** (expressive of the resemblance of its shape to that of a kidney), is distinctly recognisable as a modified *Vertebralina* by the exact conformity of the first-formed portion of the shell to the regular type, and by the characteristic form of its aperture, which is a fissure extending along the entire margin of the last nearly circular chamber; and, as already pointed out (¶ 89), a similar tendency is common in other typical forms of this division of Foraminifera. Arrests of development at the spiral condition, sometimes producing a strong resemblance to *Miliola*, are not uncommon in either of the varietal forms of *Vertebralina* (figs. 17, 20); and it is thus that the broad specimens distinguished by D'Orbigny (XCII, pl. vii, figs. 14, 15) by the name *V. Cassis*, have been produced. A curious dwarfed example, from a depth of 360 fathoms in the Mediterranean, is represented in fig. 24.

99. *Affinities.*—It is obvious that *Vertebralina* may be considered as an advance upon *Nubecularia*, alike in the symmetrical conformation of its shell, and in the more definite plan of its growth. In that early condition in which it is sometimes arrested, it presents a close affinity to the *Milioline* type; whilst its compressed and especially its reniform varieties bring it into close relationship to *Peneroplis*, which it often strongly resembles in shape, being always distinguishable from it, however, by the nature of the septal aperture, and generally also by the inferior lustre and opalescence of the shell.

100. *Geographical Distribution.*—Although specimens of *Vertebralina* are occasionally met with among the Shetland islands, yet there is strong reason to believe that they have been transported thither from some warmer region; as this genus seems, like *Peneroplis*, to belong properly to tropical and sub-tropical seas, through which it is pretty generally diffused, although in far less abundance than *Peneroplis*.

101. *Geological Distribution.*—This genus presents itself in various Tertiary deposits; and it is from these that its most aberrant forms are supplied, although approximations to them are furnished by their existing representatives.

Genus V.—MILIOLA (Plate VI, figs. 1—33).

102. *History.*—The generic term *Miliolites* was applied by Lamarck (LVIII) in 1804 to certain fossil forms belonging to a very common type, of which examples had been noticed by Linnæus (LXIII) as *Serpula seminulum*, by Soldani (CI) as *Frumentaria*, and by Montagu (LXV) as *Vermiculum*; the designation having been apparently suggested by the resemblance

* These names are erroneously cited by Prof. Williamson (CX, p. 44) as synonyms of *Peneroplis*.

to millet-seed borne by the minute bodies to which it is applied. The Lamarckian genus was adopted by various subsequent writers; its name being modified to *Miliola* or *Miliolina* for the purpose of including the recent forms, which differ in no essential particular from the fossil. But in M. D'Orbigny's first systematic arrangement of the Foraminifera (LXIX) he broke up this genus into the genera *Uniloculina, Biloculina, Triloculina, Quinqueloculina, Spiroloculina, Adelosina,* and *Cruciloculina*; and these he associated with *Sphæroidina* (of which the examples he cites as typical are really allied to *Globigerina*, having a perforated hyaline shell), and *Articulina* (which is in reality a varietal form of *Vertebralina*, ¶ 96), into his Order AGATHISTÈGUES; his definition of which might have served as the generic character of *Miliola*, if it had been founded on a correct conception of its typical structure. To the foregoing genera, D'Orbigny subsequently added *Fabularia* (at first wrongly placed by him elsewhere), a type which will hereafter be shown to present a peculiar development of the Milioline (¶ 116). Our reasons for reuniting the first seven of the genera just enumerated, with all their multitudinous species, under the single type *Miliola*, without attempting to establish even specific differentiations, will presently become apparent. With regard to his generic divisions it is not a little singular that M. D'Orbigny should have remarked as follows:—"We think it difficult to find genera more distinct one from another than are those of this Order. They present forms so sharply defined, that there really exists no transition between them; and thus any one by a few hours' study will always find himself able to distinguish them" (LXXIII, p. 256). Now although a few hours' study, prosecuted after the fashion of M. D'Orbigny, may lead to an acceptance of his generic and specific distinctions as valid, yet in precise proportion as that study is prolonged, and is made to include a sufficiently large number of examples of this type, brought from all the seas and from all the geological deposits in which it occurs, do its results prove to be of quite an opposite character. For the types which were represented by M. D'Orbigny as so sharply defined, are found, on careful comparison—as has been shown by Mr. W. K. Parker (LXXV) on whose view of this genus my own account of it is based—to graduate into one another so insensibly, that no line of demarcation, either specific or generic, can be drawn between them; so that no middle course can be adopted between ranking them all as varieties of one species, distinguished by the degree and direction of their divergence from a central type, and multiplying almost indefinitely the number of species by adopting the most trivial modifications of form or surface-marking as differential characters. This truth has already been partly apprehended by Profs. Schultze and Williamson; the former of whom (XCVII) has reunited the genera *Triloculina* and *Quinqueloculina* under the generic designation *Miliola*; whilst the latter (CX) has brought them together under the name *Miliolina*, with the addition of *Adelosina*, which he rightly states (p. 89) to be nothing else than a young form of the same type, distinguished by the peculiar retort-shape of the primordial and the next succeeding chambers. Prof. Williamson truly remarks (p. 80) that "none of the Foraminifera are more liable to variation than those comprehended in the Lamarckian genus *Miliolites*;" and adds (p. 87), that some of his "most able correspondents, who previously thought that the species of *Miliolinæ* ought to be made much more numerous, on endeavouring to group the specimens in their cabinets according to such views, found their difficulties increase with the multiplication of their specimens."

103. *External Characters and Internal Structure.*—The essential plan of conformation in the

whole Milioline series is so simple, that it may be readily apprehended from a survey of the external features of its fundamental type. Yet these features are liable to be so completely masked, as altogether to lose their characteristic aspect; and since there hence arises so complete a want of agreement between external characters and internal structure, as leads to the entire misapprehension of the latter if too exclusive confidence be placed in the former, it seems desirable to study both together in such a manner as to bring out their true relations. And in this way we shall come to perceive the fundamental unity which prevails through a range of varietal modifications so wide, as at first sight to appear to justify the creation of an almost unlimited number of genera and species.

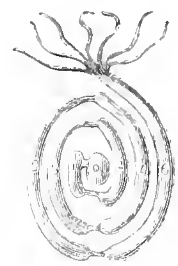
104. The fundamental "idea" of a *Miliola* is best displayed in such a form as that represented in Plate VI, fig. 1, which shows but little departure from the continuous spiral of *Cornuspira*: the difference consisting chiefly in this,—that each turn of the spiral is interrupted at two opposite points by a constriction followed by an enlargement: and that, as the interruptions in successive turns are always at the extremities of the same diameter, the whole spire is made up of a series of half-turns arranged symmetrically on its two sides. Each of these half-turns is larger than that which preceded it, but its dimensions scarcely change between its two ends; so that the increase in the diameter of the tube is not gradual, but takes place at successive intervals, each chamber being not only longer than its predecessor on the opposite side, but also larger in sectional area. The form of that area departs from the circular, in consequence of the tendency which each turn of the spire has to extend itself in some degree over the preceding. Although this extension is but slight in the example we are considering, it is enough to give a concave instead of a convex border to the inner wall of the chamber; which inner wall is, in fact, nothing else than the outer wall of the preceding turn, the shelly tube of the new chamber being there incomplete (¶ 62). The aperture of the last chamber is somewhat constricted: and it is further encroached-on by a tongue or tooth-like projection of shell substance from its inner margin (figs. 16—18); this projection, which may be conveniently termed the "valve," varies greatly in size and form, but when most developed, it converts what would otherwise have been a free nearly circular passage into a comparatively narrow crescentic slit. A similar "valve," which may be regarded as a rudimentary septum (¶ 109), exists at each of the constrictions that marks the division of the chambers.

105. It is comparatively rare, however, to find so slight a departure from the regular spiral plan, as is shown in specimens of the kind just described. For in by far the larger number of cases, the diameter at the two extremities of which the septal constrictions occur is more or less elongated; and this elongation may proceed so far as to give it twice the length of the transverse diameter (fig. 2), thus substituting for the spirality of the original type an apparently *bilateral* arrangement, which has caused D'Orbigny and his followers to define the Milioline group as if the shell were composed of "chambers clustered* on two, three, four, or five faces of a common axis.

* For the word *pelotonnées*, which is intended to indicate the kind of aggregation produced by winding a ball of cotton, there is no proper equivalent in our language.

106. The conformation of the sarcode-body of the animal obtained by the decalcification of the shell, exactly corresponds with what the characters presented by its envelope would lead us to anticipate. Starting from the ordinary primordial segment (Fig. XIV, o), we find this giving origin, by a constricted neck or "stolon," to the first longitudinal segment 1, which doubles round one side of it, and is then again constricted into a "stolon;" from this proceeds the second longitudinal segment 2, which passes round the other side of the primordial spheroid, and, having extended itself beyond the first, narrows itself at the opposite end of the diameter into a stolon; from this proceeds a third longitudinal segment 3, which passes round the first and extends beyond it, giving origin, by a constricted stolon, to a fourth 4, which in like manner passes round the second and extends beyond it; and this mode of increase may continue until a considerable number of segments have been formed on either side of the primordial spheroid, the last extending itself into pseudopodia at its termination. Hence it is obvious that each segment grows in a direction contrary to that of the segment which immediately preceded it, but corresponding to that of the ante-penultimate segment; and that the pseudopodial extensions will be put forth alternately from one and the other extremity of the body. And it is further obvious that this Milioline type involves, so far as the structure of the animal is concerned, no more considerable departure from the simple type of *Cornuspira* than that which is produced by the narrowing of the spire as it crosses each end of its long diameter,—a conclusion which derives additional support from the exact conformity to the *Cornuspira* type, which, as already shown (¶ 49), is presented by the young of *Miliola* (see XCVII, plate ii. figs. 1—6).

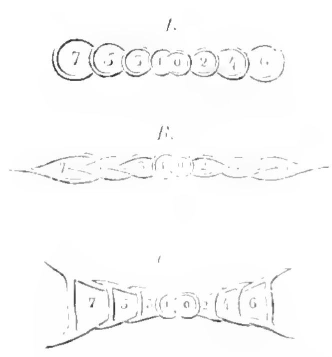
FIG. XIV.



Diagrammatic representation of the Animal of *Miliola*.

107. The characters adopted by D'Orbigny for the differentiation of his genera are for the most part furnished by the number of chambers which show themselves externally; a variation which depends upon the degree in which the later chambers invest the earlier, upon the symmetry of their shape, and upon the mode in which they are disposed with reference to the diameter of the spire. Thus if the successive segments simply increase in diameter without departing much from their primitive cylindrical form, so that the successive chambers of the shell merely apply themselves to the external surfaces of those which preceded them, then the whole series of chambers is visible on each side of the adult shell; and the *Miliola* which grows upon this plan, which will be readily understood from the ideal transverse sections shown in Fig. XV, is distinguished as *Spiroloculina* (Plate VI, figs. 1, 2). If, however, the segments of sarcode extend themselves on either side into "alar lobes," and these are symmetrically prolonged so as completely to cover each side of the chambers to which they are applied, as shown in Fig. XVI, then only *two* chambers—the last and the penultimate—are visible externally, and we have a *Biloculina* (Plate VI. fig. 7). It often happens

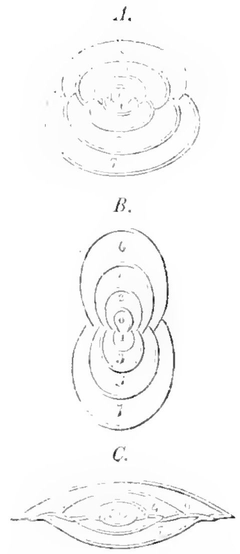
FIG. XV.



Ideal transverse sections of *Spiroloculina*.

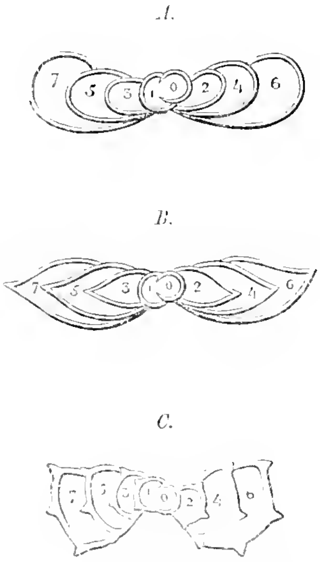
however, that the alar lobes of one side are more prolonged than those of the other, so that more of the earlier chambers of the shell are shown on the one face than on the other; in this

Fig. XVI.



Ideal transverse sections of *Biloculina*.

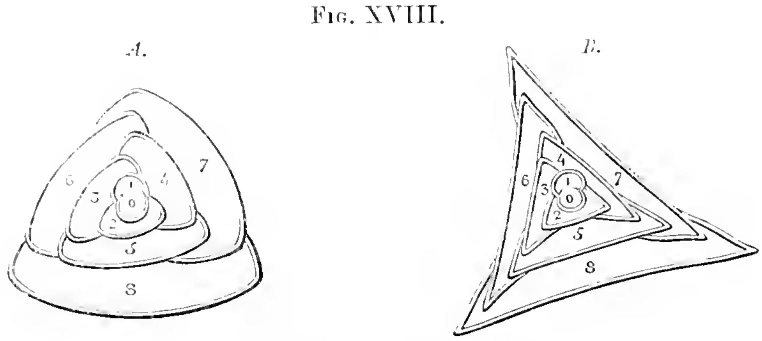
Fig. XVII.



Ideal transverse sections of *Quinqueloculina*.

way it often comes to pass that *five* chambers are visible externally on one side of the shell, whilst only *three* are apparent on the other (Fig. XVII); and this type is the *Quinqueloculina* of D'Orbigny (Plate VI, figs. 3—6). It is, however, subject to great inconstancy as to the number of chambers visible externally; this being usually from *three to eight* on one side, and from *two to six* on the other; some shells formed on this plan having only *two* chambers visible on one side and *three* on the other.* A greater departure from the ordinary mode of growth, however, is shown by those *Miliolæ* in which the alternation in the direction of the successive segments of the sarcode-body is not duplex but triplex; so that the chambers of the shell, instead of lying on the two sides of the diameter of the spire, cluster around it (so to speak) triangularly, as shown in Fig. XVIII; thus causing the shell to become three-sided, and ren-

Fig. XVIII.



Ideal transverse sections of *Triloculina*.

* It was from having perceived the unimportance of these numerical variations in shells formed on the plan above described, that Profs. Schultze (xcvii) and Williamson (cx) were led to reunite

dering three chambers always visible externally. This is the true *Triloculine* form (Plate VI, figs. 13, 14).

108. Now although, if typical specimens only were compared, these characters might well seem to be sufficiently definite to justify the generic differentiations which have been founded upon them, yet the comparison of extensive suites of specimens brought from different localities shows that they are subject to an inconstancy which altogether destroys their value. And this inconstancy is readily accounted for, when due allowance is made for the indefiniteness in the form of the sarcode-body of the animal; since, as we have seen, it is dependent upon the degree in which the "alar lobes" of the new segments extend themselves over the surfaces of the preceding chambers, and on the equality or otherwise of the prolongations on the two sides—characters which are extremely liable to variation among Foraminifera. Of those subordinate departures from the typical form of the segments, which convert their ordinarily rounded outline (Figs. XV, A; XVI, A, B; XVII, A; XVIII, A) into a carinate or angular contour (Figs. XV, B, C; XVI, C; XVII, B, C; XVIII, B)—differences on which a vast multitude of specific differentiations have been founded—it can only be here stated generally that they are subject to the same uncertainty as the larger ones already disposed of.

109. With such diversities in the form of the chambers are associated corresponding diversities in that of the *aperture*; which may be elongated laterally so as from a circle to become an oval (which is sometimes narrowed into a mere slit), or may approach the form of a square (Plate VI, figs. 8—12, 16—33). The shape of the "valve," again, varies with that of the aperture, and has further variations of its own. In the *Miliola cyclostoma* of Schultze (XCVII, plate ii, figs. 14, 15), the valve is altogether wanting, and the aperture is quite round. In the *Spiroloculina* represented in Plate VI, fig. 1, the aperture, shown in fig. 16, has but a very small projection; this projection is a little larger in the specimen represented in fig. 2, of which the aperture is shown in fig. 17, and is somewhat extended laterally; and in the *Quinqueloculina* represented in fig. 3, of which the aperture is shown in fig. 18, the valve is distinctly bifid. In *Biloculina* the usual form of the "valve," as shown in figs. 7, 8, 10, 11, 12, is that of a broad, rounded tongue, springing from the whole of one side of the aperture; but in the specimen shown in fig. 9, the valve, still much extended laterally, springs from a narrower base. In figs. 19—32 is shown a very remarkable series of apertures and valves of a large *Miliola*, from specimens brought by Mr. Cuming from the Philippine seas; of which variety an example is represented in fig. 33 broken open, so as to show the interior of the last chamber, and to allow its aperture and valve to be seen from within, whilst the much smaller aperture and simpler valve of the penultimate chamber are seen from without. This series is particularly interesting, as showing the wide range of variation that exists in regard to the form both of the aperture and of the valve, among a number of individuals which must unquestionably be regarded as belonging to the same species; some of the widest

Quinqueloculina and *Triloculina*. Neither of them, however, seems to have apprehended the essential peculiarity of the real *Triloculine* type to be next described, although this had been correctly pointed out by M. D'Orbigny.

divergences being presented at the apertures of the successive chambers of one and the same individual, as seen in fig. 33. In no two are the valves exactly alike in form; and yet it is obvious throughout that they are constructed (so to speak) upon the same model. They all possess, in a more or less developed condition, a vertical plate or keel, which rises from the median line of the horizontal part of the valve; and this keel, as is seen in the oblique view given in fig. 30, frequently forms a sort of arch hollowed beneath like a bridge. In fig. 28 will be noticed a remarkable development of two processes from the projecting angles of the aperture, which are seen in a rudimentary condition in several other figures. In fig. 31, the valve is so much extended horizontally, and the aperture is so unusually contracted, that what should be the free margin of the valve has come to coalesce completely in one part, and nearly to do so in another, with an ingrowth from the margin of the aperture; thus distinctly tending towards the formation of a complete septum perforated with separate pores, such as we find in certain other modifications of the Milioline type (§§ 110, 111, 118).

110. A more remarkable departure from the ordinary type of aperture than any of the preceding, is presented in the *Cruciloculina* of D'Orbigny: which is a well-marked "triloculine" *Miliola* (fig. 15), of which the aperture has (so to speak) four small valves instead of one, a crucial fissure being left between them. This extreme variety is very rare, being only known to occur in the coast of Patagonia; but approaches to it are met with elsewhere. Another remarkable departure from the ordinary type of aperture is occasionally found in the well known "quinqueloculine" *Miliola* of the Grignon tertiaries (the *Miliolites saxorum* of Lamarck, the *Quinqueloculina saxorum* of D'Orbigny), the walls of whose chambers are often so thick as to leave but little space for the sarcode-body, which is further encroached on by ridges that project from their inner surface: the aperture is much contracted and its "valve" small: and sometimes the internal ridges, coming up into the aperture and coalescing with the valve, form a cribriform septum that seems to foreshadow that of *Fabularia* (to which type this variety presents an obvious tendency) and of *Peneroplis*. We shall presently see that a more perfectly-developed cribriform aperture is one of the principal features of the subgenus *Hauerina*.

111. Not less variable in this genus is the surface-marking of the shell; for, although normally smooth and sometimes highly polished, it often presents a scabrous aspect, and is sometimes marked by a more or less regular pattern, formed either by longitudinal ribs as in Plate VI, figs. 3, 4, 33, by transverse plications extending to the interior of the chamber as in fig. 5, by minute pits arranged in longitudinal series as in fig. 14, by a honey-comb areolation as in fig. 13, or by various modifications and combinations of these plans. Now although such well-marked specimens as the four here figured might be reasonably considered, if taken by themselves, as distinct specific types, yet the comparison of a sufficiently large number of individuals necessitates the abandonment of any differentiation founded upon the characters they respectively present; for it is shown by such comparison that all these kinds of ornamentation shade off so insensibly into the smooth and polished surface of the ordinary Milioline shell (a specimen which is pitted or ribbed on one part of its surface being often smooth on another, and this without any appearance of having been subjected to attrition), that no use can be made of them as specific characters. Thus in the thickest-walled examples

of the *Miliola saxorum* mentioned in the last paragraph, the external surface is often marked by extremely deep circular pits; but these are not usually found on the outer walls of the earlier chambers of the very same specimens, and a gradational series of specimens may be easily selected which should show an insensible transition from the most deeply pitted to the most perfectly smooth individuals. Sometimes the shells of *Miliolæ*, especially of the "triloculine" and "quinqueloculine" varieties, acquire an arenaceous surface (fig. 6) from the imbedding of grains of sand in the ordinary calcareous substance of the shell previously to its solidification. These "arenaceous" individuals vary greatly in appearance, according to the size and character of the particles of the sandy material forming the sea-bottom in their respective localities.

112. *Affinities.*—It is obvious from what has been already stated (¶ 104), that the relationship is very close between the least specialized of the "spiroloculine" forms of *Miliola* and the ordinary *Cornuspira.* Again, not only do certain varietal forms of *Vertebralina* very closely approximate *Miliolæ* in their mode of growth, but *Miliola* occasionally takes on a uniserial plan of increase resembling that of *Vertebralina;* so that individuals not unfrequently present themselves in which the presence or absence of a "valve" is the chief diagnostic character; and even this, as we have seen (¶ 109), cannot be relied on as a constant differentiation of these two genera. With *Peneroplis,* again, the Milioline type is connected by a very interesting modification which has received from D'Orbigny the generic designation HAUERINA; this designation it will be convenient for us to retain as that of a sub-genus of *Miliola* (with which it is obviously most intimately connected), without attempting to define the precise degree of relationship of the two. The real character of *Hauerina* was completely misapprehended by D'Orbigny, who, misled by the spirality of its growth (in its early state, at least), placed it (LXXIII, p. 118) among his *Hélicostègues,* between *Operculina* and *Vertebralina,* to the latter of which it is truly allied, whilst from the former it is separated by as wide an interval as can exist among any two types of Foraminifera. In the young state of *Hauerina,* the cornuspiral form which *Miliolæ* generally present in the first instance (¶ 106) is retained longer than usual; but a distinct division into chambers shows itself in the passage to adult age; and as three or (less frequently) four chambers form the circuit of the outer whorls, the shell has a three- or a four-sided contour (Plate VI, figs. 34, 36). The aperture, like that occasionally presented by *Miliola saxorum,* is cribriform (fig. 36, B).* Although described by M. D'Orbigny as only existing in a fossil state, this type occurs at the present time in the Indian, Australian, and other tropical and sub-tropical seas. The external surface of its shell is sometimes smooth, sometimes delicately striated (fig. 36, A); whilst sometimes its walls are very deeply plicated transversely (fig. 35),—a varietal modification of which we have already seen a less strongly marked example among the ordinary *Miliolæ* (fig. 5).

113. By the *Miliola saxorum,* again, the Milioline type is obviously brought into close

* In the description and figure of *H. compressa,* given by D'Orbigny (LXXIII, p. 119, pl. v, figs. 26, 27), the septal plane is represented as perforated by a single small, oval aperture, surrounded by several large, granular elevations; but these (as appears from the examination of recent specimens of the same type) really mark the place of passages which have been filled by fossilization.

relationship with *Fabularia*, the peculiarity of whose structure consists in a higher development of that tendency to subdivision of the general cavity of each chamber, of which *M. saxorum* presents a rudimentary manifestation. Through *Fabularia*, again, the Milioline type will be seen to be related to *Alveolina*, *Orbiculina*, and *Orbitolites*, all of which are characterised by the like subdivision; and it is most interesting to trace in some forms even of the highly specialized *Orbitolites* a return, as regards the conformation and aspect of the primordial chamber and of that which immediately succeeds it, to the type presented by the corresponding portion of an ordinary *Miliola*.

114. *Geographical Distribution*.—Probably no Foraminifera are at present more universally diffused than those of the *Milioline* type, which are most abundant between the shore and a depth of 150 fathoms, but occasionally present themselves among the products brought up from deep-sea soundings. The largest and best developed forms of this type, such as that represented in fig. 33, are from the littoral zone of tropical seas. The shell is itself perfectly free; but the sarcode body of the animal by which the shell is usually invested during life attaches itself to sea-weeds, zoophytes, &c., to which *Miliola* may often be found adherent.

115. *Geological Distribution*.—The *Milioline* type may be traced back in geological time as far as the Lias, being rather abundant in the clay of that period from Stockton in Warwickshire; it is there, however, very small and delicate, presenting a condition exactly analogous to that of recent forms brought up from depths of from 350 to 500 fathoms. It is constantly present in the Gault, retaining its small dimensions, and also in the Chalk marl. From the upper Chalk to the present period it is everywhere abundant in marine deposits, having accumulated in certain parts of the Eocene period to such a vast extent that certain beds of the "calcaire grossier" are almost entirely composed of aggregations of *M. saxorum*, and are known as "Miliolite limestone."

Genus VIII.—FABULARIA (Plate VI, figs. 37, 38).

116. *History*.—The genus *Fabularia* was first distinguished by Defrance (XXIX), who applied that name to a body having a somewhat bean-like form, which occurs fossil in the Paris Tertiaries, and which he had previously confounded with *Alveolina*. He was, however, totally ignorant of its real nature; and it is now somewhat amusing to find him suggesting that, as the irregular pores of its interior could not have contained polypes, it was probably an internal shell enclosed like the "cuttle-fish bone" in the body of some Mollusk. Its place as one of the Foraminifera was first indicated by D'Orbigny (LXIX); but not being then acquainted with its real structure, he grouped it among his *Entomostègues*. Subsequently, however, he was led by more careful inquiry to perceive its essential conformity to the Milioloid type, and to group it among his *Agathistègues* (LXXIII); and he correctly states that it is most nearly related to *Biloculina*, its difference consisting in this—that the cavity of each

chamber, instead of being an empty space, is partly occupied with solid shell-substance, which is so disposed as to divide it into a great number of capillary tubes, whilst its aperture, instead of being single, is made up of numerous minute pores.

117. *External Characters.*—The general aspect of *Fabularia* (Plate VI, fig. 37, A, B) so remarkably resembles that of a gigantic *Biloculina*, as to occasion some surprise that the true relationship of this type was not earlier recognised. In fact, it externally differs only in size,—often attaining a length of 0·24 inch, and a breadth of 0·18 inch, thus far exceeding the largest *Miliolæ* in dimensions, and in the cribriform character of its aperture, in which it agrees with *Hauerina* (¶ 112). Very commonly, however, the peculiar structure of its interior is partly disclosed by the abrasion of the surface, which lays open the superficial series of the longitudinal canals into which it is divided.

118. *Internal Structure.*—The internal structure of *Fabularia* may be made out very tolerably by the examination of specimens fractured in different directions; but the most satisfactory elucidation of it is obtained from thin sections, especially from such as are carried in a direction transverse to the longitudinal axis (fig. 38). It is there seen that its general plan of growth is distinctly "biloculine;" the walls of the principal chambers on the two sides of the longitudinal axis meeting each other along the line *a b*, just as they do in Fig. XVI, B (p. 78). But the cavities of these chambers, instead of being hollow, are filled up with solid shell-substance, which is perforated by channels whose general direction is longitudinal, though these are often connected, like the Haversian canals of bone, by channels passing in a transverse or oblique direction. The longitudinal channels are arranged with some approach to regularity; a row of small orifices being observed to lie just within the external boundary of each chamber, and thus corresponding with the layer of closely approximated canals which is brought into view when the surface of the shell is removed by abrasion (fig. 37, A), whilst a much larger set of orifices, less regularly arranged, nearer to the internal portion of the chamber, shows that the channels are there much wider, but neither so numerous nor so closely approximated. The whole system of channels, whose mutual inosculations bring every part of it into the freest communication with the rest, terminates at the septal plane in a cribriform aperture (fig. 37, B), resembling that which is normal in *Hauerina* (¶ 112), and occasional in *Miliola saxorum* (¶ 110). Another curious feature of relationship to this last variety of the Milioline type is presented in the very deep pitting by which the external surface of each chamber is not unfrequently marked (fig. 38, B). This pitting is afterwards filled up by the calcareous deposit which occupies the cavity of the chamber formed around it; so that the innermost layer of this deposit comes to be furnished with a corresponding set of minute tubercles (fig. 38, A), which may be brought into distinct view by so fracturing a specimen as to separate this layer from the wall of the penultimate chamber on which it was moulded, and from which it may be commonly detached without difficulty. The manner in which these pits and tubercles are mutually applied to one another (like the pits on the under side of the epidermis to the papillæ of the cutis vera), is seen in section in fig. 38, A′, along the line *a b*.

119. *Affinities.*—The genus *Fabularia* may be considered as presenting the culmination

of the proper Milioline type of structure; that subdivision of the chambers, which we find to characterise the highest types of each series of Foraminifera (¶ 64), being here superinduced upon the simple Milioline type of growth. In the existence of that subdivision we have a relationship of analogy or parallelism to *Orbiculina*, *Orbitolites*, and *Alveolina*; but in plan of growth *Fabularia* is so distinctly related to *Miliola*, that its genetical derivation is to be looked for rather in the varietal modifications of the last-named type, than in transitional forms connecting it with those just named, which will be found to have (so to speak) a distinct line of descent.

120. *Geological Distribution.*—The genus *Fabularia* is at present only known in a fossil state, and it has not been met with elsewhere than in the tertiaries of the Paris basin, being especially abundant at Grignon.

Genus IX.—PENEROPLIS (Plate VII).

121. *History.*—The genus *Peneroplis* was first instituted by Montfort (LXVII) to distinguish a peculiar type of minute polythalamous shells, which had been previously described and figured by Schröter (XCVI) and by Fichtel and Moll (XLV), the latter of whom had ranged it with numerous others under the comprehensive designation *Nautilus*. By Montfort its distinctive character was correctly indicated as "bouche de toute la longueur de la base, et percée sérialement par une file des pores;" but he seems to have very erroneously interpreted the signification of those pores, imagining that the principal chambers are subdivided into cells, each occupied by a distinct animal, of which cells the pores are the separate orifices. Lamarck* (LIX), not adopting Montfort's genus, referred the *Nautilus planatus* of Fichtel and Moll to the genus *Cristellaria*, with which it has no relationship whatever; but the genus *Peneroplis* was recognised by Blainville (VI) and by Ehrenberg (XXXIX); and D'Orbigny has applied this name, in his various writings on Foraminifera, to the form described by Fichtel and Moll, whilst he has created one new generic term, *Dendritina*, for a series of varietal forms in which there is a single large arborescent aperture instead of a single or multiple row of separate pores, and another, *Spirolina*, for a varietal series in which the spire is prolonged rectilineally into a row of cylindrical or subcylindrical chambers with an aperture resembling that of *Dendritina*, this last being the *Coscinospira* of Ehrenberg.

122. *External Characters.*—The ordinary form of the shell of *Peneroplis* (of which an ideal representation given in Plate VII, fig. 18, is an extremely flat spire, of about two turns and a half, opening out rapidly in its last half turn. In the young shell each whorl usually does little more than adhere to the margin of the preceding, so that the first-formed portion is but slightly concealed by the subsequent growth; but sometimes the earliest whorl

* The *Renulites* of Lamarck and the *Renulina* of Blainville, which are quoted by Prof. Williamson (CX, p. 44) as synonyms of *Peneroplis*, are (as already shown, ¶ 98) aberrant forms of *Vertebralina*.

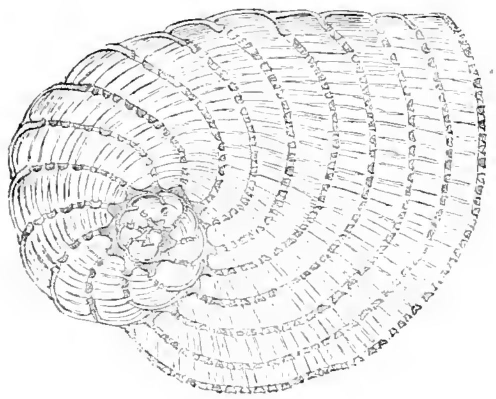
is in great degree overlapped by the next; and it very commonly happens that the last half whorl spreads itself out to such a degree as entirely to invest the preceding, the extension even reaching so far as not only to conceal the original umbilicus, but even to encroach upon the opposite half of the spire (fig. 16). When such is the case, however, the extension is usually limited to one of the lateral surfaces of the shell, which thus becomes unsymmetrical. Although this extension is sometimes confined to the inner margin of the spire. as is seen in fig. 16, yet it often occurs along the outer margin also, being usually limited, however, to the last four or five chambers. The septal plane extends itself in some instances around as much as three-fourths of the whole margin of the shell; thus showing, even in this type, an obvious tendency towards that cyclical mode of growth which we meet with in *Orbiculina*, but which is essentially characteristic of *Orbitolites*. The surface of the shell is highly polished, and has a peculiarly opaque-white, porcellanous aspect. It is very strongly marked by depressed bands, which indicate the places of the septa between the chambers; and between these septal bands the walls of the chambers rise in flattened arches. In a direction transverse to the septal bands we almost uniformly observe a strongly marked striation, the striæ running parallel at tolerably regular intervals, which average about 1-1400th of an inch, from one septal band to another; this striation, which imparts a very characteristic physiognomy to these minute shells, seems due to a sort of plication or ridge and furrow arrangement of the shelly wall (Plate VII, fig. 20), which may not improbably have the effect of imparting to it increased strength. The plication generally disappears at the junction of the walls of the chambers with the septa, and consequently we do not usually see it at the septal plane when the shell is viewed endways. Sometimes, however, it is continued on to the septal plane itself; and its character is then extremely well displayed, as in fig. 15, which, however, represents not the typical form, but one of the varieties to be hereafter noticed. On the prominences of the plicæ, there are frequently to be seen rows of extremely minute punctations (fig. 20); these, however, are not the apertures of passages through the shell, as might not unnaturally be supposed, but are mere depressions of its surface, as I have ascertained by the careful examination of very thin sections. It is remarkable that the plication of the shell is sometimes wanting, though the punctations may still present themselves in rows, as shown in fig. 2; whilst, in other cases, not only are the plicæ deficient, but the punctations are distributed uniformly over the entire surface, as shown in fig. 3. That these variations are not indicative of any specific difference, is at once proved by the fact that the shells which exhibit them in one part present the ordinary character of surface in another. Similar punctations occasionally present themselves on the septal plane of aberrant forms of the *Peneroplis* type.

123. The septal plane is perforated by numerous isolated pores, which, in those extremely compressed specimens that constitute the most typical examples of this generic form, are arranged in a single linear series (figs. 16, *a*, 18); the number of these pores depends upon the length of the septal plane, and thus it usually increases with the age of the individual, each chamber opening externally by a larger number of pores than did that which preceded it. The typical form of these pores seems to be circular, though they are apt to present various departures from that shape; they usually lie in a sort of furrows

formed by the projection of the lateral borders of the mouth somewhat beyond the septum, and each one is surrounded by a prominent annulus of shell.

124. *Internal Structure.*—On examining a thin section of a typical *Peneroplis*, taken through the median plane between the lateral surfaces (Fig. XIX), the central chamber is

FIG. XIX.



Section of *Peneroplis* through the median plane.

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

125. As I have not been fortunate enough to obtain any other than dried specimens of this organism, I have not had the opportunity of examining the structure and arrangement of its soft parts. It is obvious, however, that the body of the animal will consist of a series of compressed, flattened segments, progressively increasing in their transverse diameter, and communicating with each other by multiple threads or "stolons" of sarcode, the number of

which will augment with the length of the septal plane, whilst through the multiple pores of the last septal plane the sarcode-body can extend itself into pseudopodia. These may coalesce at their bases to form a continuous segment, on which a new chamber will be moulded when the growth of the body requires such an extension of the shell.*

126. *Varieties.*—The most frequent departure from the typical form presented by *Peneroplis* is that represented in fig. 12; in which we see that, instead of opening out and encroaching on the previous whorls, the spire becomes disengaged, and prolongs itself in a straight line, its successive chambers exhibiting little or no increase in size. Between this and the typical form every intermediate gradation presents itself; and it is curious that even here a transverse extension sometimes takes place, quite suddenly, by a doubling backwards of the last three or four chambers along the inner margin of the straight portion. In these elongated varieties of *Peneroplis* we find the spire less compressed, so that the septal plane is wider in proportion to its length (fig. 12, *a*); and this condition, which is also frequently encountered in specimens that have not thus extended themselves, is almost always coincident with a duplication in the series of pores in the septal plane. Now, it is not a little remarkable that this is almost uniformly the case with specimens furnished by particular localities, whilst those obtained from others not very remote exhibit almost as uniformly the extremest elongation and narrowing of the septal plane, with only a single row of apertures; and hence it might not unreasonably be maintained that this difference should be accounted of specific value. In reply to this, however, there is not only the analogy of *Orbiculina* and *Orbitolites*, in which (as we shall hereafter see) an indefinite multiplication in the rows of marginal pores may take place during the growth of the individual, but also the fact that in *Peneroplis* the two forms cannot be distinguished at an early age, either by the shape of the shell or by the disposition of the pores, which are often arranged neither in a single nor in a double row, but on a sort of mixture of both plans, as shown in figs. 6, *a*, 10; whilst among the more advanced examples of each type it is not at all

* A figure is given by Prof. Ehrenberg (XXXIX, taf. ii, fig. 1), professing to represent the decalcified body of a *Peneroplis* obtained alive from the Red Sea, which corresponds with the description above given in every important particular save this, that the successive segments are connected along the inner margin of the convolutions by a band much broader and thicker than the threads which pass between other parts of the segments; so that this band would seem to establish a principal connexion, to which the other threads might be considered as secondary. Now after a very careful examination both of the septal planes of numerous specimens and of sections taken in the direction of Fig. XIX, I feel myself justified in the positive assertion that no such principal aperture exists at the inner margin of the septum, as would be required to give passage to such a band as is figured by Prof. Ehrenberg. Consequently I can only account for this feature in his delineation of the animal (the idea of a difference in the conformation of the shell being negatived by the precise correspondence between his figures of it and my own, as well as by my familiarity with the Red Sea type of *Peneroplis*), by supposing that, like some of his other figures, it rather represents his *idea* of the structure of the animal than what he actually saw in its body, this principal band being apparently regarded by him as an intestinal canal by which he supposed all the segments to be connected together.

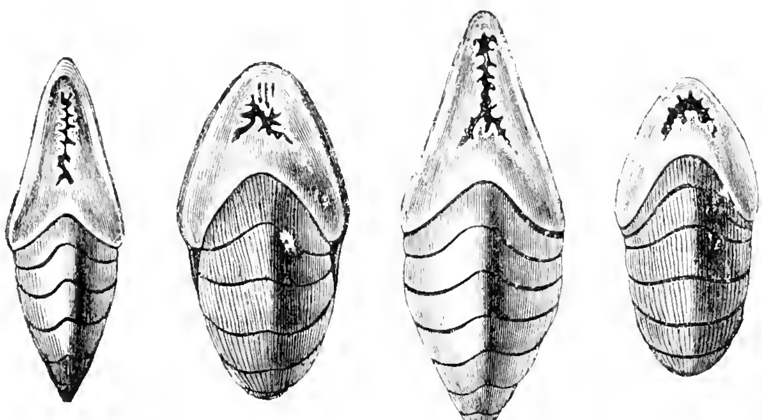
uncommon to meet with individuals which present a combination of the characters of both, the septal plane having a single row of pores in one part of its length with a double row in another (see cx, fig. 85). Sometimes, moreover, in one of the less compressed forms of the shell, although there is but a single row of pores, it is obvious from their elongated shape that there is an incipient tendency to duplication (fig. 8). Hence I consider that it may be unhesitatingly asserted that the duplication of the row of pores, and the increased turgidity of the spire which it accompanies, are but features of individual variation, and cannot be admitted to rank as specific differences; and in this view I am glad to find myself borne out by Prof. Williamson, who (cx, p. 44) defines *Peneroplis*, not (like M. D'Orbigny) as having only a single row of apertures, but as having "septal orifices scattered over the long, narrow, septal plane."

127. A much wider departure from the typical *Peneroplis*, however, is presented by that group of forms which D'Orbigny has separated under the generic designation *Dendritina*; and according to the usually received notions on the classification of Foraminifera, such a separation would seem fully justifiable. These forms are especially characterised by the possession of a single large aperture, sending out dendritic ramifications, in each septum (Plate VII, figs. 1, 14); but this is by no means the whole of their differentiation. For the spire, instead of being compressed, is very turgid (fig. 13); and its successive whorls not merely surround those which have preceded them, but also invest them with broad *alar prolongations* (*al*, fig. 14, *b*, *c*), those of the chambers of even the last whorl often extending nearly to the umbilicus. The geographical distribution of *Dendritina*, moreover, is peculiar; for, so far as I am aware, this type is restricted to the tropical ocean. I have not met with it in dredgings from any part of the Mediterranean or the Red Sea, where *Peneroplis* abounds; while the largest specimens I have seen are those furnished by Mr. Cuming's Philippine explorations, some of which measure ·078 inch in diameter, and ·030 between the lateral surfaces. To such as content themselves with glancing at strongly marked examples of this type, the propriety of its generic, or at any rate of its sub-generic, separation from *Peneroplis* would seem indubitable. Nevertheless I think that I shall be able to show adequate grounds for the belief that the two forms cannot be separated by any definite line of demarcation, and that they must therefore be ranked as not merely belonging to the same genus, but even as varieties of the same species.

128. In the first place, I would refer to the fact that the peculiar plication and punctation of the surface of the shell, which are such marked features in the physiognomy of *Peneroplis*, are repeated in *Dendritina* (fig. 21) in a manner so precisely similar, as strongly to impress every one who has his attention directed to the aspects of these two forms respectively with the idea of their very close relationship. Secondly, we observe in *Dendritina* precisely the same tendency to rectilineal extension in the later period of growth as in *Peneroplis*; for although the distinct generic term *Spirolina* has been given to the form presenting this modification, it is obvious that the example delineated in fig. 4 bears just the same relation to the typical *Dendritina*, that the one shown in fig. 12 bears to the typical *Peneroplis*. The transition from *Dendritina* to *Spirolina* is well seen in fig. 13, in which we see that the last whorl is just about to disengage itself from the earlier ones,

and that its continued increase upon the plan which has already begun to manifest itself would convert it into a *Spirolina*. On the other hand, the *Spirolina* represented in fig. 4 has, up to the time of the substitution of the rectilineal for the spiral mode of growth, all the characters of an ordinary *Dendritina*.* Thirdly, the differences of general configuration between *Peneroplis* and *Dendritina* are differences of *degree*, and present themselves in very variable amount in different individuals. For, starting from those forms of *Peneroplis* in which the spire is least compressed, the transition is easy to those *Dendritinæ* whose spire is least turgid, and whose septal plane is not broader in proportion to its length than it often is in *Peneroplis*. From the most compressed forms of *Dendritina* to those which have the most turgid spires and the widest septal planes the gradation is insensible, scarcely any two individuals according in their proportions; thus we find that whilst the septal plane is sagittate in some (Fig. XX, A, C), it tends to become reniform in others (B, D), the margin of

Fig. XX.



A B C D

Front views of four specimens of *Dendritina*.

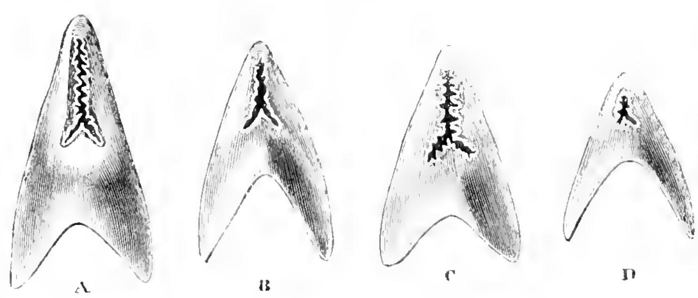
the spire, which is almost carinated in the first case, becoming obtuse and even crescentic in the second. Again, the extent of the investment of the earlier whorls by the latter varies as much as the degree of turgidity; for whilst in some of the most compressed forms, as in *Peneroplis*, each whorl does little more than apply itself to the margin of the preceding (Fig. XXI, A, C), the more turgid the spire becomes the more completely (generally speaking) does it embrace the preceding, the alar prolongations of the chambers thus coming to bear a large proportion to their principal cavity (Fig. XXI, B, D).

129. Still it may be said that, notwithstanding all these points of resemblance, the difference between *Peneroplis* and *Dendritina* is clearly marked out by the difference in the

* The elegant crozier-like form of *Spirolina* is sometimes rudely imitated by *Lituola*; and specimens of the latter, the *Sp. agglutinans* of D'Orbigny (LXXIII, p. 137) for example, have not unfrequently been described under the former designation, although the texture of the shell, which is *never* arenaceous in *Spirolina*, and *always* arenaceous in *Lituola*, affords a ready and certain means of discriminating them.

modes of communication between the chambers of the two types, and that such a difference is sufficiently important to constitute a valid generic character. I freely admit that this would be the case, if the difference were constantly to present itself between all the individuals of the same type, as it does between their characteristic examples (Plate VII, figs. 13, 16); but the fact is far otherwise. We have seen that among those which would be unhesitatingly ranked under the designation *Peneroplis*, there is not only a tendency to multiplication of the rows of separate pores, but also an occasional fusion of two or more pores, so as to form a single large pore of irregular shape. On the other hand, among the unquestioned *Dendritinæ* we observe not merely that the form of the single large dendritic aperture is extremely variable, but that it is frequently so simple as to suggest the idea of having been formed by the coalescence of a linear series of pores. The highest development of the dendritic form of aperture that I have met with, is shown in fig. 14, *a*, *b*; two examples of a remarkable departure from this have just been seen in Fig. XX, B, D, where the proportions of the aperture are altogether reversed, its breadth being much greater than its length, and its central part being enlarged at the expense of its ramifications; while, on the other hand, in Fig. XX, A, C, we have marked examples of a narrowing and elongation of the aperture, with such a reduction of its dendritic ramifications that it comes to present little more than a linear fissure. From a comparison of these cases it will be seen that the form of the aperture bears a pretty constant relation to that of the septal plane; the broadest apertures presenting themselves in the individuals which have the most turgid spire, and the narrowest in those whose spire is most compressed; whilst the proportionate development of the two principal alar prolongations seems related to the degree of that alar extension of the chambers over the whorl they enclose, of which I have already spoken. But the most satisfactory proof of the wide extent of range of variation in the form of the aperture in *Dendritina*, is afforded by a comparative examination of the apertures connecting different chambers of the same individual. Thus, in the interior of the very shell (fig. 13) that presented the peculiarly characteristic example represented in fig. 14, we find a form of aperture closely corresponding to that shown in Fig. XX, C; and in four septa of the inner part of another shell we have the simple forms of aperture represented in Fig. XXI, A, B, C, D.

FIG. XXI.



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

130. But further, not only do we thus meet with examples of each type which present more or less of approximation towards the other, but we also not unfrequently encounter

individuals in which the characters of the two types are so blended as to make it difficult, if not impossible, to say to which they should be referred. Thus in the specimen (fig. 10) already referred to as presenting a linear series of pores, the marked elongation of which shows each to be formed by the coalescence or imperfect separation of two, there is an additional pair precisely in the situation of the alar prolongations in fig. 14, *c*; and it is obvious that the simple form of dendritic aperture there represented would result from the coalescence of these pores along the middle of the septal plane. Another example, also from a young specimen, is shown in fig. 6; and it is readily intelligible how in such a case the subsequent compression of the spire and the narrowing of the septal plane may cause the pores to present the simple linear arrangement characteristic of *Peneroplis*; whilst if, with a continuance of the early mode of growth, the separate pores of later septa should coalesce into one aperture, we should have a *Dendritina*. In another young specimen, shown in fig. 11, such a fusion of several pores into a single dendritic aperture has actually taken place (*a*), whilst another broad aperture is seen just below this. Again, in fig. 7 we see the broad septal plane irregularly perforated by numerous pores, some small and rounded, others large and irregular, each of the latter being obviously formed by the coalescence or imperfect separation of two or three; the turgid spire of *Dendritina* and the separate pores of *Peneroplis* here coexisting with each other, so as to make it difficult to say to which type the specimen should be referred. Again, the transition is easy from the specimen represented in fig. 10 to that shown in fig. 9, and thence to the one whose septal plane is shown in fig. 15; here the coalescence has proceeded so far as to produce a number of separate branching apertures, and nothing is wanting but the removal of the line of shell which passes down the middle of the septal plane to unite these into the most characteristic form of the single ramifying orifice. This individual, like the one represented in fig 13, was already beginning to assume the *Spiroline* form, the rounded shape of the mouth showing that the spire has detached itself completely from the previously formed convolutions; in figs. 4, *a*, and 5 are shown the septal planes of more advanced examples of the same type, which present such a combination of the large dendritic aperture of *Dendritina* with the isolated pores of *Peneroplis* as to complete (in my opinion) the proof that no valid distinction can be drawn between these two types, either from the number, the isolation, the position, or the shape of the apertures in the septa. Hence it follows that not merely must the genera *Dendritina* and *Spirolina* be relinquished, but that both these forms must be regarded as mere varieties of *Peneroplis planatus*.

131. *Affinities*.—A sort of sketching out of *Peneroplis* may be traced, as we have seen, in some forms of *Nubecularia* (¶ 90); and the type becomes still more defined in *Vertebralina*, some of whose forms can only be distinguished from *Peneroplis* by their undivided aperture. If the elongated slit of the compressed *Vertebralinæ* were to be subdivided into a linear series of pores as in the typical *Peneroplis*, or the circular aperture of the cylindriform variety were to be modified in like manner so as to resemble that of *Spirolina*, the transition would be complete. Again, we have seen that an approximation to the Peneropliform type is presented in the cribriform subdivision of the aperture of a true *Miliola* (¶ 110), whilst a still closer relationship to it is exhibited in the *Hauerine* modification of the Milioline type (¶ 112). Looking to the inconstancy of the aperture in the Peneroplis type itself, we

can scarcely fail to perceive how slight are the differential characters which separate it from either *Vertebralina* or *Hauerina*. On the other hand, it presents a very close approximation to the spiral variety of *Orbiculina;* a sort of preparation for the subdivision of the chambers characteristic of that type being made in the subdivision of the aperture, and perhaps also in the ridge-and-furrow arrangement of the lateral walls of the chambers. And, as we shall hereafter see (¶ 143), there are certain aberrant forms of *Orbiculina* in which the subdivision of the chambers is wanting, so that no perfectly defined boundary between these two types can be said to exist.

132. *Geographical Distribution.*—The genus *Peneroplis* is very widely diffused through warmer latitudes, especially frequenting the laminarian zone; so that few collections of Foraminifera from sands or dredgings brought from the Mediterranean, the Ægean Archipelago, the Red Sea, the East or West Indies, the Philippine Seas, or the shores of Australia or the Polynesian Islands, will fail to present numerous examples of it. A few specimens have been found on British coasts; but it seems most probable that, as Prof. Williamson has suggested (cx, p. 46), these have been brought by the Gulf Stream from the West Indian Seas. The prevalence of particular modifications seems in some degree determined by temperature. For it is only in tropical seas that the Dendritine variety presents itself 127); and although the ordinary type also abounds in the same localities, yet it is there that it shows the greatest tendency towards the dendritine variety, both in the turgidity of its spire and in the arrangement of its septal pores, whilst the Spiroline variety generally shows some tendency to the dendritic form of aperture. In the Red Sea the ordinary *Peneroplis* is very abundant; and in its young state the spire is turgid, and its pores are frequently arranged in a double row or even tend to coalesce, though with each addition to the number of segments the spire becomes flatter and broader, and in the older specimens the pores are almost invariably arranged in a single row. Now here the proper Dendritine variety is either absent altogether, or is extremely rare; and the Spiroline (which presents every gradation from the cylindrical to the compressed form) rarely has any other kind of aperture than a multiplication of separate pores. In the Mediterranean, on the other hand, which seems to be the most northern limit of its diffusion, not only is the *Dendritine* variety altogether wanting, but the *Peneroplis* type seems (as it were) to be starved out, the spire presenting the extreme of attenuation, and the septal pores being almost uniformly arranged from the beginning in a single row.—The *Spiroline* variety, which is usually of smaller dimensions, seems to replace both the Dendritine and the Peneroplis type in the deeper waters of the tropical ocean; both the large turgid *Dendritinæ* and the broad *Peneroplides* being inhabitants of comparatively shallow water.

133. *Geological Distribution.*—Neither the ordinary *Peneroplis* nor its Dendritine and Spiroline varieties has been traced backwards in geological time further than the commencement of the Tertiary epoch.* The Grignon and Paris Tertiaries contain several forms of

* The statement of some authors that *Spirolina* occurs in the Cretaceous and even in earlier formations of the Secondary epoch, has resulted from their having mistaken the crozier-shaped forms of *Lituola* for the true *Spirolina*.

Peneroplis and *Spirolina*, to the exclusion of *Dendritina*; whilst in the Vienna Tertiaries we meet with *Dendritina* and *Spirolina*, to the exclusion of *Peneroplis*.

Genus X.—Orbiculina (Plate VIII, figs. 1—12).

134. *History.*—The interesting group of organisms belonging to this type seems to have early attracted notice, probably on account of the great abundance in which it presents itself on the sands of many of the West Indian shores. Three species are described and figured by Fichtel and Moll (XLV), under the names of *Nautilus orbiculus*, *N. angulatus*, and *N. aduncus*. Lamarck (LIX), however, separated them from *Nautilus*, and raised them to the rank of an independent genus, to which he gave the name of *Orbiculina*; and he also changed two of the specific names, the three standing respectively as *O. numismalis*, *O. angulata*, and *O. uncinata*. By Montfort (LXVII), these species were raised to the rank of independent genera, under the names of *Helenis*, *Archaias*, and *Ilotes*; but these genera have not been adopted by any other systematist. M. d'Orbigny, in his first classification of the Foraminifera (LXIX), not merely adopted Lamarck's generic designation, but affirmed that the three reputed species were really nothing else than one and the same organism in different phases of growth, *O. angulata* being the youngest, *O. numismalis* the next in age, and *O. uncinata* the adult. He arrived at this result, of the truth of which I am myself well assured, by the comparison of a great number of specimens, a process which it would have been well for science if he had more constantly adopted. The name of the adult form should, of course, stand as that of the species; but the organism in question is more commonly known under the designation *Orbiculina adunca*, which seems to have been conferred upon it by M. Deslongchamps (XXXII). A considerable number of figures of this species are given by M. d'Orbigny in his treatise on the Foraminifera of Cuba (XCII); they serve only, however, to give a general idea of the diversities of external conformation which had presented themselves to him; and notwithstanding their number and variety, they do not include some of the most important among the protean shapes of these bodies, nor do they throw any light upon their internal structure. The memoir of Prof. Ehrenberg, in which his group of Bryozoa was originally constituted (XXXIX), contains the first recognition of the near relationship between *Orbiculina* and *Orbitolites*, which he grouped in close proximity among the Bryozoa. His description of their structure, however, is so greatly prejudiced by his erroneous idea of the nature of the animal body to which they belonged, and is rendered so imperfect by his want of acquaintance with the appearances presented by their sections, that it serves rather to mislead than to inform any one who may consult it. It was by Prof. Williamson (CVIII) that the real structure of *Orbiculina*, and its very close conformity to that of *Orbitolites* as previously described by myself (XII), were demonstrated; and that the frequent exchange of the *spiral* for the *cyclical* plan of growth, with the advance of age, was recognised; and the few slight errors into which he fell are probably attributable to the imperfect state of the specimens on which his description was founded.

135. *External Characters.*—The form under which *Orbiculina* is most commonly known is that represented in Plate VIII, figs. 8, 9, 10, which has suggested the specific designation *adunca;* but such a departure from this as is shown in figs. 1, 2, 3, 4, is not at all infrequent; and a continuance of the mode of growth which characterises these last sometimes leads to the assumption of the discoidal form shown in figs. 5, 6, which seems to be the highest phase of this type, being always presented by the largest specimens of it, some of which attain a diameter of ·20 of an inch. Among young specimens it is not at all uncommon to meet with some (fig. 2) that bear a strong resemblance in form to *Peneroplis;* they are distinguished from that type, however, by the absence of the striation that so generally characterises it; and when the surface-layer of shell is sufficiently thin, a division of each principal chamber by secondary partitions passing between the septa at right angles to them may also be very commonly made out. In older specimens, however, these secondary partitions are seldom to be seen externally, being usually obscured by the greater thickness of the surface-layer of shell; sometimes, however, they continue to be distinguishable even in the most developed forms (fig. 5). The large discoidal specimens bear so strong a resemblance to *Orbitolites* as not to be distinguishable from that type except by the prominence of the umbilical region, which is occasioned by the investment given by each turn of the spire to the preceding, so long as the spiral growth continues.

136. The essential unity which prevails through these and other less important diversities will be understood by following the growth of *Orbiculina* from that early condition shown in fig. 7, which is common to all. Its form is then lenticular, or even, in the thicker varieties, almost orbicular; each septal band, commencing from the centre (*a*) of the spire, goes off, in the first instance, in such a manner as to encroach on the opposite side of the convolution; it then curves round with a strong convexity directed forwards (*b*), turns back, and finally terminates at the margin (*c*) in such a manner as to form its continuation. By this curvature the septal plane (*a*, *b*, *c*), which, as yet, corresponds to only half the diameter of the spire, is greatly elongated, so as to present a much larger apertural surface than it would possess if it passed directly from the centre to the margin in the line *a c*. When viewed on its anterior face, it has the form of that of a *Peneroplis* whose spire completely invests the preceding; its breadth varying in proportion to its length, as the shell is orbicular or lenticular in shape, but its alar lobes being always much prolonged. Its entire surface is perforated with pores exactly resembling those of *Peneroplis*, each being surrounded by a prominent annulus of shell: and these pores show some definiteness of arrangement, being disposed in more or less regular rows, as to the number of which, however, there is no constancy whatever. In a more advanced stage of growth (fig. 8), we see that the septal band, still commencing at the centre (*a*), and partly encroaching on the opposite side of the spire, then bends round as before; but instead of speedily turning backwards, it makes a gentle curve (*b*), which forms a large part of the margin of the shell, and then terminates abruptly at *c*, this termination being the source of the "aduncal" form. Here we see that the septal plane with its apertural surface is greatly extended; and along all that portion of it which forms the margin of the shell, the pores are disposed with more approach to regularity, the number of rows, however, being very variable. In a yet more advanced stage of the "aduncal type," the later portion of the spire ceases to invest the

earlier, the newest chambers stopping short at its margin or but slightly encroaching on it (fig. 9, *a*); and the septal plane, which now forms from two-thirds to three-fourths of the entire circuit, is much narrower in proportion to its augmented length, more resembling that of an advanced *Peneroplis* (Plate VII, fig. 16, *a*), but usually showing multiple rows of pores. This mode of increase may continue during the whole life of any individual, so that specimens attaining a diameter of ·12 of an inch not unfrequently preserve the "aduncal" shape. But it often happens that the outer extremity of the newly formed chambers (fig. 4, *c*), instead of abruptly terminating at the most anterior part of the margin, extends itself by an inward curvature, so as to double back upon the earlier portion of the spire, and thus to approximate the inner extremity of the same chamber (fig. 4, *a*); and the septal plane with its apertural surface is thus carried round nearly the entire circuit of the shell. A persistence in the same plan of growth causes the two extremities of the chambers to meet and completely to surround the original spiral (fig. 5); and from that time forth each new chamber forms a complete and continuous ring around the preceding, and the apertural surface of the septal plane extends round the entire circuit. In the most advanced stage of its growth, the disk often thins out to such a degree that the apertural margin is no broader than that of a *Peneroplis*, and has, like it, only a single row of pores.

137. Now this change from the *spiral* to the *cyclical* plan of growth may take place at any period of life. In the individuals represented in figs. 1 and 3 there is obviously a preparation for it; these showing no tendency to that abrupt termination of the outer ends of the later chambers which gives rise to the "aduncal" form, but, on the other hand, exhibiting a marked disposition to the extension of these towards their inner extremities, so that they will assume the discoidal form without passing through what is usually the intermediate stage. Hence it is impossible to regard it in any other light than as a varietal modification, the conditions of which are as yet unknown, though related in some degree to the advance of age.

138. The shell of *Orbiculina* corresponds closely in texture with that of *Peneroplis*, having (in well-preserved specimens) very much of the same polish and enamel-like lustre. Its surface is frequently marked (like that of the *Miliolæ*) by pits which present the semblance of pores, and which have been mistaken for them by Prof. Williamson (CVIII). A careful examination of thin sections, however, makes it clear that the continuity of the shelly wall is nowhere interrupted.

139. *Internal Structure.*—In a large proportion of ordinary specimens of *Orbiculina* the natural surface has been so far removed by abrasion as in some degree to disclose the internal structure of the shell; this, however, is much better displayed by thin sections carried through the median plane, such as those represented in figs. 6, 10, 11, and by sections taken at right angles to this, such as that represented in fig. 12. An idea of the structure will be best formed by supposing each elongated gallery which forms the chamber of a *Peneroplis* to be partially subdivided into "chamberlets" (if the coinage of such a diminutive be admissible) by a series of partitions that pass transversely from each septum to the

next; all the "chamberlets" of the same row, however, communicating with each other by a passage that runs continuously through their partitions (see Diagram, p. 52); and each "chamberlet" also communicating with the chamberlets of the adjacent rows by perforations in the principal septa. This is, in fact, exactly what we see in the peripheral portion of those thinned-out specimens of discoidal *Orbiculinæ* which have but a single row of marginal pores, as will be clearly understood from fig. 11, which represents a part taken from the edge of fig. 6, seen as an opaque object under a much higher magnifying power. At *aa′*, *aa′*, *aa′*, *aa′* are seen portions of four of the principal septa which separate from each other the principal chambers or galleries *cc′*, *cc′*, *cc′*; these galleries are again divided into the "chamberlets" *d*, *d*, *d* by the secondary partitions *e*, *e*, *e*, *e*, which do not, however, completely separate them from each other; and the successive galleries communicate with each other by the passages *b*, *b*, that traverse the principal septa, those of the last-formed septum showing themselves as a row of pores upon its external surface. The animal body which occupies the interior of a shell thus divided will obviously consist (as we shall see to be the case in *Orbitolites* (Plate IV, figs. 14, 23) of a series of principal segments of sarcode, each of which is divided by constrictions into a necklace-like series of sub-segments, strung (as it were) upon a connecting cord; whilst each principal segment will communicate with the segments anterior and posterior to it, as in *Peneroplis*, by stolons of sarcode that pass through the septal passages, those of the last segment issuing forth as pseudopodia from the marginal pores.

140. It is seldom, however, that the arrangement is so simple as in the case just cited; for it much more frequently happens that the space between the two surfaces of the shell exceeds by many times the distance between each septum and that which succeeds it, so that the "chamberlets" are greatly elongated in the direction perpendicular to the surface. This is shown in fig. 12, which represents the central portion of a section whose plane passes at right angles to that of the spire, and brings into view the successive convolutions 1, 2 2′, 3 3′ and 4 4′, of which each is seen completely to enclose the preceding. Each "chamberlet" is here elongated vertically, and the adjacent "chamberlets" of the same series communicate with one another, not by one passage, but by many (*a*); whilst the successive series also communicate with each other by multiple rows of septal pores (*b*). In neither set of communications, however, do we observe any great regularity, whether as regards number or arrangement. The height of the chambers, with the number of the connecting passages proceeding from them in each direction, is seen to increase progressively from the first-formed convolution (1), whose chambers are disposed upon the simple type previously described, through the second (2 2′) and third (3 3′) to the fourth (4 4′), in which last it reaches its maximum at no great distance from the centre; and from this it often diminishes as the chambers extend themselves more and more widely along the margin, which (as already stated) may thin out until we find in the peripheral portion a recurrence to the simple type of the central.—The disposition of the sarcode-body that occupies this more complex system of chambers must obviously be modified in correspondence with it, as we shall see in the complex form of *Orbitolites* (Plate IV, fig. 25). The subdivisions of each principal segment, instead of resembling beads strung upon a single cord, will rather have the form of a row of columns standing side by side, and connected together by numerous bands passing transversely from one to the

other; whilst similar multiple bands pass from each series to the rows that stand behind and in front of it.

141. A comparison of figs. 6 and 10,—of which the former represents the internal arrangement of the *cyclical* type, and the latter that of the *aduncal*,—shows that the early growth of the former, up to the period when the mouth of the spire widens out on both sides, takes place after precisely the same fashion as that of the latter; after which the aduncal termination is concealed by the extensions of the subsequently formed chambers along its margin, which extensions, having once advanced far enough to meet those advancing in the opposite direction, unite with them, so that each gallery of "chamberlets" thenceforth returns into itself, instead of terminating by two blind extremities. A conception of the probable mode in which the successive additions are made to the shell will help us to understand how the one mode of growth may be exchanged for the other, without any departure from the fundamental plan. The extensions of the sarcode-body which form the pseudopodia issuing from the marginal pores will first coalesce with each other at their bases, so as to form a continuous segment which will lie along the external surface of the last septum; if this segment were of uniform size along its whole length, the shelly chamber formed by the calcification of its surface-layer would be simple, like that of *Peneroplis*; but it is thickened in front of each septal pore, and narrowed in the intervals between these thickenings, so as to form a series of secondary segments united by a continuous stolon; and the shelly envelope moulded upon this will have a corresponding series of "chamberlets" connected by a continuous gallery. Now the tendency of each new segment of the sarcode-body is usually to extend itself along the margin beyond the preceding; but this extension is commonly limited in the early growth of *Orbiculina* to the inner extremities of the successive segments, which gradually creep round the earlier portion of the spire, whilst their outer extremities terminate abruptly, and may continue so to do through the whole of life. But if these outer extremities of the segments of sarcode should share in the extension, they will creep along the margin of the older part of the shell in the contrary direction, until they meet and coalesce with those of the inner extremities; and from that time each successive segment of sarcode will be a complete ring which will encircle the entire margin of the disk, and the successive additions made to the shell will be formed upon the cyclical plan.

142. A larger size and higher development are attained by some fossil forms of *Orbiculina*, which there is nevertheless no sufficient ground for regarding as specifically different from the existing type. Under the erroneous designation of *Orbitolites Malabarica*, Mr. Carter has described (xx) a species of *Orbiculina* that abounds in a Tertiary limestone apparently corresponding with the Nummulitic limestone of the South of Europe; and of this species I have, through his kindness, had the opportunity of carefully examining several examples. In size it greatly exceeds the existing type, its diameter being sometimes as much as seven or even eight lines; in general structure, however, it altogether conforms to the description already given, with this one exception, that each surface is formed (as in the complex type of *Orbitolites*) by a layer of shallow chambers that are partially cut off from those of the thick intermediate substance. This difference, however, possesses no greater claim to be accounted a specific distinction in *Orbiculina* than it does in *Orbitolites*; and since,

when we come to examine into its value in the latter type, we shall there find it to be a mere varietal or developmental diversity, it cannot here be accepted as of higher value.

143. *Affinities.*—The genus we have been considering occupies a position precisely intermediate between *Peneroplis* and *Orbitolites*, to both which types it is most intimately related. As already mentioned, young specimens of *Orbiculina* are often to be met with which bear a very strong external resemblance to *Peneroplis*; and even the absence in the former of the striation usually characteristic of the latter does not furnish an absolute ground of differentiation, since the striation is not unfrequently obsolete in *Peneroplis* (¶ 122). In ordinary cases, however, the difference becomes evident so soon as we examine into the internal structure of *Orbiculina*; being marked by the subdivision of the principal chambers into "chamberlets" by the partitions which extend transversely between the septa. It is a fact of not a little significance, however, that those partitions are sometimes wanting, not merely in feebly developed peneropliform varieties, but even in good-sized adunciform specimens; so that the chambers are formed upon the model of those of *Peneroplis*, and must be occupied, as in that genus, by transversely elongated lobes of sarcode, instead of by a moniliform series of sub-segments. In such cases, therefore, no absolute line of demarcation can be laid down between *Peneroplis* and *Orbiculina*; for, although there may be practically little or no difficulty in referring any given specimen to one or the other type, by the aggregate of the characters it presents, yet no one of these characters taken by itself is sufficiently constant to serve as the basis for a precise definition. So, on the other side, the resemblance between the peripheral portion of an *Orbiculina* that has taken on the cyclical growth, and the corresponding portion of those varieties of *Orbitolites* in which the superficial chambers are not differentiated from those of the intermediate stratum (¶ 173), is so extremely close, as well in internal structure as in external aspect, that the two could not be distinguished by any character or combination of characters. It is, in fact, only in their early mode of growth that *Orbiculina* and *Orbitolites* essentially differ from each other; the former being *always* spiral, whilst the latter is *typically* cyclical from its commencement. But we shall see (¶ 180) that the early growth of *Orbitolites* is often spiral; and the difference between the two types seems to resolve itself essentially into this, that the spiral mode of growth gives place to the cyclical in *Orbitolites* before a second convolution is formed, so that the primordial chamber and the first convolution are never invested by subsequent growths.

144. *Geographical Distribution.*—This generic type appears to be limited to the warmer parts of the ocean. It is found in great abundance near the shores of the West Indian Islands, also near those of the islands of the East Indian and Polynesian Seas, being especially large and abundant in the neighbourhood of the Philippine Islands. It occurs also in the Red Sea, and is asserted to present itself in some parts of the Mediterranean and in the Ægean, though it is certainly not a common inhabitant of those seas. So far as is at present known, *Orbiculina* is entirely deficient in the seas of colder latitudes.

145. *Geological Distribution.*—We have at present no certain knowledge of the existence of *Orbiculina* in any formation anterior to the Tertiary series; but in several members of this it is very abundant. A fossil form closely resembling that of the Malabar Limestone has been

found in the Tertiaries of St. Domingo; and the type is also found fossil in a white (Tertiary ?) limestone at Corfu.

Genus IX.—ALVEOLINA (Plate VIII, figs. 13—15).

146. *History.*—Most of the examples of this type at present known are fossils, occurring in association with *Nummulites*, *Orbitolites*, &c. in the Nummulitic limestone, or in other formations which represent it; and those first described (by Fortis) were confounded with Nummulites and Orbitolites under the term *Discolithus*. By Fichtel and Moll (XLV) they were ranked as a sub-type of their comprehensive genus *Nautilus*. The designation *Alveolites* was first given to this type by Bosc,* who erroneously referred two minute forms of it to a genus which had been previously established by Lamarck (LVII) for a group of corals; but Montfort, (LXVII), not accepting this determination, raised three of Bosc's species to the rank of genera, under the names of *Borelis*, *Clausulus*, and *Miliolites*. Lamarck did not adopt either Bosc's or Montfort's generic designations, but substituted new ones (LIX, LX), *Melonites* for the fossil, and *Melonia* for the recent forms. Defrance (XXIX) proposed yet another name, *Orizaria*. And finally M. D'Orbigny (LXIX) adopted Bosc's name, with a slight alteration in its termination, which served at the same time to mark the continued existence of the type, and to distinguish it from the Lamarckian genus of Corals. The name *Alveolina* was soon afterwards adopted by M. Deshayes (XXX), and it may now be considered as the established designation of the genus, the synonymy of which has recently been very fully treated by Messrs. W. K. Parker and Rupert Jones (LXXX *a*).

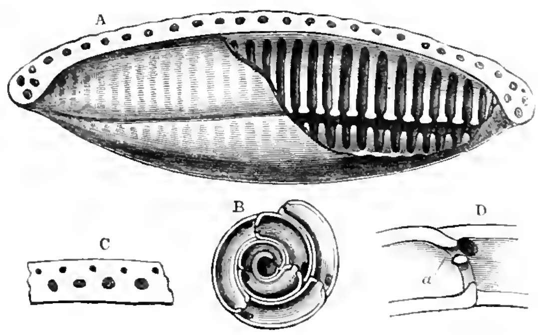
147. *External Characters.*—The recent specimens upon which my investigations have been made belong to a fusiform variety which was tolerably abundant both in Mr. Jukes's Australian dredgings, and in Mr. Cuming's Philippine collection; they were obviously identical specifically, but those from the latter source considerably exceeded those from the former in average size. The length of the longest complete specimen in my possession is ·35 of an inch; but I have a specimen whose shape is nearly cylindrical (the *A. Quoii* of D'Orbigny), which, though incomplete at one end, measures ·50 of an inch. The ordinary form, from which any considerable departure is very rare, is that which is exhibited in Plate VIII, fig. 13; and it is obviously produced, as correctly stated by M. D'Orbigny, by the involution of a spiral around an elongated axis. The surface is marked out by depressed septal bands into a succession of segments of tolerably uniform breadth; and each of these segments is crossed by secondary furrows, which lie so closely together as to mark out each into a series of very elongated areolæ, that remind us of the oblong superficial areolæ of the complex type of *Orbitolites* (Plate IX, fig. 7), but are much narrower in proportion to their length. The apertural plane of the spire is closed by a solid wall, the surface of which is nearly flat, and

* 'Bulletin des Séances de la Société Philomathique,' No. 61.

which is perforated by multiple rows of rounded pores, each surrounded by a prominent annulus of shell, and bearing a very close resemblance to the pores at the margin of *Orbiculina* and *Orbitolites*. One such row is pretty uniformly to be made out at the inner border of each apertural plane; and another row of very small pores, closely set together, may be detected in well-preserved specimens along the outer border. The apertural surface increases considerably in breadth towards its two extremities, and the rows of pores are there more numerous but less regular.

148. *Internal Structure.*—The internal structure of *Alveolina* will be best understood by supposing the cavity of an *Oliva* (or any other univalve shell that winds spirally round an elongated axis) to be crossed not only by transverse partitions, which divide it into principal chambers (indicated on the surface by the depressed septal bands that run parallel to the axis), but also by a set of partitions at right angles to these, which divide each principal chamber vertically into a row of long, narrow "chamberlets" in lateral contiguity with each other, these secondary septa corresponding with the secondary furrows of the surface (Fig. XXII). The chamberlets thus divided will open at the apertural plane by a single row

Fig. XXII.

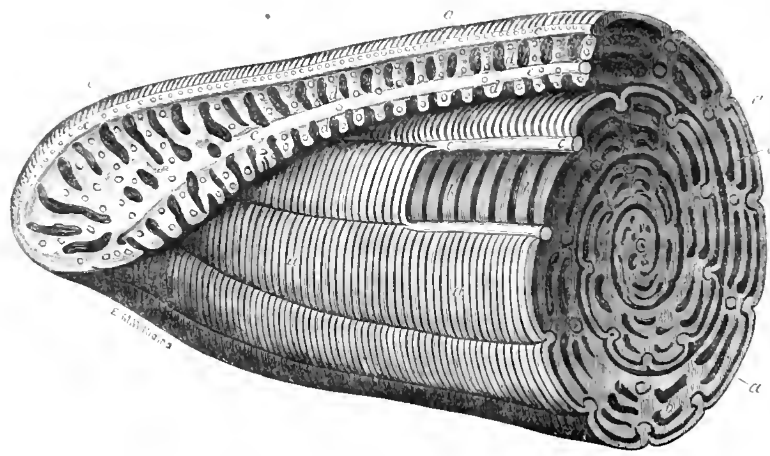


Simple type of *Alveolina*, as seen laid open at A, and in transverse section at B. At C is shown a portion of the apertural plane of a specimen which exhibited two rows of pores; and at D, a transverse section of one of the septa.

of pores resembling that which is characteristic of *Peneroplis*. It may occasionally be noticed, however, that the septal pores form a double row, as shown at C; in which case those nearest the exterior are directed towards the longitudinal canal, as is seen in section at D, *a*, so as to establish a direct communication between each segment and the longitudinal stolon from which the next appears to commence. Such is, in fact, the structure of all the fossil *Alveolinæ* I have examined; and we may characterise it as that of the *simple* type of *Alveolina*.—In the recent form which I have specially studied, however, the structure is much more complex; for each principal chamber is subdivided not only by vertical, but also by horizontal partitions or floors, so as to form a succession of "storeys," which are indicated externally by the multiplication of the rows of pores on the apertural plane. This will be partly understood from Plate VIII, fig. 15, which represents a section of *Alveolina* taken in the direction of its elongated axis, and which shows the general mode of increase by successive convolutions around the primitive spheroidal chamber, each convolution extending considerably in a longitudinal direction beyond its predecessor, and thus adding much more to the length than to the diameter of the shell. In this section the long narrow chamberlets are divided transversely, so that they are merely seen as rows of rounded apertures channelled out in the solid substance of the shell; they correspond in relative situation with the pores of the apertural plane, but are usually of much larger size. Generally about four such rows may be distinguished in each convolution; but they are far from being regularly disposed, especially towards the two extremities of the axis of growth. Along the outer margin of the last and of each preceding segment, we see a row of apertures much smaller than the rest, and much more closely set together; these are the transverse sections of the superficial layer of chamberlets, the dimensions of which are indicated by the furrowing of the surface, and which are about twice as numerous as those of the rows that lie internally to them. This difference is peculiarly interesting when taken in connection, on the one hand, with that which we have seen to exist between the superficial and the more deeply seated chamberlets of *Fabularia* (¶ 118), and on the other with that which we shall encounter between the superficial and the intermediate layers of chamberlets in *Orbitolites* (¶ 166), the type in which this differentiation seems to acquire its fullest development. The form and arrangement of the chamberlets are better displayed by transverse sections of the shell, such as is represented in fig. 14; in which figure the solid substance is left white, the shallow cavities occupied by the sarcode (here laid open in the direction of their length) are shaded of a half tint, whilst the black spots represent the openings of long galleries that pass continuously from one end of the shell to the other, so as to bring all the chamberlets into free communication with each other laterally. As each whorl is in regard to all essential particulars but a repetition of the rest, it will be sufficient to describe the structure of the outer convolution. This is divided into principal segments, which obviously correspond with the spaces that intervene between the depressed septal bands of the external surface; the places of those bands being marked, not only by slight inflections of the external outline, but also by prolongations (*a*, *a*, *a*) of the superficial lamella, which are directed inwards so as to contract the mouth of the spire at what may be considered the termination of each formative act. Just within these projections are seen the orifices (*b*, *b*, *b*) of one set of longitudinal channels, whilst nearer the internal side of the convolution are seen the orifices (*c*, *c*, *c*) of another much larger series of longitudinal channels, which are like galleries connecting the contiguous chamberlets of the same floors. Between the orifices *b*, *b*, *b*, and the orifices *c*, *c*, *c*, which respectively correspond to them, there is no division of the principal cavity of the spire into "storeys" of chamberlets; but, to carry out the analogy, those intervening spaces may be likened to the well-staircases by which a vertical communication is established between the several "storeys" in a large mansion. The principal cavity of each segment is elsewhere separated by the intervention of three concentric laminæ of shell (d, d^1, d^2) into a set of superposed chamberlets (e, e^1, e^2, e^3), which are usually four in number, though in a portion of the convolution that is rather narrower than the rest we see only two lamellæ and three chamberlets, whilst in a wider portion of the interior convolution we see four lamellæ and five chamberlets, and even this number is frequently exceeded. The thickness of these lamellæ is by no means uniform, and the capacity of the chamberlets between which they intervene is subject to variation accordingly. Generally speaking, the lamellæ are thickest at their posterior extremities, so that the entrances to the chamberlets from the vertical "wells" are there much narrowed; in front of these constrictions the cavities of the chamberlets usually open out considerably; and they become narrower again towards their anterior extremities, where their terminations appear as the pores on the apertural plane which closes in each segment as its formation is completed.

149. The idea of the structure of the composite animal which we gain from the examination of these sections of the shell is fully borne out by the examination of the silicified "casts" of the interior, which Messrs. Parker and Rupert Jones have been fortunate enough to obtain (p. 10); for these casts, which exactly represent the form of the sarcode-body whose place they have occupied, exhibit just the arrangement and connections which might have been predicated. The whole body (Fig. XXIII) is made up of a series of minute elongated sub-segments, united together at their extremities, in the mode to be presently described, into groups which represent the principal segments of Foraminifera of less complex type. Every such group consists of several rows (usually four or more) of sub-segments, arranged vertically

Fig. XXIII.



Portion of an Internal Cast of an *Alveolina* of complex type:—*a*, *a*, *a*, *a*, superficial series of sub-segments; *b*, *b*, *b*, subjacent series; *cc*, *cc*, longitudinal stolons; *d*, *d*, vertical columns.

one over the other; but the sub-segments (*a*, *a*) forming the superficial layer are of only about half the breadth of those (*b*, *b*) of the subjacent layer, and are about twice as numerous. The superficial sub-segments spring by slender peduncles from a band or "stolon" (*c*, *c*) that passes in a longitudinal direction from one end of the series to the other, and terminate at their anterior extremity in a similar band. The sub-segments that form the subjacent layers spring posteriorly by constricted necks from vertical "columns" (*d*, *d*) which occupy the "well-staircases," and terminate anteriorly in similar columns; and the columns forming each of the rows that intervene between one segment and another are brought into lateral connection by two or more "stolons" which pass along the entire series. Thus although the sub-segments themselves have no direct communication with each other, they are intimately united into one system by the intervention of these "columns" and "stolons." Looking to the place of the connecting passages in the transverse section (fig. 14), it becomes obvious that the stolons which occupy them are formed by the union of the pseudopodial extensions that issue from the pores of the aperture. A coalescence of those proceeding from the four sets of pores (one of them close to the inner margin of the spire) corresponding to each other vertically along the septal plane in fig. 13, would establish what I have termed the "columns" which seem to constitute the first-formed portion of a new segment; a lateral coalescence of these columns at tolerably regular intervals would establish the longitudinal "stolons;" and the formation of solid shell between these columns and stolons would leave them in occupation of the two sets of communications that have been designated as the "well-staircases" and the "horizontal galleries." The further development of the segment will consist in the anterior extension from each "column" of a set of sub-segments of sarcode separated from each other both vertically and horizontally by partitions of shell; and the extremities of these will appear, when the growth of the segment is completed, at the apertural pores, where they will be again connected through the coalescence of their extensions, so as to form vertical "columns" and longitudinal "stolons."

150. *Varieties.*—The foregoing plan of structure may be traced, with or without modification, through a series of extinct forms which presents a wide range of variation in shape, and which closely approximates at one extremity to that of *Orbiculina*. Thus the (so-called) *Orbiculina rotella* of D'Orbigny (LXXIII, p. 140), notwithstanding its nautiloid discoidal form, seems pretty certainly to belong rather to the Alveoline than to the Orbiculine type of structure; from this the transition is by no means abrupt to the oblately spheroidal and thence to the spherical varieties of *Alveolina melo*, which is a very common fossil of the early Tertiary Limestones both of the Continent of Europe and of India. From its spherical we pass to its prolately spheroidal forms, and thence to its ovoidal (the *A. ovoidea* of D'Orbigny), some of which last attain enormous dimensions, specimens being not unfrequent in the Tertiary Limestones of Scinde whose length reaches three inches and whose diameter is an inch and a half. A still greater elongation of the axis, with attenuation towards the extremities, gives the fusiform shape of the *A. Boscii*, a variety which is common in the Paris Tertiaries, and which bears a strong external resemblance to the one at present existing in tropical seas; and it is clear that the yet more elongated sub-cylindrical forms presented by *A. elongata* and *A. Quoii*, of which the former is fossil and the latter recent, are nothing else than a result of the tendency to elongation of the axis carried out to a still greater extent. There is, however, an important difference in internal structure between the entire series of fossil forms and most of their existing representatives; for although the external aspects are so nearly identical in certain specimens that they are only distinguishable by the difference in the number of rows of pores in their septal planes, and although the general plan of the fossil is exactly conformable to that of the recent, yet that plan seems to be uniformly worked out in fossil forms, however large may be their dimensions, upon the "simple" plan, the "complex" being only met with in the type at present inhabiting equatorial seas. Now this difference, being apparently well marked and constant, would obviously be entitled to rank as of specific value; if we did not find in *Orbitolites*, to which *Alveolina* is closely allied in general plan of structure, that a difference of an exactly parallel character between what will be there termed the "simple" and the "complex" types must be reduced to the grade of a mere varietal modification, since the passage from the former to the latter is frequently presented in one and the same individual.*

* It seems requisite for me to state, that I find myself unable to admit the existence of any

151. *Affinities.*—It will be obvious from what has preceded, that notwithstanding the apparently wide interval which separates the typical *Alveolina* from its congeners, it has a strong analogy both to *Orbiculina* and to *Fabularia* in its general plan of structure. Its closest affinity, however, is evidently to the regularly spiral type of *Orbiculina*, since we find in it no trace of that Milioline plan of growth which so remarkably characterises *Fabularia*. It has been already pointed out that *Orbiculina* essentially differs from *Orbitolites* in the investment of the first-formed convolutions by the latter, so that its umbilical region becomes prominent instead of being depressed, and its spire coils round an axis instead of round a point; and, by the gradation which has been just shown to have an actual existence, the progressive elongation of the axis round which the spire revolves converts the flattened lenticular spiral of the *A. rotella* into the almost cylindrical volution of *A. elongata*. The difference in shape, in fact, is not nearly so great between *Orbiculina adunca* and *A. rotella* as it is between *A. rotella* and *A. elongata;* but it requires an examination which I have not yet had the opportunity of making into the internal structure of *A. rotella*, to enable me to affirm with certainty that the transition which it so obviously presents to the Orbiculine type in its external form extends also to its plan of growth.

152. *Geographical Distribution.*—The recent examples of this type are limited, so far as we at present know, to the seas of tropical or southern temperate regions; the larger fusiform and cylindrical forms having been chiefly brought from the shores of New Holland and of the Philippine Islands in the eastern hemisphere, and from those of Cuba and the Antilles in the western; whilst a small spheroidal variety, which appears to belong to the simple type, is figured by Ehrenberg (XLII, pl. xxxvii, 10, fig. 1, *a—f*) from the Adriatic.

153. *Geological Distribution.*—The extinct forms of *Alveolina* belong for the most part to the formations coeval with the Nummulitic Limestone; and they present themselves in various proportions, sometimes so abundantly as almost of themselves to make up the substance of the deposit, in the early Tertiaries of Paris, Bordeaux, the Pyrenees, and Austria, as also in those of Persia and Northern India (XIX, XXI). One species is stated by D'Orbigny (LXXIII, p. 145) to present itself in the Turonian or Lower Chalk formation at the mouth of the Gironde, although none has been hitherto met with in any part of the Senonian or Upper Chalk.*

"canaliferous system" in *Alveolina;* and that the appearances which have been interpreted by Mr. Carter (XXI) as indicative of its presence in the fossil *Alveolina* of Scinde are quite comformable with the account of its structure which I have given on the basis of a very careful examination of that of its recent analogue.

* I cannot agree with my friends, Messrs. Parker and Rupert Jones (LXXX *a*), in referring the Palæozoic *Fusulina* to this type; for although the metamorphic condition of the shell, in all the specimens I have examined, forbids my speaking with full assurance, yet the appearance presented by thin sections is such as to leave scarcely any doubt in my mind that its structure was tubular, and that it consequently holds somewhat the same place in the *hyaline* series that *Alveolina* does in the *porcellanous*.

Genus X.—ORBITOLITES (Plate IX).

154. *History.*—The *Orbitolite* has been chiefly known, until very recently, rather by its fossil than by its existing forms. The abundant occurrence of its disks in the 'Calcaire grossier' of the Paris basin early attracted attention; but Orbitolites were not clearly distinguished by the older observers from Nummulites, and their true nature was entirely misunderstood. Thus we find them designated, often in association with Nummulites, under the title of *Umbilicus marinus* by Plancus (LXXXIII), who imagined them to be opercula of Ammonites; of *Porpitæ nummulares* by Stobæus and Bromell, who seem to have regarded them as representing the disks of the existing Porpitæ; of *Helicites* and *Operculites* by Guettard, who considered them as opercula of Gasteropods; of *Discolithi* by Fortis, who supposed them to be skeletons of Mollusks; of *Madreporites* by Deluc, and of *Milleporites* by Faujas de St. Fond, whose idea of their nature is sufficiently indicated by the names they assigned to them. (See I, § i.) The genus *Orbitolites* seems first to have been erected on the type of the *O. complanata* of the Paris basin, and to have been differentiated from Nummulites, by Lamarck (LVII), who ranked it between *Lunulites* and *Millepora*, among his "Polypiers Foraminés." He subsequently (LX) altered the name from *Orbitolites* to *Orbulites*; but the latter designation having been previously employed in Malacology, the first appellation was restored by M. Milne Edwards in his posthumous edition of Lamarck's work. Under one of the designations *Orbitolites* or *Orbulites*, the genus has been generally recognised by systematists (XIII); none of them, however, have either given any account of its internal structure, or made any essential modification in the definition of the genus; and they all left it in the place which Lamarck had assigned to it, until after the appearance of my own description of the microscopic structure of *Orbitolites* (XII), in which I showed its identity with the recent Australian *Marginopora* of MM. Quoy and Gaimard, and of the subsequent memoir by Prof. Williamson (CVIII), in which the Foraminiferous character of this type was proved by the close conformity of its plan of organization to that of *Orbiculina*.* It was not until the publication of his 'Cours Elémentaire' (LXXIV) in 1852, that M. D'Orbigny admitted this genus into his systematic arrangement of Foraminifera; the order CYCLOSTÈGUES, in which it is associated with *Cyclolina* (which I believe to be only a variety of *Orbitolites*), with *Orbitolina* (a generic type of quite a different structure, to which I have thought it better to restore De Montfort's name *Tinoporus*), and with *Orbitoides* (whose affinities with *Cycloclypeus* and *Nummulites* are of the most intimate character), being then first created.

* It is due to Prof. Ehrenberg to state that he had long before recognised this relationship (XXXIX); but by ranking *Orbiculina* as well as *Orbitolites* among *Bryozoa*, and by representing the superficial cells in both types as occupied by eight-armed polypes furnished with moveable opercula, he so completely departed from the truth of nature, that it is not surprising that what was really correct in his doctrines received little attention.

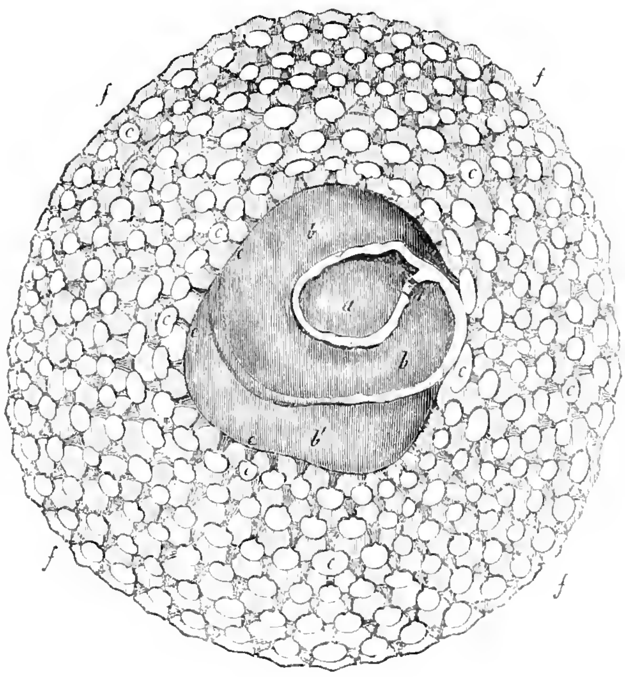
155. *External Characters.*—The calcareous disks of *Orbitolites* (Plate IX, figs. 1, 7) vary in diameter from about 1-30th of an inch to 7-10ths of an inch; whether large or small, they are almost invariably circular or nearly so; they are usually flat or slightly biconcave, any difference in thickness being generally in favour of the marginal portion; and if, as sometimes happens, there is a slight central prominence (fig. 7, *a*), this consists only of that first-formed portion of the shell which I shall describe as the "primitive disk" (¶ 157), and does not result (as in *Orbiculina*, ¶ 135) from any overlaying of the original centre by subsequent growths of shell. Around this "primitive disk" we see an indeterminate number of concentric zones marked out by furrows of the surface; and each of these zones is subdivided by transverse furrows into a uniform series of areolæ, which correspond with "chamberlets" within. In the smaller specimens (fig. 1) these areolæ are usually somewhat ovate in form, their long diameter lying transversely to the radius of the disk; in the larger specimens (fig. 7), on the other hand, they have usually a narrow, rectangular shape, and their length lies in the direction of the radius of the disk. This difference will presently be shown to be related to an important diversity in internal structure. In those disks which have their surface divided into ovate areolæ (fig. 1), the margin presents a series of convexities with intervening furrowed depressions; whilst in the thicker disks (fig. 7) these are less regular and less strongly marked. Unless the surface of the disk has been partially or entirely removed by abrasion (as is often the case with dead specimens collected by dredging), it presents no openings whatever, and the only orifices by which the interior of the shelly disk normally communicates with the exterior are the pores (figs. 1, 7, *f, f*) that are seen upon its margin. Of these pores, in the thinnest specimens (fig. 1), we find but a single one, or in some instances two, lying in each of the marginal hollows; in disks somewhat thicker we find each furrow to contain three or four such pores; whilst in the largest and thickest disks (fig. 7) the number of pores occasionally rises to ten or even twelve. Thus, on the one hand, by the form of the superficial areolæ, on the other, by the singleness or multiplicity of the rows of marginal pores, there is marked out a distinction between two types of Orbitolite structure which have been accounted specifically or even generically different, but which, as they frequently coexist in the same individual, have no title to be so regarded. It will be convenient, however, to describe them separately, in the first instance, as the *Simple* and the *Complex* types; and to consider their mutual relationship subsequently. In both these types the aspect of the shell much resembles that of *Orbiculina*, but has usually less of the opaque whiteness by which it is characterised in that genus; and sometimes, as in *Orbiculina*, the surface is minutely punctated, giving a semblance of perforations, which, however, have no real existence. In very thin specimens the calcareous laminæ which form the two surfaces of the disk are so translucent that, when such specimens are mounted in Canada balsam, the chambers they enclose can be clearly made out. Moreover, even in larger specimens which have been collected alive, and which consequently contain the animal body in a desiccated state, the translucency of the shell allows the crimson hue of the sarcode to be seen through it, so that the whole disk seems to be tinged by this, although the proper substance of the shell, when examined by transmitted light under a sufficient magnifying power, is found to present the brownish-yellow hue characteristic of the Milioline type.

156. Simple Type: *External Characters.*—In sands and dredgings brought from the seas of any of the warmer regions of the globe, and especially in those from the Philippine shores, we almost constantly meet with an abundance of minute Orbitolite-disks, whose diameter is ordinarily about ·05 of an inch, and which usually contain from ten to fifteen concentric zones. These constitute the *Orbitolites marginalis* of Lamarck (LX), the *Sorites orbiculus* of Ehrenberg (XXXIX). Although these disks are typically plane or nearly so (there being usually no great difference between the thickness of their central and that of their peripheral region), yet it not unfrequently happens that the successive zones gradually increase in thickness from within outwards (as is shown in Plate IX, fig. 2), so that the disk becomes somewhat biconcave. Sometimes, again, without any alteration in the thickness of the several parts, the disk comes to assume, by the depression of its central portion, the shape of a plate, or that of a watch-glass, or (by the more complete upturning of its edges) that of a saucer. In any case in which either surface of the marginal zone is more exposed by its projection than those of the zones which it encloses, there will be a special liability to a laying-open of its chamberlets if the disk should be subjected to attrition; and I doubt not that in this mode have been produced the supposed large pores of the fossil *O. macropora*, the figure of which given by Goldfuss ('Petrefacta,' pl. xii, fig. 8) corresponds exactly with recent specimens I have frequently encountered, presenting a row of large ovate apertures along the surface of the outermost zone. The true pores (which have been very commonly overlooked) are situated in the depressions between the marginal convexities (Plate IX, fig. 1, *f, f*); in each of these depressions there is but a single pore, and this is almost always of a regularly circular form, and is surrounded by a prominent annulus of shell.

157. *Internal Structure.*—When the interior of an *Orbitolites* of simple type is laid open by a section that passes in a direction parallel to one of its surfaces (which in the case of these discoidal forms will be most conveniently termed a horizontal section), as shown in Fig. XXIV, the central portion is seen to be occupied by a large cavity, that is somewhat irregularly divided by a sinuous partition; notwithstanding some irregularity, this partition always marks out a "primordial chamber," *a*, of a somewhat pyriform shape, from the "circumambient chamber" *b*, *b*, which passes round it; in this partition there is an aperture, *d*, which establishes a communication between the narrow prolongation of the "primordial" or "central" chamber and the large "circumambient chamber." (See also Plate IX, fig. 1.) The meaning of this arrangement will at once be made apparent by reference to the disposition of the "primordial" and "circumambient" segments of sarcode, which occupy the cavity of what may be conveniently termed the "primitive disk" (¶ 161). In a *vertical* section passing through the centre of this disk, such as that seen in Plate IX, fig. 2, it seems to present *three* chambers; but this is simply due to the fact that such a section will traverse the circumambient chamber twice, that is, will cut it through on both sides (*b*, *b*) of the central chamber *a*. Some sections present only *two* such chambers; in this case the plane of division seems to have traversed the "primitive disk" just where the neck of the primordial chamber touches its margin, so that the circumambient chamber is only on one side of it. If, on the other hand, the plane of division should happen not to pass through the primordial chamber at all, so as to traverse the circumambient chamber alone, a *single* broad cavity will present itself in the vertical section, as shown in fig. 8, *b*.

Frequently, however, it happens that the circumambient chamber is partially subdivided on one side by an interposed partition (Fig. XXIV); and then a vertical section will show *four* chambers, the central chamber having the undivided part (*b*) of the circumambient chamber on one side of it, and the divided part (*b, b'*) on the other. Each zone, as seen either by transmitting light through the thinnest and most translucent specimens after mounting them in Canada balsam, or by making horizontal section of thicker specimens, consists of a circular set of small ovate *chamberlets* (*c, c*, Fig. XXIV, and Plate IX, fig. 1), excavated, as it were, in the

Fig. XXIV.



Diagrammatic representation of the anterior of an *Orbitolites* of simple type:—*a*, primordial chamber; *b, b*, circumambient chamber; *b'*, portion of the same partially separated by an incomplete partition; *c, c, c*, chamberlets of the concentric annuli; *d*, passage from the primordial to the circumambient chamber; *e, e, e*, passages from the circumambient chamber to the chamberlets of the first annulus; *f, f, f*, passages from the gallery of the last annulus, opening at the margin of the disk.

shelly substance of the disk, and communicating with each other laterally by *annular passages* which unite them together into a continuous gallery. The zone which immediately surrounds the "primitive disk" is connected with it by radial passages (Fig. XXI, *e, e*), which extend from the outer margin of the large circumambient chamber to the several chamberlets of which that zone is composed; and each zone communicates with the one on its exterior by similar *radial passages* (Plate IX, fig. 6, *e, e*), which usually extend, however, not from the chamberlets of the inner zone to those of the outer, but from the *annular passage* (*h, h*) of the inner zone to the chamberlets of the outer; and thus it comes to pass that the chamberlets of each zone usually *alternate* with those of the zones that are internal and external to it.—A vertical section of the disk, such as is shown in Plate IX, fig. 2, exhibits the same arrangement under a different aspect. The chamberlets *c', c', c'* of the concentric zones are seen to be much higher than they are broad, so that they present a somewhat columnar form; the proportion of their height to their breadth, however, may vary greatly in different parts of the same disk, the former often increasing from the centre towards the periphery, whilst the latter remains constant, or nearly so; and the columns, instead of being straight, are generally more or less curved, and are sometimes bent in the middle at an obtuse angle. The gradation which presents itself from one of these forms to the other, and their coexistence even in the same specimens, clearly prove that no value can be attached to the form and proportions of the chamberlets, thus seen in a vertical section, as furnishing specific characters. In every perfect specimen the columnar chamberlets are seen to be closed at their two extremities by a thin wall of shell; and this is sometimes flat, sometimes more or less convex.

158. In this manner any number of concentric zones may be formed, which are exact repetitions of each other, except that the number of chamberlets in the outer zones is greater than that of which the inner zones are composed. It does not increase, however, in the regular ratio of the respective diameters of the zones; for the chamberlets of the outer zones, being usually both larger and more widely separated from each other than are those of the inner, are less numerous in proportion; thus, in a specimen before me, there are twenty-eight in the innermost row and only forty-nine in the outermost, though the latter is more than twice the diameter of the former. The augmentation in number is accomplished by the occasional *interpolation* of an additional chamberlet, communicating directly with the one immediately interior to it, between the two chamberlets which are connected with the annular passage on either side of the latter, as is shown in Plate IX, fig. 6, *c''*, *c''*. The chamberlets of the last-formed zone communicate with the exterior by the same kind of radial passages as in other instances communicate with the next zone; and the external orifices of these form the pores which present themselves at the margin of the disk (Plate IX, figs. 1, 2, *f*, *f*). Thus it is seen, on the one hand, how it happens that these pores are intermediate between the chamberlets, instead of opening directly into them; and on the other, how each pore leads, by the divarication of its passage, into two chamberlets, one on either side of it. When a new zone is formed, each pore opens into one of its chamberlets; and this zone, in its turn, communicates with the exterior through a new set of pores at its own margin. When the section passes through the prominent annulus of shell which surrounds each pore, this will be indicated by a little "beak" on either side of the entrance to the passage; such "beaks" (which are, of course, repeated through the entire disk) are shown in their ordinary aspect in Plate IX, fig. 6, *f*, *f*), but they are frequently more prominent. In all cases in which the growth of the disk takes place with normal regularity, a *complete circular zone* is added at once. Exceptions to this regularity are rare, and they can be generally traced with probability to some accidental interruption.

159. It is a fact of much importance, in the due appreciation of the relations of *Orbitolites* to other types of Foraminifera, that the calcareous partition which separates each chamberlet of any one zone from the adjacent chamberlets on either side is not double, but *single*. And this is in great part the case, even with regard to the partitions which separate

the chamberlets of successive zones, the inner or central boundary of one being chiefly formed by the peripheral wall of the other. It is not easy, even in thin *sections*, to distinguish the boundary between the walls of one zone and those of another, so absolutely continuous do they appear to be. But it not unfrequently happens that, in *fracturing* these disks, their component zones come apart from each other along their natural lines of junction, so as to disclose the real inner margin of the outer zone (Plate IX, fig. 1, *g*, *g*), which is then found to present a set of wide fissures, through which we look at once into its chamberlets, thus proving their incomplete enclosure by proper walls on that side.

160. There cannot be any reasonable doubt that the number of concentric zones which any disk may present is entirely determined by its stage of growth, and that it affords no basis whatever for specific distinction. Just as in the case of the concentric layers of wood in the stem of an exogenous tree, a minute "primitive disk," surrounded only by a single annulus of chamberlets, may come in time to be the centre of a large disk consisting of many scores of concentric zones. Although, as already stated (¶ 156), most of the Orbitolites formed upon this simple type are of comparatively small size, yet there does not seem to be any definite limit to the multiplication of zones; for I possess specimens attaining ·25 of an inch in diameter, and consisting of about fifty zones (much larger, therefore, than the younger disks of the complex type), in which there is no appearance of any departure from the original mode of growth.

161. *Structure of the Animal.*—The entire animal body, obtained by the decalcification of the shells of specimens that have been taken alive and preserved in spirit (Plate IV, fig. 14), is composed of a numerous assemblage of minute segments, arranged at tolerably regular intervals in concentric zones, around what it may be convenient to term the "primitive mass." This primitive mass consists of a pear-shaped "primordial segment" (Plate IV, figs. 16—20, *a*) occupying the central or primordial chamber, from the small extremity of which a peduncular process (*d*) extends, that dilates again into the still larger segment *b*, *b*, which, from its almost completely surrounding the former, may be conveniently designated the "circumambient segment." Thus, the "primitive mass" very closely resembles what the body of a young *Miliola* would be, if the segment first budded-off from the primordial segment were prolonged, so as completely to surround it (¶ 49, Plate IV, fig. 4, B). From the outer margin of this circumambient segment there radiate a number of slender pedicles (*c*), which presently enlarge into as many columnar segments, having a circular or oval base, and these are united to each other laterally by a connecting band or "stolon" (*h*, *h*), which passes entirely round the "circumambient segment" and forms a complete annulus. It is usually from the portions of this "stolon" which intervene between the segments of each annulus of sarcode, that the radiating pedicles (fig. 23, *e*, *e*, *e*) are given off, which go to originate the next zone; but sometimes a pedicle is given off from one of the segments (as shown at *e'*, *e'*), which goes to form a segment (*c''*, *c''*) in the next zone, that is interpolated between two which have originated from the intervening annular stolon; and it is in this manner that the *number* of segments in successive zones receives an increase, the *size* of those segments not undergoing any considerable augmentation. Each successive zone exhibits precisely the same structure; and it is obvious that the radiating pedicles of the outermost

zone will issue from the marginal pores, and will give origin to the *pseudopodia* by whose action the life of the entire composite organism must be sustained. The analogy of other Rhizopods would lead us to suppose that it is by the introduction of alimentary particles (chiefly minute forms of vegetation), through their means, into the mass of sarcode of which they are extensions, that the fleshy body pervading the entire disk is nourished. For although there is nothing like a digestive cavity in any part of it, or an alimentary tube passing from one portion to another, still less any vascular communication between the segments, yet as the sarcode forms one soft homogeneous mass everywhere continuous, the body as a whole will receive the benefit of any incorporation of new matter with its substance, in whatever situation this may be made. That organic particles small enough to pass through the marginal pores are thus introduced into the chambers of the disk, is proved by the curious fact that the residuum left after the decalcification of large and therefore aged disks, whose animal contents have not been preserved, consists almost entirely of an assemblage of remains of minute *Diatomaceæ*, *Desmidieæ*, &c., which have obviously been retained in the interior of their cavities after the assimilation of the nutriment they were competent to afford. The sarcode-body of the animal, growing at the expense of the nutriment thus appropriated, will gradually, it is probable, project itself through the marginal orifices, not merely in filamentous pseudopodia, but in quantity sufficient to form a new zone; and it is easy to understand, from the analogy of other Foraminifera, that such extensions will coalesce with each other laterally, so as to form a complete *annulus* around the entire periphery of the disk. This, at any rate, must be the case when a new zone is to be added to the shell; and it would seem as if this annulus then undergoes a thickening into segments by the accumulation of sarcode at the points at which it receives the radiating pedicles from the last zone of the sarcode-body included within the shell, whilst it becomes narrowed in the intervening portions, which form the connecting bands between the segments. It may be presumed to be by a calcareous exudation from the surface of this beaded ring of sarcode, that the formation of the new shelly zone is accomplished; and if the calcifying process commence on the segments, and extend from these along the surface of their connecting stolons, we can understand why the passages that are left for communication with the exterior should arise from the intermediate divisions of the annular canal rather than from the segments themselves.—Although the body of the animal is so far decolorized in the spirit-specimens which alone have hitherto come under my observation as to present only a brownish hue, yet as specimens that have been gathered fresh and have been then dried possess a reddish aspect, which is due to the desiccated body they contain, it may be presumed that the sarcode of the living *Orbitolites* has the same bright-red colour as that of *Rotalia* and many other Foraminifera.

162. I have not met with the least indication that the sarcode is contained within any *proper membrane;* and the absence of any such indication, notwithstanding the various manipulations to which I have subjected its segments, may be taken, I think, as strong negative evidence that it has no more existence in this animal than it has in the species of Foraminifera which have been so well studied by M. Dujardin and Prof. Schultze. Nor is there the slightest trace of distinct *organs*, either in the mass of sarcode which forms the "primitive mass" or in that which constitutes each one of the surrounding segments; and

he would, I think, be a mere speculator who should maintain the presence of a digestive cavity in any of these parts, or the existence of an intestinal canal in the peduncular threads which connect them together. The homogeneity of the component substance of the "primitive mass," and of the entire assemblage of multiple segments, seems, indeed, to be conclusively established by the following facts:—In all the spirit-specimens which I have examined, the cavities of the outer zones are completely void, whilst those of the "primitive disk" and of the inner zones are quite filled with their animal contents. This drawing together of the soft body towards the centre is evidenced also in many of the larger specimens which have been dried when collected in the living state, by the limitation of the red colour that indicates the presence of the sarcode to the inner portion of the disk. In both cases it may be presumed that the animal matter has shrunk together, in the former through the corrugating action of the spirit, in the latter through desiccation. Now if the "polypidom" of a Zoophyte or the "polyzoary" of a Polyzoon be similarly treated, there is no such drawing together of the entire body, but each cell is found to contain the shrunk contents of its own zooid; and this difference seems to me to indicate a complete dissimilarity in the characters of the two kinds of organisms. For it is obvious that the substance of the peripheral segments of the Orbitolite-body can only be brought together towards the centre, through being completely unattached to the walls of the cavities which it occupies, and through having a form so alterable as to be capable of being drawn in threads through the narrow connecting passages, and of then coalescing together again so perfectly that the masses they form do not present the least trace of having been thus spun out. There is no known kind of animal texture except *sarcode* that is susceptible of this kind of alteration; and the evidence of it which I have adduced seems to me extremely valuable, not only as establishing the general nature of the animal body of *Orbitolites*, but also as fully justifying the assumption that, in the living state, the sarcode is projected in pseudopodia through the marginal apertures, and that alimentary particles are introduced by their instrumentality, as in other Foraminifera.*

163. Complex Type: *External Characters.*—From the simplest it will be convenient to pass at once to the *most complex* type of structure presented by *Orbitolites*, the existence of which is marked externally (as already noticed, ¶ 155) by a multiplication of the ranges of marginal pores. I have met with this form in specimens obtained by dredging from the coast of Australia and from various parts of the Polynesian Archipelago, from the neighbourhood of the Philippine Islands, from the Red Sea, and from the Ægean; and as the sands of all these localities present the simpler type in great abundance, I am disposed to believe that the former is really not the less widely diffused than the latter, and would be discovered wherever it abounds, if properly searched for. The largest specimen in my possession, measuring 7-10ths of an inch in diameter, is from the coast of Australia, where these Orbitolites are so abundant at certain spots (as I learn from Mr. Jukes) that their entire

* I think it desirable to repeat what I have already (XIII) stated upon this point, since the persistence of Prof. Ehrenberg in his affirmation of the Bryozoic nature of these organisms might induce those who rely on his authority to accept his figure of their animal (XXXIX) as the representation of a *fact*, instead of being merely the expression of their author's *idea*.

disks and fragments, with fragments of Corallines (chiefly, I believe, the *Corallina palmata* of Ellis), constitute the great mass of the dredgings. Among the Australian specimens several attain a diameter of ·45 inch, and a considerable proportion as much as ·30 of an inch. Hence the Orbitolites of this type are among the largest forms of existing Foraminifera, being only surpassed, as far as I am aware, by the *Cycloclypeus* hereafter to be described. Of two specimens in my possession from the Fiji Islands, one measures ·63 inch, and the other ·53 inch in diameter; but the average of the Polynesian specimens seems to be considerably lower than that of the Australian, as their diameter seldom exceeds ·25 of an inch, and is usually not more than ·10 or ·12.

164. The disks formed on this plan, like the preceding, may be considered as typically circular, although they are seldom or never exactly so in reality. They may be considered too, as typically flat, with a slight concavity in the central part, from which, however, the primitive disk often projects; but, as will hereafter appear, there is no constant relation either between the thickness and the diameter of different specimens, or between the thickness of different parts of the same specimen and the distance of these parts from its centre. The only remarkable departure from the ordinary form which I have met with, presents itself in certain Orbitolites from the Fiji Islands, of which several specimens in the Museum of the Royal College of Surgeons, and two in my own possession, exhibit a curious plication towards their margins; the degree of this departure varies so much, however, in different individuals (the plication being almost obsolete in some), that it cannot be admitted to mark a specific diversity. These same specimens, moreover, also exhibit another curious abnormality; namely, the projection of the upper and lower edges of the margin, so that a groove is left between them, the projecting laminæ being thin and foliaceous, and their chamberlets very irregularly arranged. This peculiarity, again, being far from uniform in its degree, and being altogether wanting in specimens which in other respects precisely resemble those with plicated and foliated margins, must be considered merely in the light of an accidental variety; but I cannot suggest any explanation of its occurrence, or of its limitation (so far as I am aware) to this particular locality.

165. The surface of the disk (Plate IX, fig. 7)* is marked out, as in the simpler type, by concentric zones, the number of which bears a general (though not a constant) ratio to its diameter; these zones are traversed by radiating lines, which mark out areolæ that are usually somewhat rectangular in shape and sometimes approach a square, but are more commonly nearly twice as long in the line of the radius of the disk as they are in the transverse direction, their long sides being nearly parallel to each other. We shall hereafter see, however, that the form of these areolæ is very subject to variation, and that it may be very dissimilar

* In order to avoid a multiplication of figures, I have thought it preferable to combine in three ideal representations (Plate IX, figs. 7, 8, 9,) the details I have made out from a great number of preparations which are faithfully represented in separate figures accompanying the original Memoir in the Archives of the Royal Society; these last of course furnish the real authority for every point in the description, the ideal figures, however, serving to display the relation of different parts to each other in a manner that no single preparation would possibly admit.

even in different zones of the same disk (¶¶ 173, 178). The pores *f, f,* at the margin of the disk are disposed, as in the simpler type, between the projections formed by the convexities of the chamberlets; but they are less regularly circular than in the simple type, and the surrounding annuli of shell is less distinct. The number of pores in each vertical row is by no means constant, even in different parts of the margin of the same annulus; and their disposition is far from regular (fig. 10), as they seldom form rows that seem exactly continuous with each other horizontally, while the vertical rows are often interrupted, the two adjacent rows then usually inclining towards each other.

166. *Internal Structure.*—The disks of this complex type are not distinguished from those of the simple type already described, by any difference in the structure of the "primitive disk;" and there is frequently nothing specially characteristic in the structure of the zones that immediately surround it. Each of the peripheral zones, however, consists of two *superficial* layers, and of an *intermediate* stratum (Plate IX, figs. 7, 8, 9); these will now be described *seriatim*. The *superficial* layers are formed of the (usually) oblong chamberlets, whose contour is indicated by the surface-markings; when they are laid open horizontally, by rubbing away the thin shell which covers them in (fig. 7, *i, i, i*), it is seen that the floor of each chamberlet has an aperture at either end; but no communication can be traced, either through the side-walls between the contiguous chamberlets of the same zone, or through the end-walls, between the chamberlets of successive zones. Moreover, there is no such alternating arrangement of the chamberlets of successive zones, as we have seen to prevail in the simpler type (¶ 157); and they altogether seem to be quite independent one of another. When this superficial layer is examined in a vertical section having a radial direction (Plate IX, fig. 8), it is seen that the floors of its chamberlets are formed by the expanded summits (*l, l,*) of the irregular septa which separate from each other the successive zones of columnar chamberlets of the intermediate stratum (*c′, c′, c′, c′,*); and that the apertures at the two ends of the floor are the entrances to passages (*m, m′*), which lead obliquely downwards (the passages on either side of the partition between two successive chamberlets of the *superficial* layer always inclining towards each other) towards these cavities. It is observable, moreover, that just at the point at which the contiguous passages meet each other, there is always a round aperture (*h, h′*) in the partition which divides the contiguous chamberlets of each zone; and when, in a horizontal section, the superficial chamberlets have been entirely ground away, so as to lay open the most superficial part of the intermediate stratum, this part is found to be traversed in each zone by a continuous circular gallery (Plate IX, figs. 7, 9, *h, h, h,*) with large rounded openings that lead into the columnar chamberlets beneath. The meaning of this arrangement becomes obvious, when we examine the disposition of the animal substance which occupies these cavities; for we find, as might have been anticipated, that the superficial cells are filled with segments of sarcode of corresponding shape (Plate IV, figs. 24, 25, *a, a′*); and that whilst these have no direct connexion with one another, each of them is connected by means of fleshy peduncles with the annular stolons *b, b′* that run along its extremities; whilst from the under side of these annular stolons (fig. 25) descend the thick columns of sarcode (*c c, c′c′*), which occupy the columnar cells of the intermediate stratum. The absence of any essential dependence of the segments of the *superficial* and of those of the *intermediate* strata upon

each other, seems indicated by the fact that there is no constant numerical relation between them,—a circumstance which extremely perplexed me, until I had ascertained, by examination of the animal, that the passages proceeding from the former (Plate IX, fig. 8, *m*, *m'*) debouch, not (as I had at first supposed) into the columnar chamberlets *c'*, *c'*, but into the annular canals, *h*, *h'*, which serve to bring the superficial and columnar segments of each zone into mutual communication.

167. As the description now given of the superficial layer applies equally to both surfaces, we may now proceed to the *intermediate* stratum. When this is laid open by a horizontal section (Plate IX, figs. 7, 9), it is seen to consist of a series of concentric zones, the chamberlets of which *alternate* with each other, like those of the Simple type (¶ 157). The chamberlets are usually cylindrical (or nearly so) in form ; but often differ considerably in size in different parts of the same disk, and sometimes even in different parts of the same zone. It may be often observed that the cylindrical cavities do not always pass from end to end in a straight line (Plate IX, fig. 11) ; nor do they always maintain a complete isolation from each other, an inosculation of two columns (which is indicated in vertical sections like that represented in Plate IX, fig. 8, by irregularly disposed apertures) not being unfrequent, while more rarely there is a fusion of two columns into one. All these features of structure presented by the shell, are beautifully displayed by the animal (Plate IV, fig. 25) ; the columns of sarcode *c c*, *c'c'* exhibiting the generally cylindrical form, the not unfrequent inosculation, and the occasional fusion, which we have seen to exist in the cavities which they occupy. At their upper and lower extremities, they unite with the annular stolons *bb'*, *bb'*, which pass continuously round, in each zone, between the intermediate and the superficial layers.

168. Save in the case of such accidental inosculations as those just noticed, no other lateral communication seems to exist between the contiguous chamberlets of the same zone, than that which is established by the annular stolons just mentioned. The chamberlets of the successive zones communicate with each other, however, as in the Simple type previously described (¶ 157), but with a curious modification; for whereas a horizontal section of the latter shows that each chamberlet communicates with the *two* chamberlets alternating with it in the interior zone (Plate IX, fig. 6), a like section of the Complex type seems to show that such a connexion exists with only *one* chamberlet of the interior zone, by a passage running obliquely from one to the other, and extending continuously through several successive zones (Plate IX, figs. 7, 9, *e*, *e*), the very same section exhibiting opposite obliquities in contiguous parts. The study of vertical sections, however, made tangentially instead of radially, so as to *cross* these connecting passages, shows the explanation of this apparent anomaly to be simply as follows. Each cylindrical chamberlet really communicates with the *two* alternating chamberlets in the next interior zone, but by two distinct passages, instead of by the divarication of one ; these inter-zonular passages are not upon the same plane, but those of different planes are directed alternately towards one side and the other ; and thus, as the disks are seldom perfectly flat, the section which traverses, at one part of the disk, the set of passages running in one direction, will traverse the other set of passages, where, by the flexure of the disk, the plane of section is slightly altered in regard to it. So

the marginal pores of any one vertical row, even when in a line with each other, open alternately into the chamberlets on the *right* and on the *left* of that row; these pores being nothing else than the orifices of the oblique inter-zonular passages, which, when another annulus is added, will lead into its chamberlets. The import of this arrangement is at once made evident by an examination of the segments of the animal body that occupy the cylindrical chamberlets; for, as is shown in Plate IV, fig. 25, each column of sarcode in one zone (*c c*) communicates with the two columns alternating with it in the next zone (*c′c′*) by two rows of peduncles; and the peduncles which pass from each pair of contiguous columns to the single column of the next zone, incline towards one another, so as to enter it nearly in the same vertical line, though in different horizontal planes.

169. That which has been already stated in regard to the partial deficiency of the inner wall in each of the concentric zones of the Simple type (¶ 159), holds good also in regard to the septa which divide the successive zones of the "intermediate stratum" in this more Complex type; for the walls of the cylindrical chamberlets close-in around them very imperfectly on their inner or central side, leaving large irregular vertical fissures (Plate IX, fig. 11) which are applied to the vertical rows of orifices (fig. 10) on the outer margin of the included zone.

170. The thickness of this "intermediate stratum," and the number of superposed segments (indicated by that of the inter-zonular peduncles) of which each column of sarcode consists, are found to vary considerably in different parts of the same disk; being usually least near its centre, and gradually augmenting in successive zones as their distance from this increases (Plate IX, fig. 8); or ceasing to augment at a certain point, so that the outer part of the disk is flat; or even diminishing again, so that the disk thins away towards its margin. It is specially worthy of note that whatever differences of this kind may exist, they are entirely due to the variable length of the columns of the *intermediate* stratum; the depth of the chamberlets of the *superficial* layers being nearly constant, and no vertical multiplication of these ever taking place.

171. The addition of new zones usually takes place with the same regularity in the Complex as in the Simple type of structure; but departures from this regularity, occasioned by a want of completeness of particular zones, are more frequent; and this is perhaps to be accounted for by the larger size of the disk, which will tend to produce a less intimate dependence of each part of the animal body upon every other, and will thus favour the partial action of any cause (*e.g.* an excess of nutrient materials) which promotes a more rapid growth on one side than on the other. And this view is most remarkably borne out by the fact, that in the genus *Cycloclypeus*, which, though normally growing upon the cyclical plan, possesses a much greater degree of segmental independence, such irregularities occur far more frequently; so that, in fact, it is rare in that type to meet with a disk whose increase has taken place with uniformity throughout.

172. The foregoing description applies in every particular to those specimens only, which present the structure of the Complex type of *Orbitolites* in its most regular and charac-

teristic development; and the differences between this and the Simple type previously described are such as at first sight to preclude the idea of their specific identity. But when a large number of specimens are carefully examined and compared with each other, it becomes obvious that not only may a vast amount of diversity present itself in the arrangement of the chamberlets of the shell and of the segments of the animal,—so that one after another of the characters which at first seem most clearly marked and therefore most distinctive, may be shaded off (so to speak) in such a manner as to establish a complete transition between the two types,—but they frequently coexist in the very same disk. Such a coexistence is exhibited in the vertical section represented in Plate IX, fig. 8, where we see that the zones *b*—*k*, which immediately surround the "primitive disk," are formed in all respects upon the Simple type; between *k* and *n* we see an incipient differentiation between the "superficial" and the "intermediate" strata, the annular canal, however, still remaining single; but at *n*, the annular canal becomes double, and from this point to the margin of the disk we see the "superficial" layers completely differentiated from the "intermediate," and the former becoming more and more widely separated from each other by the increasing thickness of the latter. Now as the Complex type of growth may show itself in the very first annular zone, or may thus evolve itself out of the Simple at any distance from the centre, and this either suddenly or gradually, it seems obvious that between these two types no essential distinction can exist. If the growth of such a disk as that whose vertical section is represented in fig. 8, had been stopped at *k*, or even at *n*, it would have undoubtedly been regarded as belonging to the Simple type; and every disk formed upon the Simple type must be considered as having the power to evolve itself upon the Complex plan. It would not be right, however, to affirm that the Simple disks are the young of the Complex, since we find that the former may continue to increase without change, until they far exceed in diameter and in number of zones the smaller disks which have early assumed the latter type. Of the conditions which determine the original evolution of the Simple or of the Complex type respectively, from "primitive disks" which appear to be in all respects identical, or which determine the evolution of the latter from the former, we know nothing whatever.

173. Even where the annular canals have been separated from each other, and a distinct "intermediate stratum" has been formed between them, the superficial chamberlets are not always clearly marked off from its cylindrical cavities; for instead of being separated by floors formed by the expanded summits of the zonal septa (¶ 166), they sometimes open at once into the chamberlets of the intermediate layer, so as to be quite continuous with them; and this continuity of the superficial with the intermediate chamberlets is sometimes maintained throughout the disk, so that in no part of it are the former clearly marked off from the latter. This method of growth is so remarkably constant in the fossil Orbitolites of the Eocene strata, whose intermediate layer is fully and very regularly developed, that it might be considered to be specifically characteristic of them, did we not occasionally find it to occur in certain zones of recent disks, which are elsewhere exactly conformable to what I have described as the regular type. Where the superficial chamberlets are continuous with those of the intermediate substance, they present the rounded or ovoidal shape, instead of the elongated straight-sided figure which is their characteristic form; and the former seems

to give place to the latter, whenever the chamberlets of the superficial layers are perfectly separated from those of the intermediate stratum, and are connected only with the annular passages.

174. The "intermediate stratum," again, may be altogether wanting, notwithstanding that the two superficial layers are separated from each other by a horizontal partition. In this case, each layer may have its own annular canal, or there may be but a single canal, which is then generally very large; and the chamberlets of the two layers have an alternating arrangement as regards each other. Such an arrangement may present itself as one of the modes of transition from the Simple to the Complex type, the cylindrical chamberlets being disposed to subdivide transversely when they attain a considerable length, and the annular canal to become double; whilst in zones more distant from the centre, the two layers are separated by the interposition of the intermediate stratum. Sometimes, however the disk continues to increase and attains a considerable size on this duplex type, as we see especially in the *Orbitolites* of the Red Sea; and its edge then presents two rows of rounded prominences with pores between them, those of the upper and lower rows alternating with each other. It is on a disk of this type that Prof. Ehrenberg has founded his genus *Amphisorus* (XXXIX), which I cannot regard as even specifically distinct from the ordinary *Orbitolites*.—There is sometimes a complete absence of regularity in the disposition of the cylindrical chamberlets of the intermediate stratum, so that they present an assemblage of indefinitely-shaped passages, communicating with each other in various directions. This variety is chiefly interesting, as showing how little importance is to be attached to smaller deviations of the same kind. Further, the septa dividing the contiguous chamberlets of the same zone are occasionally deficient, so that the interior of the zone is a continuous circular gallery, with only slight indications of the normal divisions; thus corresponding exactly with the peneropliform condition of *Orbiculina* (¶ 143). In such a case, it is obvious that the ring of sarcode must have been everywhere of nearly uniform thickness, showing no division either into horizontal or into vertical segments; and it may not be thought improbable that this is its first condition in every case, and that its segmental division is a subsequent process, so that the shelly investment, if formed previously to the segmentation, will have the character of incompleteness just described. I cannot help suspecting, that the peculiar groove around the margin of the Fiji specimens formerly noticed (¶ 164), is referable to a still greater incompleteness of the production of the calcareous investment around the newly-forming zone.

175. *Reparation of Injuries.*—Much light is thrown on the physiology of the Orbitolite type of structure, by the examination of specimens—of which I have met with several—whose conformation makes it evident that, after larger or smaller portions of the disk had been broken away, a new growth has taken place along the fractured edge. Two examples of this are shown in Plate IV, figs. 26 and 27.—In the first of these, it is obvious that so large a portion of the disk has been broken away, as to leave only an irregular fragment, including its centre and about an eighth of its margin. Here seven zones have been formed since the injury; and the chamberlets of these, whilst produced conformably to those of the uninjured margin *a*, *a*, present the most marked want of conformity to those of the fractured

margin, which, nevertheless, they completely surround. A careful examination of this specimen, indeed, seems to me to leave little room for doubt, that the growth of the innermost or what I may call the *reparative* zone of chamberlets took place, not from the broken edge, but from the margin of the unbroken; just as, to use a professional simile, an ulcerated surface "skins-over" by an extension of the integument from its edges, not by the direct formation of skin upon the granulation-surface itself. All the six rows subsequently produced are conformable to each other and to the first or reparative row, from which they have obviously extended themselves after the normal manner. It is observable, however, that the breadth of these rows varies in different parts, being least where they invest the projecting portions of the fractured edge, and greatest where they sink into its hollows. And thus it comes to pass that the irregularities left in the shape of the disk, by the loss of a large part of its substance, are gradually compensated, so as to restore it to a form much more nearly corresponding to its typical symmetry. It is interesting to find evidence in *fossil* specimens, that the same kind of reparation has taken place. Among the Orbitolites which I have examined from the *Calcaire grossier* of Paris, is a disk of which a large part had obviously been lost by fracture, but of which the original symmetry had been in great degree restored by a similar outgrowth from the zones formed from the uninjured margin, along the fractured edge.—In the specimen represented in fig. 27, in which but a very small fragment appears to have served as the nucleus for a new disk, the tendency to the reproduction of the typical form, by the compensative reparation just described, is still more curiously marked. This specimen also presents the very unusual feature, that the new growth has taken place from the *inner* margin of the original fragment (*a*, *a*), and not from its *outer* or growing margin, as in the case previously noticed. Having carefully examined it in various modes, I cannot entertain the slightest doubt that such has been the case; for the chamberlets of the first new zone, as well as those of all the zones subsequently produced, are so manifestly conformable to those of the thinner and older portion of the fragment, and are so unconformable to those of the thicker and newer margin, that it seems obvious that the sarcode must have extended itself from the former part, along the fractured edge on each side, and have then enveloped the margin which had been left entire. This may have more readily taken place in the present instance, because at the part *a*, *a*, the fracture seems to have followed the course of one of the zones, instead of passing (as at the sides of this fragment, and as in the instance previously cited) in such a direction as to cut the zones transversely.—Again, I have met with several specimens, in which the central portion of the disk having been broken-out, a growth of new zones seems to have taken place from without inwards, so as to fill up the void space thus left; the included portion being evidently as unconformable to that which surrounds it as in the preceding case, and a void remaining unfilled, the shape of one part of which clearly indicates that it occupies the site of the original centre;—so as to render the conclusion almost inevitable that the included portion, and not the peripheral, must be the after-growth.

176. This series of abnormal phenomena, then, not only confirms the conclusion that seemed fairly deducible from our previous examination of the normal mode of growth, with regard to the independent endowments of the component segments of the sarcode-body of Orbitolites, but also affords some additional information of much interest. For we see, in

the first place, that there is no relation of necessary dependence between the several portions of the disk; since not only can the greater part of the peripheral portion be lost without any diminution in the growing power of that which is left, but even a fragment of the peripheral portion, altogether detached from the centre, can not only maintain its vitality, but become the centre of a new disk. Secondly, the growth of the sarcode and the addition of new parts may take place not merely in the peripheral direction from the normal outer margin, but also in the direction of the centre, provided that a free edge be exposed at the *inner* margin of any zone. Thirdly, the reparative *nisus* seems always to tend towards the production of a disk whose shape shall approach the circular, whatever may be the form of the fragment which serves as its foundation; thus showing that, notwithstanding the repetition and independence of the separate parts of these organisms, each cluster, whether large or small, is an integer, having an archetypal symmetry to which it tends to conform,—strongly reminding us of the phenomena of crystallization. And fourthly, the plan by which this recurrence to the discoidal form is provided for, seems partly to consist in the limitation of the new growth to the natural margins of the zones; no such growth taking place from the edge of a fracture which has crossed the zones transversely, although it may proceed from the remains of a zone which has been broken off by a fracture that partly follows its course.

177. *Varieties.*—We have already seen that diversities both in the *diameter* and in the *thickness* of the disk arise directly from the degree in which the animal substance (whereon the skeleton is modelled) has extended itself either horizontally or vertically, so as to multiply either the number of concentric rings, or the length of the columnar segments of which each ring consists. This, however, is not the only source of variation in size; for a most extraordinary diversity presents itself in the dimensions of the individual components by whose repetition the entire disk is made up. It is in the "primitive disk" that I find this diversity most strongly marked, the central area of one specimen in my possession being about *twenty-eight* times that of another, and every intermediate gradation being presented by other specimens. There is not by any means the same amount of difference between the dimensions of the ordinary segments which form the concentric annuli; nevertheless, these also exhibit marked diversities in size in different specimens (the largest chamberlets being usually found to spring from the largest primordial chambers, and *vice versâ*), and the individual cells of the very same disk being occasionally found to differ no less widely amongst each other. Similar differences present themselves in the vertical height of individual chamberlets; as is of course best seen in the Simple type of *Orbitolites*, in which the augmentation in the thickness of the disk is produced merely by the elongation of the columnar segments. I possess a series of vertical sections of different individuals, in which the same gradual transition is seen from the thinnest to the thickest, as I have just stated to exist in regard to superficial area; and which also proves that the relative thickness of the central and of the peripheral portions is equally liable to variation.—It seems obvious, from the foregoing considerations, that neither the absolute nor the relative dimensions of the individual parts of these composite fabrics can, any more than the dimensions of the entire disks, be taken as affording valid characters for the discrimination of species; and that such a wide range of variation exists among individuals, as would, if the extreme cases alone were known, seem fully to justify their separation under distinct specific designations.

178. The appearances presented on minute observation by the *surface-markings* of *Orbitolites*, which indicate the *form* and *arrangement* of its contained chamberlets, are so far from being uniform, that to any one whose eye had not become familiarised with their variety by the examination of a considerable number of specimens, they would become sources of great perplexity. We have already seen that the subdivisions of the annuli visible externally present two very distinct forms, the *rounded* or *oval* (Plate IX, fig. 1), and the *rectangular* (Plate IX, figs. 7, 9); the first of these being specially characteristic of that Simpler type of structure in which there is only a single layer of cells, but not being confined to it; whilst the second is peculiar to the Complex type, in which there are two superficial layers distinct from the intermediate stratum. Now the occasional co-existence of both these plans of structure in a single individual (¶ 172) sufficiently proves that the diversity of the surface markings to which they respectively give rise, cannot be regarded as a basis for specific distinction; and when these extremes of diversity are kept in view, it must be felt to be highly improbable that any modifications of either form should possess greater importance That such modifications are mere individual varieties, is further evidenced by their *gradational* character, and by the fact that two or more of them may present themselves in the same disk. In describing them, I shall limit myself to an account of those more remarkable and frequently-recurring varieties, which will serve, I think, as a key to any others that are likely to be met with.—Although each surface, in either of the two principal types, ordinarily shows a division into concentric zones, which are again transversely subdivided so as to mark the separation of the chamberlets, yet sometimes the concentric zones are alone visible, and no transverse subdivision is indicated, save by the alternation of lights and shadows proceeding from a like alternation of solid substance and of hollow spaces beneath This predominance of the concentric divisions, which gives a very distinctive aspect to the disks that exhibit it, is usually most apparent in individuals whose vertical section exhibits two planes of cells; and it has seemed to me to depend on an unusual freedom between the *lateral* communications, which I have noticed in certain individuals thus formed, so that the animal portion of each zone might be described as an annulus of sarcode, merely constricted at intervals. This peculiarly cyclical aspect of the surface may pass into either of the principal types previously noticed; the concentric zones sometimes breaking up (so to speak) into bands of rounded chamberlets with slightly convex roofs; whilst in other instances they are subdivided by very definite transverse lines into cells of remarkable squareness, which still retain the original flatness of their surfaces.—On the other hand, the appearance of concentric division is sometimes almost entirely wanting; the surface of the disk exhibiting excentric circular markings, which resemble those of an engine-turned watch-case, and the boundaries of the cells being formed by the intersection of these with each other. This aspect, which seems due to an unusual freedom in the *oblique* communications between the cells in each zone and those alternating with them in the contiguous zones on either side, insensibly passes into the ordinary type; and it is not uncommon to meet with disks, especially fossil, which exhibit in one part the engine-turned aspect, and in another that of concentric zones transversely subdivided. Indeed I have sometimes found that the very same disk might be made to present either of these aspects, according to the manner in which the light is made to impinge upon it and is reflected from it.—Although the rounded or oval form of the superficial divisions is specially characteristic of the Simple type of

Orbitolites, yet it is by no means restricted to this; being frequently met with in the thicker disks of the more Complex type, and being almost constant in the fossil forms that abound in the early Tertiaries. Its occurrence, however, may always (I believe) be considered as indicating an incomplete separation between the superficial segments and the columnar segments of the intermediate stratum (¶ 173); so that the former present the shape of the latter, in place of that which properly characterises them. The shape of the chamberlet is sometimes marked out in unusual strength by the convexity of its roof or cover; and this feature is often so pronounced in the large fossil Orbitolites of the Paris basin, as to become visible to the naked eye. A very marked diversity in its degree, however, as well as in the size of the cells, is often to be noticed in contiguous zones; whence it is obvious that the convexity is a mere accidental variation, and is a character of no value whatever as regards the differentiation of species. The relation of the rounded to the square or rectangular chamberlets is made evident by the occurrence of intermediate links of transition.—The foregoing considerations seem to render it obvious, that diversities in the *form* of the superficial chamberlets do not afford any ground whatever for the establishment of a corresponding multiplicity of specific types, but that they must rank as individual variations to which there is scarcely any definite limit.

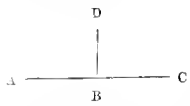
179. Besides those regular markings of the surface which correspond to the division of the interior into chamberlets, a peculiar aspect is frequently given to it by extraneous calcareous deposits, which are sometimes irregular, but which occasionally present an approach to radial symmetry. It is worthy of note that these deposits present themselves far more frequently, and also in a far more characteristic manner, in the Orbitolites of the Philippine Seas, than in those of the Australian or of any other provinces; and this circumstance seems to render it probable that the outgrowth is directly due to the influence of some external condition, probably an excess in the proportion of carbonate of lime in the waters inhabited by these particular specimens.

180. Although the cyclical *Mode of Growth*, when once established, is subsequently maintained with great regularity, and although in what may be considered the typical form it commences from the "primitive disk" itself, yet there are numerous instances in which the typical regularity is more or less widely departed from, so that the early increase seems to take place after an altogether different plan. The most marked antithesis to that regularly concentric type of growth, in which a complete annulus of chamberlets immediately surrounds the primitive disk (see Fig. XXIV, ¶ 157), is presented by those forms in which the circumambient segment has only given origin to new segments at its extremity; these in their turn bud forth others, which extend and multiply themselves laterally as well as in advance; and thus a kind of spiral is produced, which opens out very rapidly, the lateral portions of its mouth tending to grow round and embrace the primitive disk. An example of this kind, in which as many as twenty-two zones (counting the primordial segment as the first) succeed one another before the first complete annulus is formed, is shown in Plate IX, fig. 5. Another example of the like abnormality, taken from a specimen in which the "primitive disk" had a remarkably *Milioline* aspect, is shown in Plate IV, fig. 21. Now if these two plans of growth—the one *cyclical* from the beginning, the other cyclical only after having

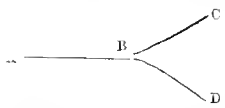
been at first *spiral*—were constantly presented in well-marked contrast with each other, there would be good ground for considering them, as Prof. Williamson has done (CVIII), to be characteristic of distinct specific types. But this idea cannot be sustained when a large number of individuals are examined and compared. For it then becomes apparent that the number of cases in which the primitive disk is surrounded on all sides by the same number of zones, indicating that the concentric mode of growth has prevailed from the first, are very few; but that in by far the larger proportion of specimens there is a slight excentricity of the primitive disk, with a larger number of zones on one side than on the other, as in Plate IX, fig. 3; indicating that the first-formed zones have been incomplete circles, owing to a restriction of the gemmation of the circumambient segment to one part of its periphery. This is shown extremely well by decalcified specimens of the animal, scarcely any two of which, in fact, precisely resemble one another as to the mode in which the first zone originates in the circumambient. Thus in the specimen represented in Plate IV, fig. 14 of which the primitive mass is represented on a larger scale in fig. 20, the circumambient segment gives off only *three* peduncles, at the end most remote from its connexion with the primordial segment; and the first zone of segments is far from being entire, the cyclical type not being completely attained until two or three successive additions have been made. In fig. 19 *eight* peduncles are seen to be given off from the circumambient segment, and from the half-zone which they form an entire circle is next produced; thus affording a remarkable confirmation to the idea I have already suggested (¶ 175), as to the capacity of a portion of a zone to give origin to a complete annulus, by the lateral extension of its bands of sarcode. In fig. 18 the circumambient segment gives off *eleven* peduncles on one side, and there are indications of *three* or *four* on the other. In fig. 17 the peduncles come forth from a still larger proportion of the periphery of the primitive mass; the zone which first surrounds it, however, is still incomplete in some parts, though the succeeding zone forms an entire circle. In fig. 15 we see peduncles coming off from various parts of the circumambient segment, in which (as in the specimens represented in figs. 16, 17, 18) there is a partial separation of a secondary segment *b'*. Finally, in the specimen represented in fig. 16, which is almost the exact counterpart of the disk represented in Plate IX, fig. 4, and diagrammatized in Fig. XXIV, the peduncles come off from the entire circumference of the circumambient segment, and the annular zones of segments are complete from the first. The greater the limitation of the power of gemmation to one side of the nucleus, and the larger the number of incomplete zones, the more will the early plan of growth approximate to the spiral type, such as is represented in Plate IX, figs. 3, 5.—It is obvious that the existence of such intermediate gradations breaks down that barrier between the extreme forms, which Prof. Williamson had proposed to erect; and shows that in this, as in many other particulars, differential characters which at first sight appeared to be perfectly satisfactory, lose all their force when carefully traced through a sufficiently extended series of specimens.

181. *Monstrosities.*—Besides those departures from the normal type of growth which have been described as variations or irregularities, there are certain others of rarer occurrence, which can only be regarded as "monstrosities by excess;" consisting in the production of one or more incomplete secondary disks by outgrowth from the first. Thus in one specimen in my possession the secondary disk forms a half-circle B D, of about the same diameter with

the primary A C, and is superposed vertically upon the latter, the plane of junction passing



through its centre. In other specimens the secondary disk is relatively smaller, extending only from the centre to the margin of the primary, but still meeting it nearly at right angles.—In another specimen I have met with, it would seem impossible to say which is the primary and which the secondary disk: and it might be more correct to describe the entire structure as consisting of a single half-



disk A B and of two half-disks B C and B D, meeting each other at an acute angle C B D, neither of them being in the same plane with the single half-disk, but both of them meeting it at similarly obtuse angles A B C and A B D. In another case there rises from the surface of the disk a triradiate crest, formed by three vertical plates meeting one another at nearly equal angles, but all of them nearly perpendicular to the plane on which they rest. It is a very remarkable feature in this specimen, however, that the line in which the three vertical planes meet is traceable at its base to the centre of the horizontal disk; so that they all bear the same relation to the primitive disk as does the single outgrowth in the instances previously cited. Hence we may attribute all such monstrosities (of which I possess a remarkable collection) to an excess of productive power in the sarcode of the primordial segment, which has put forth its first extension, not merely in the horizontal, but also in the perpendicular direction; the whole subsequent development of these outgrowths taking place after the normal plan, from the foundation thus laid. I have occasionally met with instances, however, in which a vertical plate rises from the peripheral portion of the disk, at a distance from the primordial chamber.—It is interesting to remark that the presence of such outgrowths as those now described is far more frequent in certain localities than it is in others. Among some hundreds of specimens which I have examined from the coast of Australia, I have only met with five or six; among those yielded abundantly by the sand of the shore at Suez, such monstrosities are far more frequent, and the excess more pronounced; but in a small collection which I have inspected from the Ægean Sea, the monstrosities of this kind were so numerous, that I think I am scarcely wrong in asserting that one specimen out of every three or four presented some excess.* Among the *fossil* Orbitolites of the Paris basin, the presence of a completely semicircular vertical plate is not at all uncommon.

182. *Essential Characters of Orbitolites, and its Relations to other Types.*—If, now, we seek to determine the essential characters of *Orbitolites*, we find them to lie in the presence of *a series of annuli of sarcode* (and of corresponding *galleries* in the shelly disk) arranged concentrically round a "primitive disk," which resembles a young *Miliola;* each zone in the simpler type containing but a *single* annulus, so constricted at intervals as to form a series of somewhat columnar segments, which occupy the chamberlets of the shelly disk and are connected with each other by stolons of sarcode: whilst in the more complex type each zone

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

contains *two* such annuli, including between them a portion of its series of columnar segments, so as to constitute an *intermediate* stratum, distinct from the *superficial* portions. In either case, the segments of successive zones freely communicate with each other by radiating *peduncles* of sarcode (also leaving *passages* in the shelly disk), whose normal direction is such as to connect each segment with the two segments that alternate with it in each of the adjacent zones.—The extreme freedom with which all the cavities of the shell mutually communicate is a very marked feature in the structure of this type, as in that of *Orbiculina*, *Alveolina*, and *Fabularia*; and shows that the several parts of their animal bodies are far more closely connected into one whole, than they are in those Foraminifera with perforated shells which they most resemble in general plan of conformation.—The addition of new zones, each similar to the last, is a simple matter of *growth*; but the passage from the Simpler to the more Complex plan marks an advance in *development*; and this advance essentially consists (here as elsewhere) in a *progressive differentiation of parts*. When, with the vertical extension of the columnar segments, the annular canal subdivides itself into two, the communications between the successive zones no longer come-off, as before, from the annular canal, but from the intermediate portions of the columnar cells; and instead of the two diverging passages from each cell being in the same plane, they lie in different planes, alternating with each other vertically. Up to this point, we observe little else than a multiplication of parts vertically, as well as horizontally, and a separation of connexions that were previously confluent. But in the highest stage of development we find a marked alteration in plan; for those portions of the columnar segments, which lie between the two annular canals of each zone and the two surfaces of the disk, become completely differentiated from the portions that occupy the intermediate stratum, so as to form a peculiar set of *superficial* chamberlets; and these are so equally connected with *two* zones, as to make it impossible to say that they belong specially to either.—Now we have seen that *development* may be checked, while *growth* continues, at any period of its progress; so that we find Orbitolites growing to a considerable size upon the very simplest plan, others still larger formed upon the duplex plan, the largest yet known (fossilized in the Paris basin) developed upon the multiple plan without separation of the superficial chamberlets, while the most complete, in regard alike to multiplication and to differentiation of parts, are only found among the disks at present existing; and it is interesting to observe that some of these present this highest grade of development, while as yet of comparatively minute size. There is scarcely any other type of Animal structure, in which so wide a range of developmental variation normally exists. The lower classes of the Vegetable Kingdom, however, especially the group of *Fungi*, afford abundant examples of it.*

183. The relation of *Orbitolites* to *Orbiculina* is of the most intimate kind. As already mentioned (¶ 143), it would not be possible to distinguish with certainty a fragment of the peripheral portion of the former from a corresponding fragment of the cyclical type of the latter; though it is curious to observe that, whilst the differentiation of the *superficial* from the *intermediate* strata is *most* complete in the *Orbiculinæ* of the early Tertiaries, it is *least* complete in the *Orbitolites* of the same epoch; and conversely, whilst it is *least* complete in the *Orbiculinæ*

* For a more detailed examination of the reputed species of *Orbitolites*, see XIII, p. 221.

of the present time, it is *most* complete in the *Orbitolites* of our Southern Ocean. These two types are at once distinguishable from each other, however, by a comparison of the centres of their respective disks; for not merely does *Orbiculina* invariably commence on the *spiral* plan, but it invariably persists in this until the spire has made three or four turns, of which each invests the preceding, so as to augment the thickness of the centre, and to cause this to project as a rounded knob above the plane of the peripheral portion of the spire or disk. In *Orbitolites*, on the other hand, the *cyclical* mode of growth seems characteristic of the type; for even when the early growth follows a spiral arrangement, this seems simply to result from a defective power of gemmation in the "primitive mass" of sarcode, and the spire never proceeds beyond a single turn, or encroaches on the surface of the primitive disk, but from the first shows a tendency to pass into the cyclical form.

184. The relation of *Orbitolites* to *Tinoporus* (the *Orbitolina* of D'Orbigny), to *Orbitoides*, and to *Cycloclypeus*, is one of mere similarity in mode of growth, and consequently of analogy only; their essential characters being such as to remove them most widely from it. For as *Orbitolites* is the cyclical type of the *Milioline* series, so shall we see that *Tinoporus* stands in the like relation to the *Rotaline*, and *Cycloclypeus* to the *Operculine*, whilst *Orbitoides* seems to be a connecting link between the two latter.

185. *Geographical Distribution.*—This type, like *Orbiculina*, is pretty generally diffused along the shores of the warmer seas; but it is interesting to observe that it is most abundant where *Orbiculina* is comparatively rare, and *vice versâ*. Thus, it is more commonly met with in the Australian and Polynesian seas than in the West Indian or Philippine, and is peculiarly abundant in the Red Sea (the shell-sand of Suez yielding it in extraordinary copiousness), though not there attaining any large size or high development, whilst it seems to die out in the Mediterranean, the specimens gathered on its shores being all of stunted growth. Its largest size and highest development at the present time are attained in the Polynesian seas, especially on the sides of Coral-reefs, where the disks that have become detached from the sea-weeds to which they are usually attached, often accumulate to an enormous extent.

186. *Geological Distribution.*—The early part of the Tertiary period appears to have been unusually rich in Foraminifera of the largest size. The *Calcaire Grossier* of the Paris basin, and corresponding formations in the south of Europe, contain enormous numbers of Orbitolites, which often attain a diameter of 8-10ths of an inch; and the Limestones of the north-west of India, which in some parts are rich in *Orbiculinæ* and *Orbitoides*, are elsewhere almost entirely composed of an equally large variety of *Orbitolites*, which Mr. Carter (XIX) has described under the name of *Cyclolina*, supposing it (from the peculiarly cyclical aspect of its surface, ¶ 178) to belong to the genus so named by D'Orbigny, which seems, however, to have been really founded on a varietal form of *Tinoporus*. The true *Orbitolites* first makes its appearance in the rich Polyzoic deposits of the shallow-water Maestricht chalk; and it has probably continued to inhabit the ocean waters, from the time when it first accumulated so as to form an important constituent of the Eocene Limestones, down to the present epoch. Whenever the Coral islands at present submerged shall in their turn undergo elevation, a new series of Orbitolite-limestones, now in progress of formation, will probably be brought to light.

Genus XI—DACTYLOPORA (Plate X).

187. *History*.—The most singular varieties of opinion have existed as to the true character of the fossil organisms on which the genus *Dactylopora* was founded by Lamarck (LX). They had been previously noticed by Bosc, and had been referred by him to the genus *Reteporites*, belonging to the group then regarded as Zoophytes, but now ranked as Polyzoan Mollusca; and in this allocation he was followed by Lamouroux. In separating them generically from *Retepora*, Lamarck still associated them in the same group of supposed Zoophytes; his genus was adopted by Blainville and Defrance (VII), who assigned the like place to it; and it was accepted by many subsequent palæontologists, as Goldfuss, Michelin, and Bronn, without any question as to its character. By Blainville and Defrance, moreover, another genus, *Polytrype*, was erected upon a mere variety of the same type; and this also has been accepted as a zoophytic form nearly allied to the preceding. In 1852, however, *Dactylopora* was included among the *Foraminifera* by M. D'Orbigny (LXXIV); who showed, notwithstanding, by the place he assigned to it, a misapprehension of its real nature scarcely less complete than that under which his predecessors had lain; for he ranks it in his Order *Monostègues*, next to the unilocular *Ovulites*, and says of it:—" C'est une *Ovulite* également percée des deux bouts, pourvue des larges pores placés par lignes transverses." How utterly erroneous is this description will appear from the details to be presently given; yet M. D'Orbigny's authority has given it currency enough to cause it to be accepted by such intelligent palæontologists as Pictet and Bronn, who, in the latest editions of their respective systematic treatises, have transferred *Dactylopora* to the place indicated by him, not without the expression of a doubt, however, on the part of the last-named author (X, 'Uebersicht,' p. 25), whether its true place is not among the *Fistulidæ*, in alliance with *Synapta* and *Holothuria*,—a suggestion that indicates a perversion of ideas on the subject, for which it is not easy to account. The complex structure of the organism in question was first described, and the interpretation of that structure on the basis of an extended comparison with simpler forms was first given, by Messrs. Parker and Rupert Jones (LXXIX) in so unobtrusive a manner as scarcely to challenge the attention which their investigations deserve; and I gladly avail myself of the opportunity which the present publication affords to give a fuller account, with the requisite illustrations, of this remarkable type, the elucidation of which seems to me not unlikely to lead to a reconsideration of the place assigned to many other organisms at present ranked among Zoophytes or Polyzoa. This account will be chiefly based on the descriptions already given (loc. cit.) by those excellent observers; but it will depart from these upon several points, as to which the further investigations which we have jointly prosecuted have led to a modification of their original conclusions. The illustrations in Plate X are carefully drawn, by Mr. G. West, from the beautiful series of specimens with which they have furnished me, and which they have kindly allowed me to treat in any manner that I thought desirable for the elucidation of their structure.

188. *External Characters and Internal Structure*.—The type we have now to investigate is one which, like the three preceding, exhibits itself under such a variety of modifications of form, and so many dissimilar phases of development, that only by a careful and extended

comparison can the mutual relations of these be discovered; and it will be desirable, instead of commencing with the complex organism on which the genus was originally established, to examine in the first instance those simpler or more elementary forms which afford the clue to the interpretation of its character. For each of the principal modifications I am about to describe, I shall adopt the distinctive name assigned to it by Messrs. Parker and Rupert Jones; but these names are to be understood as used merely for the sake of convenient identification, and not as intended to indicate a definite boundary between the forms they respectively designate,—no such boundary having, in our opinion, a real existence.

189. In the East Indian and other tropical seas, generally adherent to the surface of large, foliated, bivalve shells, such as *Chama* or *Hippopus*, but occasionally free in shell-sands, the simple pupoid forms represented in Plate X, figs. 1—7, are not uncommon. Each of these is composed of a linearly-arranged series of chambers entirely disconnected from each other; the external walls of these chambers and their dividing septa are very thick, and are composed of porcellanous shell-substance exactly resembling that of the higher types of Foraminifera with which we have been last engaged; and their surface sometimes exhibits minute pits, resembling those which we have seen to be common on the exterior of many of the porcellanous series. Although the succession of these chambers is sometimes almost rectilinear, it is generally more or less curved; and the curvature is sometimes so great that the series forms a half ring. Every chamber opens separately by a single large pore on the middle of the concave side; and this pore is surrounded, as in *Peneroplis*, *Orbitolites*, &c., by a prominent annulus of shell, which is sometimes so thick and large as to form a nipple-shaped protuberance. The number of chambers is extremely variable, and is obviously dependent upon successional growth. Although specimens are occasionally met with in which the surface is smooth or nearly so, it much more commonly presents a strongly marked alternation of ridges and furrows (figs. 3, 7), the former corresponding with the interseptal spaces, and the latter with the septa; there are instances, however, in which the interseptal spaces are depressed, as in fig. 8, instead of being elevated. It now and then happens that the chambers are piled one on the other, so as to form part of a double series (fig. 6). The length of any series will, of course, depend upon the number of chambers which it contains; the breadth of these bodies usually varies between ·007 and ·012 inch. The simple structure of this organism is diagrammatically represented, as shown by horizontal and vertical sections, in Fig. XXV. Its mode of growth would be not a little perplexing, if we did not bear in mind what has been already stated as to the extension of the sarcode-body over the exterior of the shells of Foraminifera (¶ 33), and the formation of new envelopes by portions of that body protruded from the aperture (¶ 31). It has been shown to be probable, in the case both of *Orbitolites* and *Alveolina*, that (at certain times, if not habitually) the pseudopodial extensions from the separate pores coalesce with each other on the exterior of the aperture; and there is no more difficulty in understanding how, from such a coalesced stolon of sarcode, a new chamber may be added to either extremity of the linear series, or may be built (so to speak) as part of a new storey above it, than there is in accounting for the formation of such a chamber in direct continuity with the aper-

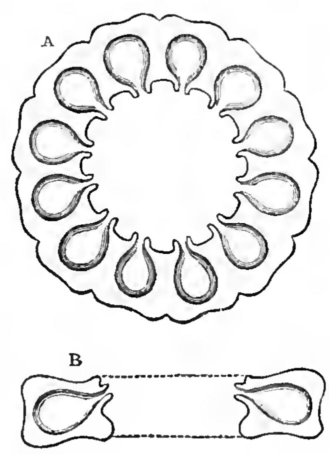
Fig. XXV.

Diagrammatic Sections of *Dactylopora eruca*:—A, horizontal; B, vertical.

ture of the preceding. We shall presently see in the more complex forms of *Dactylopora* a very marked indication that such a coalescence really takes place; the apertures of the principal chambers being received into a gallery that obviously lodged a stolon by which the isolated segments are brought into mutual connection.—The type now described, which presents itself in some of the French Tertiaries under a form (see figs. 4, 8) precisely identical with the recent, is distinguished as *D. eruca.*

190. It is obvious that the continued growth of such bodies along a circular curve would ultimately complete them into rings; but it does not appear that such an elongation of the pupoid form of *Dactylopora* ever takes place, as would be required to complete the large circle which their moderate curvature would generate. In the "calcaire grossier" of Grignon and other Tertiary deposits, however, the pupoid forms are accompanied by complete annular disks (figs. 10—14), having a structure in every essential respect similar to theirs, and varying in diameter from ·025 to ·035 inch. Each of these rings is composed of a series of flask-shaped chambers, usually from ten to twenty-four in number, regularly packed side by side; the chambers being surrounded by thick walls and separated from each other by thick, imperforate septa, as is shown diagrammatically in Fig. XXVI, A. Each chamber opens into the central cavity of the annulus by a single aperture in the centre of a mamillary protuberance; this protuberance, however, is usually nearer to one surface of the disk than it is to the other (Fig. XXVI, B); and it is not always seated on the internal margin of the ring, but is sometimes a little removed from it on the surface of the disk, and then points, not directly, but somewhat obliquely inwards, as shown in figs. 11, 14. The surface of the annular disks exhibits the same varieties as that of the pupoid forms, being sometimes uniform, but more commonly presenting an alternation of radiating elevations and furrows, the furrows corresponding to the septa, and the elevations to the intervening spaces that cover-in the chambers beneath. The number of the elevations and of the intervening furrows, however, is usually much greater in these annular forms than that of the chambers; for the primary elevation is often itself divided into two ridges by a secondary furrow, especially towards the outer margin of the annulus; and thus we have a series of sharply defined radiating ridges (fig. 13) resembling the teeth of a flat wheel, the furrows between which, however, do not all extend to the inner margin of the annulus, which may be divided only by those that correspond to the septa. This ridge-and-furrow arrangement is far more strongly marked in some instances than it is in others; a gradational variety being obvious, on the comparison of a sufficient series of specimens, between the smoothest and flattest of these annular disks and those whose surface is most unequal. In some instances, moreover, the ridges are continued along the outer margin of the annulus, so as to give it the appearance of a wheel toothed at its edges; and it is curious that this dentated margin is sometimes most strongly exhibited by disks whose surfaces are the flattest, as is shown in fig. 19. There is a

Fig. XXVI.

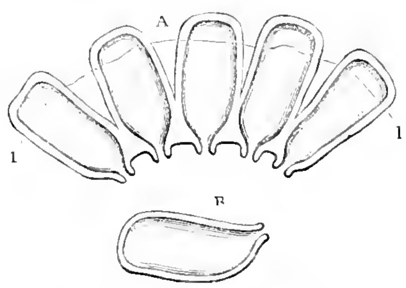


Diagrammatic sections of *Dactylopora annulus*:—A, horizontal; B, vertical.

considerable variety, too, in regard to the proportion which the central space bears to the breadth of the annulus; the inner circle being for the most part relatively smaller in the flattest annuli, and increasing in diameter as the annulus itself swells out and diminishes in breadth. It is a remarkable feature in this type, which may be distinguished as *D. annulus*, that the annulus is usually divided with great regularity into chambers of equal size; a regularity for which it is difficult to account on the supposition that the entire ring has been developed by the successive growth of independent chambers. After a careful examination of numerous specimens, I have only met with one which gives any distinct indication of a line of junction, such as might be expected to result from the meeting of the two ends of an imperfect ring completed by the successional addition of new chambers. And it may therefore be fairly questioned whether the uniform annulus, which is certainly the normal type, did not originate in a radiating outgrowth of segments from one large primordial mass of sarcode occupying its centre, in the same manner as the first annulus of chamberlets in the typical *Orbitolites* (¶ 161) is formed around the primitive disk; the space at first occupied by the primordial segment being not covered-in by shelly walls, and being perhaps vacated in these annular forms so soon as the surrounding ring of chambers has been consolidated. We shall hereafter see reason to believe that in the more complex type of *Dactylopora* the central cavity continues to be occupied by the sarcode-body through life, and that it is in this portion that all new annuli have their origin (¶ 197).

191. In each of the two forms now described a curious variety is occasionally met with, resulting from what may be termed a "wild" growth of the segments (such as we shall frequently encounter in certain forms of the vitreous series), which tends to convert the closely set, flask-shaped chambers into elongated, divaricating tubes. This is most strongly marked in the pupoid type, the chambers of which occasionally undergo such an elongation as to be converted into cylinders (fig. 16) so closely resembling the cells of *Tubulipora* or *Cellepora*, that, if detached from each other, they might easily be mistaken for fragments of those Polyzoa; and, in fact, the determination of this form as a variety of *Dactylopora*, under the designation *D. digitata*, chiefly rests on its evident relationship to that to be next described. No specimen has yet been found sufficiently perfect to exhibit the unbroken terminations of the cells; but there can be no reasonable doubt that they are closed at their diverging extremities (as shown diagrammatically in Fig. XXVII), like those of the forms to which they are related.—A similar tendency occasionally shows itself in a less marked degree in the annular type (fig. 15); giving rise to the form which has been described and figured by Michelin ('Icon. Zooph.,' p. 177, pl. xlvi, fig. 27), under the name of *Clypeina marginoporella*, as a member of the family *Tubuliporidæ*. The chambers here also are elongated and subcylindrical; but they remain in adhesion to each other laterally, so as to lie obliquely to the axis of the ring, and to form a sort of inverted funnel, as is shown in the diagrammatic sections in Fig. XXVIII. The pores represented by Michelin along the external margin have no real

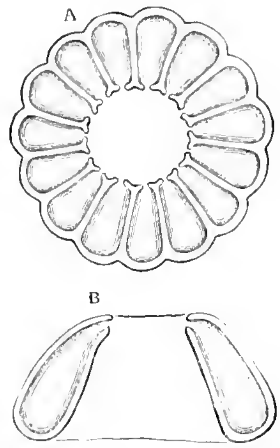
FIG. XXVII.



Diagrammatic sections of *Dactylopora digitata*:—A, horizontal; B, vertical; 1, 1, line of fracture.

existence, being merely the result of the attrition of the most exposed part of the walls of the chambers; and the true apertures of the chambers are seen along the inner margin of the annulus. It is convenient to retain as the specific designation of this organism the generic name conferred upon it by Michelin; so that we shall distinguish it as *D. clypeina*.*—The resemblance which *D. digitata* and *D. clypeina* bear to tubuliporous polyzoaries is much strengthened by the deep pittings of their surface, which so nearly present the aspect of the perforations common in the shelly walls of the cells of Polyzoa, as to be readily mistaken for them. It is to be borne in mind, however, that such deep pittings are not infrequent among the porcellanous Foraminifera (¶ 111, 138); and we shall find similar, though shallower, pittings presenting themselves in other forms of *Dactylopora*.

FIG. XXVIII.



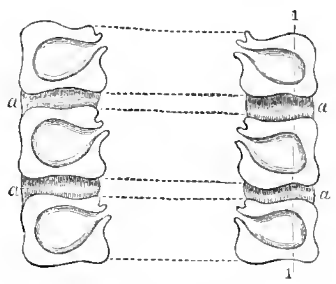
Diagrammatic sections of *Dactylopora clypeina*:—A, horizontal; B, vertical.

192. Returning now to the ordinary type of *D. annulus*, we have next to remark that it is not uncommon to meet with two or more rings adherent to each other serially by their surfaces (fig. 9); when these surfaces are flat, there will be no spaces left between them; but when raised into ridges, the mutual adhesion of these ridges completes the intervening furrows into canals (Fig. XXIX, *a*, *a*). These canals may or may not pass through the entire breadth of the annulus, according as the furrows by the junction of which they are formed are primary (septal) or are secondary (intermediate, ¶ 190); and even the septal furrows do not always extend to the interior of the annulus, so that there may be every kind of variety in the size and number of these *junctural interspaces*. In what may be considered the typical form of this variety, which is designated *D. reticulata*, the symmetrical piling of the rings one upon another forms a compact cylinder, the exterior of which is marked at regular intervals by single rows of large pores closely approximated to each other (figs. 17 B, 18, *a a'*), and in the intervals between these by the marginal ridges of the annuli. On the internal surface the annuli are less intimately connected with each other, as their projecting ribs most commonly stop short of the internal margin of the ring; and thus there is seen a deep grove or furrow (fig. 17 B, *b b'*) at the junction of each pair, from the peripheral margin of which the junctural interspaces diverge. The apertures (*c*) of the chambers (*d*, *d*) seldom, if ever, lie in the median plane of the annulus, but are directed more or less obliquely towards one of its surfaces, so as to approach the furrow just mentioned; and their obliquity is sometimes so considerable that they discharge themselves into that furrow.—But if the surfaces and margins of the rings should be nearly smooth, the pores formed by the "junctural interspaces" will be very small and inconspicuous; and when, as often happens, these are filled up by fossilizing deposit, the composition of the column will only be indicated externally by the constrictions which it exhibits at intervals. In other cases, again, the "junctural interspaces" are of extraordinary size.—It not unfrequently happens that the cavities of the chambers are laid open by attrition (fig. 17 B, *c' c'*)) at the parts of the surface (*c*, *c*)

* By Messrs. Parker and Rupert Jones the specific designation *marginoporella* was the one employed; but this is so obviously inappropriate as to render its retention undesirable.

where their walls are thinnest; and such specimens, worn down to the line 1, 1, in Fig. XXIX, will present a series of large pits or openings between the rows of "junctural interspaces." This seems to be the condition of the form described by Defrance (XXIX, tom. XXV, p. 287), under the name *Larvaria reticulata;* and as there is here nothing inappropriate or deceptive in the trivial name, we retain it to distinguish the form of *Dactylopora* now described. The close relationship between this type and the preceding is evident, not merely from the general identity in the composition of each annulus, but also from the circumstance that the average number of chambers which it contains is the same in *D. reticulata* as it is in *D. annulus,* and that the average diameter of the cylinder of the former is the same as that of the rings of the latter. There is, in fact, every gradation between those disconnected rings, which are not unfrequently found slightly adherent in pairs, and the compact column of which the original annulation is but very imperfectly indicated on the surface. It is to be noticed in some of the most compact specimens of this type (fig. 21) that the succession of the chambers in the adjacent rings is not altogether regular, but that they in some degree alternate with each other, so as to present a transition to the next variety; and even when the annular divisions are well marked by the rows of large "junctural interspaces," these divisions are sometimes considerably inflected.

Fig. XXIX.



Diagrammatic vertical section of *Dactylopora reticulata* :—*a, a, a, a,* junctural interspaces; 1, 1, line of attrition.

193. A modification of this simple type sometimes presents itself, in which the chambers are more than usually isolated from each other; each being surrounded on all sides by its own proper wall, and being connected with the adjacent chambers by projections of that wall (Plate X, fig. 25); between these projections are left "junctural interspaces" (*b, b*), which are sometimes passages of considerable size (fig. 28), and are sometimes narrowed to mere pores (fig. 26, 27). The apertures (*a, a*) of the chambers are here uniformly central, and are seated on nipple-shaped prominences (figs. 25, 26, 28). The external surface of the walls of the chambers, in well-preserved specimens, is roughened by an irregular sculpture (fig. 27); a circumstance of interest with reference to the nature of the original surface in *D. cylindracea.* The piling of these chambers one upon another is not, as in *D. reticulata,* in distinct annuli; for, although they usually form tolerably regular rows, the chambers in successive rows alternate with each other, those of one row lying in the hollows formed by the convexities of those in the rows above and below.—This seems to be the Microzoon figured and described by M. D'Archiac ('Mém. Soc. Géol.,' 1850, tom. iii, p. 407, pl. viii, fig. 20) under the name *Prattia glandulosa;* and as there can be no reason to regard it as anything else than a modification of the ordinary type of *Dactylopora* (approaches to the alternating arrangement of the chambers being not unfrequently met with in *D. reticulata*), it will here be distinguished as *D. glandulosa.*

194. We now arrive at the type on which the genus *Dactylopora* was founded, the *D. cylindracea* of Lamarck; which presents a very marked dissimilarity to all the preceding, both in form, superficial aspect, and internal arrangement; and yet it will be shown to be not so far removed from them in the essentials of its structure, as to require being ranked in

a different category. A completely developed specimen of this organism is usually rather barrel-shaped than cylindrical; and it is in the more attenuated varieties (on one of which, presenting a difference of superficial characters that will be shown to depend merely upon the degree of attrition to which the specimen has been subjected, Defrance founded his genus *Polytrype*) that the cylindrical form is most pronounced. The specimen of *D. cylindracea* figured by Defrance (XXIX, 'Zooph.,' pl. xlvii, fig. 4) measures nearly half an inch in length, and one sixth of an inch in diameter at its largest part; but the largest specimens which have fallen under our observation are by no means of these dimensions; and we have some that are quite perfect as to form, the length of which does not exceed one sixteenth of an inch. The extremities are rounded off by an inflection of the wall of the cylinder towards its axis, so as partly to close-in the cavity; there always remains, however, a large central orifice, at least at one termination; but whether this is maintained throughout life at both ends we are not able to speak positively, the figures of Defrance indicating a complete closure at one end, which none of our specimens exhibit. Notwithstanding the very considerable diversities in internal structure which (as will presently appear) are exhibited by different varieties of this organism, the external surface presents the same characters in all; being covered with a series of somewhat funnel-shaped cups, at the bottom of every one of which (usually, but not always, in the centre) is a circular pore (Plate X, figs. 20 A, 29, *g*, *g*). The superficial edges of the dividing partitions between these cups, in the specimens which show least evidence of having been altered by attrition, are roughened by a sort of rude sculpture, which reminds us of that of the outer surface of the chamber-walls of *D. glandulosa* (fig. 27); and this circumstance seems to indicate that we have here the normal exterior of the organism, and not (as was supposed by Messrs. Parker and Rupert Jones, LXXIX) a surface produced by the wearing-away of the outer walls of cavities that were originally closed or nearly so. The pores in these cups are the orifices of a system of radiating passages that constitutes the peripheral continuation of the "junctural interspaces;" and it is in the extraordinary development of this "interspace-system," and in the formation of a sheath of solid shell-substance (often of considerable thickness) around the chambered cylinders, that the distinguishing peculiarity of *D. cylindracea* consists. The degree of development of this solid sheath, and that of the "interspace-system," vary greatly in relation to that of the chambered cylinder; but they always correspond so closely the one to the other, that it is impossible not to recognise in this "interspace-system" the representative of the "canal-system" of the larger hyaline Foraminifera, and in the solid sheath the analogue of their "intermediate" or "supplemental skeleton" (¶ 63). This difference, however, although one that greatly modifies the aspect of the walls of the cylinder as they show themselves in transverse section, is not really of so much account as a very remarkable diversity in the relations between the "interspace-system" and the chambers; a diversity that seems at first sight of so fundamental a nature, as to justify the belief that the specimens which exhibit it must be formed on plans which are essentially unlike. I have succeeded, however, in tracing these differences so gradationally, not only through an extensive series of distinct specimens, but through the different parts even of one and the same, that I can entertain no doubt of their being all varietal modifications of a common type; and much of the perplexity at first caused by them disappears, when it is remembered that the "interspace system" is not a definite fundamental part of the organism, but that it is an indefinite residue (so to speak) left by the non-consolidation of certain passages which seem to be left for the extension of the sarcode-body (which probably occupies the whole cavity of the cylinder) through the thick layer of solid shell-substance that ensheaths the chambered portion.

195. In what we may consider the simplest form of *D. cylindracea*, represented in Plate X, fig. 20, the wall of the cylinder is but little thicker than the length of the chambers; the solid sheath and the "interspace-system" being but slightly developed. The relative position of the chambers is the same as in *D. reticulata;* but instead of each chamber opening at once into the general cavity of the cylinder, it is received into a "junctural space" (an arrangement of which we have already seen an indication in *D. reticulata*); and these "junctural spaces" form annular rows of large open mouths upon the interior of the cylinder (as in fig. 24). The large "junctural space" terminates where it embraces the nipple-shaped aperture of the chamber, just in the manner that the vagina terminates where it receives the cervix uteri; but instead of being a closed *cul-de-sac,* it gives off a radiating series of tubular passages (fig, 22, *b, b*) which pass towards the surface in close proximity to the proper wall of the chamber (as in fig. 24), and terminate there in the funnel-shaped depressions already mentioned. This condition presents itself only in small specimens, in which the number of chambers in each annulus does not much exceed that which we meet with in *D. annulus* and *D. reticulata*. Some of these specimens are differentiated by the presence of a circular gallery passing between each annulus of chambers and the internal margin of the cylinder-wall (fig. 20 B, *a, a*), so as to connect with each other all the "junctural interspaces" of the same annulus; and it is easy to see how such a gallery may be formed by an endogenous addition of shell-substance, arching over a furrow left at the junction of the annuli (as in *D. reticulata*, ¶ 192), and thus inclosing a stolon of sarcode which (as there is strong analogical reason to suppose) would unite together the separate radiating stolons proceeding to the chambers through the "junctural interspaces." But further, in the larger and highly developed specimen of which a portion is represented in fig. 24, A, we find this coalescence still more complete; for the pouting orifices which project into the general cavity of the cylinders open at once into a wide gallery (shown in vertical section at *a', a'*, and in horizontal section at A, *a, a*) of uniform diameter throughout; whilst on the peripheral side of this gallery there are a number of small apertures, of which some lead to the chambers *b, b*, whilst others (of which there seem to be two to each of the preceding) form the commencements of the "interspace-systems" of diverging canals *d, d*, that terminate in the funnel-shaped cups *e, e*, on the surface of the cylinder.

196. Returning now to the simpler type in which the internal orifices of the "junctural interspaces" remain distinct, we find that the diameter of the cylinder may be greatly augmented by exogenous deposit around the chambered portion, so as to add a solid wall of great thickness to its exterior. The whole thickness of this wall is traversed by the "interspace system" of passages, which end on its surface in the ordinary mode; these passages do not ramify or divaricate, so that their number does not augment as they diverge from each other radially; but in proportion to the separation which thus takes place between their surface-terminations, the diameter of the cup-shaped depressions increases. In the specimens which are distinguished by the greatest development of this exogenous deposit, a most remarkable modification presents itself in the position of the chambers; for instead of lying on the peripheral side of the internal orifices of the "junctural interspaces," they are disposed

(very much as in *D. clypeina*, Fig. XXVIII, B) so as to lie in the cylinder-wall, *between* the successive annuli of those orifices (fig. 29); each chamber *a*, *a*, opening by the usual contracted neck and narrow aperture into its corresponding "junctural interspace" *b*, *b*, at a little distance from the internal orifice of the latter. Each "junctural interspace" is here a large cylindrical passage (*c*, *c*), which runs sometimes transversely, sometimes obliquely, towards the external surface; the former being for the most part its direction in the median portion of the cylinder, and the latter towards its extremities. When, as sometimes happens, the direction is extremely oblique, the passage is very greatly elongated. Before subdividing into the bundle of smaller passages *e*, *e*, to which it gives origin, the main passage dilates into a *cul-de-sac* (*d*, *d*), which has sometimes an almost globose form, so that it might be easily mistaken for one of the proper chambers. Here, then, the ordinary relations of the chambers and the "interspace system" of passages appear to be completely changed; for the bundles of branching passages lie altogether apart from and between the chambers, instead of closely embracing their walls; and the aperture of each chamber lies just within the commencement of the main passage, instead of being seated at its peripheral termination in the centre of the ring of orifices leading to the diverging branch-passages. Yet this change is so far from being of any essential importance, that we find the transition from the one arrangement to the other presenting itself in the different parts of the very same specimen; the axis of the flask-shaped chamber, which may be said to correspond in the first instance with that of the junctural passage, being gradually bent out of continuity with it, and at last coming to be nearly at a right angle with it. It seems to be in the largest and most developed forms (which are unfortunately only known to us by fragments) that this modification is most completely effected; and in these a further modification takes place in the shape of the chambers, which lie in such close contiguity to each other as to be separated only by thin and nearly straight parallel walls, and to be separated from the general cavity of the cylinder by a wall of almost equal thinness. It is only in well-preserved specimens of this type, that the true chambered lining of the cylinder is found; for in those fragments which have been subjected to attrition, this part is so entirely removed that scarcely any indication remains of it; and the dilated *culs-de-sac* of the "junctural passages" may thus be more readily mistaken for proper chambers.* The external surface, again, may be removed by attrition: and a very different set of appearances will be presented, according to the proportion of the thickness of the exogenous sheath which has been thus removed, as will be readily understood from fig. 29. For only the cupped exterior may be worn away, and the surface will then present (as at *e′*, *e′*) the transverse sections of the clusters of diverging canals which terminate in its funnel-shaped depressions. But if more has been removed, the *culs-de-sac* of the principal passages may be laid-open, close to the origin of their diverging branches, the orifices of which are seen around them, as at *f*. A specimen in precisely this condition is represented in fig. 23. If the abrasion should proceed further, the diverging canaliculi will be altogether lost, and only the orifices of the main junctural passages will be seen. It is very easy to imitate the effects of any degree of attrition by the careful application of dilute acid, either to the internal or to the external surface; and in several specimens thus prepared, I have noticed that the solid

* It was by such a mistake that Messrs. Parker and Rupert Jones were formerly led astray in their descriptions of the supposed varieties *D. polystoma* and *D. bambusa*.

sheath is divided into tolerably regular areolæ by sutural lines, which seem of different texture from the rest (fig. 30). Each horizontal row of these areolæ corresponds to one annulus; and the sutural lines which bound it horizontally, divide that annulus from the annuli above and below. Each division marked out by the vertical lines corresponds to the cluster of branches radiating from one of the great junctural canals of the interspace-system; and the shell-substance which it includes was probably deposited by the extensions of the sarcode-body which passed through those canals. As no such sutures are discernible in *sections*, however thin, it seems obvious that the substance of the shell at the lines of junction must closely accord with that of the rest, its difference being only brought out by its more ready solubility in dilute acid. I have noticed in some instances that sutural lines are only distinguishable between the successive annuli; the portions of the exogenous sheath belonging to each annulus being entirely homogeneous.

197. It is obvious, from the account now given of the structure of this, the most developed type of *Dactylopora*, that the development of the thick exogenous sheath which is formed around the chambered portion of the cylinder could scarcely have taken place from the isolated segments of the sarcode-body contained within its chambers; but that it must have proceeded from an aggregate mass filling the whole interior of the cylinder. For it appears scarcely questionable that the "interspace-system" of large canals, with their bundles of smaller branches, must have been occupied during life by extensions of the sarcode-body; since the peculiar structure of the exogenous sheath cannot be probably accounted for in any other way, than by supposing each constituent portion of it to have been built up by the agency of one cluster of such extensions; each of these clusters remaining as distinct from those adjacent to it, as are the segments occupying the cavity of the chambers themselves. But it is the distinctive peculiarity of this "interspace-system," that it has extremely little connection with the chambers; in this respect differing widely from the true "canal-system" of *Calcarina* (in which genus the "intermediate skeleton" attains a development that is unexampled elsewhere), the connection of which with the cavities of the chambers is so direct, that it may be said to be nothing else than a prolongation of these into the parts of the fabric most removed from them. In *Dactylopora*, indeed, such connection as it has with the chambers seems to be rather accidental than essential, resulting from the fact that the "junctural canals" and the apertures of the chambers happen to coalesce near to the point of their common connection with the general cavity of the cylinder. And it seems to me that we cannot form any other rational conception of the animal of this curious organism, than by regarding it as an aggregate mass of sarcode, occupying the whole cavity of the cylinder, and in connection, on the one hand, with the segments that occupy the chambers, and on the other with the extensions that radiate past them through the exogenous sheath beyond.

198. *Affinities.*—Looking at the most complex and specialized forms of *Dactylopora*, we should not easily recognise in them any but a very remote affinity to either of the porcellanous types hitherto described. But the true "idea" of its structure is to be looked for in its simpler forms; and, as already pointed out, there is much in the structure of *D. annulus* that reminds us of that of a single annulus of *Orbitolites*. If, in fact, the segments were united by *internal* continuity instead of by external, and if the new rings were developed from the

margins of the old, so as to form an expanded disk, instead of being piled up one above another, so as to form a cylinder, we should have the essential features of the simple type of *Orbitolites*.—It may be conjectured, without much improbability, that *Dactylopora* is only a single representative of a group whose various forms filled up the hiatus which at present intervenes between itself and its nearest allies among the ordinary Foraminifera; one such link, indeed, we shall presently find in the comparatively simple type to be described under the name *Acicularia*.

199. *Geographical and Geological Distribution*.—The recent forms of *Dactylopora*, which all belong to the simple type *D. eruca*, have not been met with anywhere save in the tropical seas; and the fossil forms are for the most part limited to the Eocene Tertiaries of the Paris basin, though *D. reticulata* occurs in the Tertiaries of Italy and San Domingo.

Genus XII.—Acicularia (Plate XI, figs. 27—32).

200. *History*.—The history of the genus *Acicularia*, first instituted by M. D'Archiac in 1843 ('Mém. Soc. Géol.,' tom. v, p. 366), is scarcely less singular than that of *Dactylopora*. The genus was founded upon certain minute bodies detected by M. D'Archiac in the "calcaire grossier," the narrowness, elongation, and occasional pointedness of one extremity of which gave them some resemblance to a needle; and the place assigned to this type by its discoverer was among the composite organisms now distinguished as "polyzoaries." In this he was followed by Michelin, who repeated his figure of it ('Icon. Zooph.,' p. 176, pl. xlvi, fig. 14); but M. D'Orbigny in the second volume of his 'Paléontologie Stratigraphique' published in 1850, ranked it in the Foraminiferous genus *Ovulites*, in close approximation to *Dactylopora*; and in this determination he has been followed by Pictet ('Traité de Paléontologie,' tom. iv, p. 484), who still, however, regards *Acicularia* as generically distinguished from *Ovulites* proper by the pointedness of one of its extremities. By Bronn, on the other hand (x, bd. i, p. 11, bd. iii, p. 166), it seems to be thought more probable that *Acicularia* is a peculiar form of sponge-spicule! We shall see that a careful microscopic examination of this type affords adequate evidence that it is really Foraminiferous in character, but that its true structure and its position in the series are altogether at variance with the ideas formed of it by M. D'Orbigny; since it is, like *Dactylopora*, a composite organism made up by the aggregation of a number of separate and independent chambers, being generically distinguished from it, however, by a different arrangement of those chambers. This fact has been fully apprehended by Messrs. Parker and Rupert Jones, although they have not yet stated it publicly; and the description I give of the type is entirely based on the materials which they have kindly placed at my disposal.

201. *External Characters*.—The bodies to which the generic designation *Acicularia* seems applicable, vary through a considerable range of forms; being sometimes elongated cylinders gradually narrowing to a point at one end, but hollow through the greater part of their length (Plate XI, figs. 27, 31, 32); sometimes flattened, but still hollow; and

sometimes so much compressed that their two sides meet, and the internal cavity is altogether obliterated (figs. 28, 29). In this last type, of which the dimensions are usually considerably less than the preceding, it is not uncommon to meet with two or more long narrow rods, adherent side by side, like the frustules of some Diatoms; and as the rods are usually smaller at one extremity than at the other, their direction is radiating rather than parallel (fig. 30). Their surface is marked with large pores, usually disposed with considerable regularity in a somewhat alternating arrangement; the direction of this alternation varies, however, in the different forms, being sometimes transverse, sometimes longitudinal, and sometimes oblique. Each pore in unworn specimens is surrounded by a broad, slightly prominent lip (fig. 28); this, however, is very commonly lost by attrition, leaving a large circular orifice (fig. 27). In some instances the chambers to which these pores lead only partially adhere to each other by their external walls, "junctural interspaces" being left between them, which mark (as in *Dactylopora glandulosa*) their essential dissociation.

202. *Internal Structure.*—Under whatever form *Acicularia* presents itself, its structure is always essentially the same,—an aggregation of separate chambers, more or less closely packed together. In the cylindrical forms, the cylinder may be considered to be made up of a pile of annuli resembling those of *Dactylopora annulus* in every other essential respect than this, that the chambers open on the external margin of the ring, instead of its internal margin. They are usually, however, packed more closely together vertically; and those of the successive rows alternate with each other, like the cells of a honeycomb, so that there is no space lost between them, as is well seen in cylindrical specimens of which the surface has been so much worn away that the chambers are laid completely open (fig. 32). The aspect of such specimens so strongly resembles that of the most attenuated forms of *Dactylopora cylindracea* (¶ 194), that the one type might readily be mistaken for the other, if regard were not had to the fact that in the latter there is a pore at the bottom of every one of the funnel-shaped depressions (Plate X, fig. 20 A), which does not exist in the former. In those compressed forms in which the cavity is obliterated and the two sides close completely together, the inner walls of the chambers will of course meet back to back; and the same kind of alternation in the position of the chambers of the opposite surfaces may be then observed, as is well known to exist in the cells of a honeycomb. In some of the narrowest of the rod-like forms, there are not, even at their broader ends, more than three chambers in each series, two showing themselves on one side, and only one on the other; and the alternating disposition of these gives rise to the arrangement of the pores exhibited in the upper part of the composite specimen represented in fig. 30. Towards their narrower extremities we find the pores arranged in only a single row, as shown in the lower part of the same specimen; the chambers of the two sides then alternating simply with each other.

203. *Affinities.*—It is extremely curious to trace in this type a reversion to the same fundamental plan as that on which the simplest forms of *Dactylopora* are constructed; the entire composite organism, in each case, being made up of an aggregation of separate chambers. Of the additional structure which is superinduced upon this, however, in the higher forms of *Dactylopora*, no trace whatever has yet presented itself in *Acicularia*. It is important, also, to observe that in these composite organisms we have another illustration

of the impossibility of maintaining the existence of a fundamental distinction between the Monothalamous and the Polythalamous Foraminifera. It was formerly pointed out (¶.52) that there are organisms which although *actually* monothalamous are *potentially* polythalamous: the growth of the single chamber being unlimited, like that of the animal which forms it; and nothing being required but the development of septa marking out the whole body into an aggregation of segments (which we shall see to take place in the parallel forms belonging to the arenaceous type), to convert such Monothalamia into Polythalamia. Now in *Dactylopora* and in *Acicularia* we have organisms which, though *actually* polythalamous, are *potentially* as monothalamous as the *Ovulites* to which they were likened by D'Orbigny. For although the organism, as a whole, is made up of an aggregation of chambers, yet the absence of any internal communication between these chambers, and the want of any other external connection than that which is established by the more or less complete adhesion of their walls, really place them upon exactly the same footing of mutual relationship as that which might exist among a colony of separate *Lagenæ* or *Orbulinæ* developed by gemmation from a single individual. It seems quite obvious, that, as in *Dactylopora* (¶ 189), the parts of the composite fabric must have been brought into mutual relationship by the continuity of the sarcode-body, which probably extended itself over the exterior of the shell during the whole of life, and added new chambers whenever it had the material to construct them.

204. *Geological Distribution.*—It is only, as yet, in the Eocene Tertiaries of France, that this genus has been found. It is not known to exist at the present time.

CHAPTER VI.

OF THE FAMILY LITUOLIDA.

205. The series of generic forms which there seems reason for bringing together under the family designation Lituolida, is distinguished from all other types of Foraminifera by this circumstance,—that whereas we find both in the porcellanous and in the vitreous series that the individuals of particular genera occasionally exhibit an arenaceous incrustation, this is simply an addition to the calcareous shells proper to their respective types, and is not a substitute for it,—whilst in these arenaceous types the investment of the body, although presenting the regular conformation of a calcareous shell, is really a "test" composed of an aggregation of particles obtained from external sources, the organic cement by which these particles are united being all that is furnished by the animal. The group thus constituted includes a wide range of forms, of which a large proportion have been associated, by the systematists who have treated of them, with the genera of the vitreous series to which they respectively seemed most nearly allied. But, as already pointed out (¶ 75), the affinities of the purely arenaceous types are essentially with the porcellanous series, since their animals can only put forth their pseudopodia from the terminal aperture; and they are also allied in the relatively large size of that aperture, in the mode in which the new chambers are added to the preceding even in the highest forms, and in the incompleteness of the testaceous envelope in those humbler forms which attach themselves, like *Nubeculariæ*, to the surfaces of other bodies, and are dependent upon these for part of their protection. It is not improbable that future research may add largely to our knowledge of these arenaceous forms, the special study of which has hitherto been prosecuted only by Messrs. Parker and Rupert Jones. At present they appear referable to three generic types; of which the first, *Trochammina*, starts from a rank parallel to that of *Cornuspira* in the porcellanous, and of *Spirillina* in the vitreous series, but has a much wider range of variation in form, and the cavity of which, though originally unilocular, not unfrequently becomes multilocular by the formation of imperfect septa; the second, *Lituola*, closely corresponds with *Nubecularia* in its lower adherent forms, but ranges in its higher free forms with the "spirilline" variety of *Peneroplis*, and, in the subdivision of its principal chambers presents a rude sketch of *Orbiculina*; whilst the third, *Valvulina*, presents features of approximation to certain occasionally arenaceous types of the vitreous series, not merely in a very close similarity of external configuration, but also in the primary investment of its body by a thin lamina of shell formed upon the perforated vitreous type, which is subsequently covered-in by a layer of arenaceous cement-substance, so as to be rendered actually imperforate.

Genus I.—TROCHAMMINA (Plate XI, figs. 1—10).

206. *History.*—The genus *Trochammina* was first instituted by Messrs. Parker and Rupert Jones, in 1859 (LXXVII, p. 347), as a sub-genus of *Rotalia;* on the basis furnished by the peculiar arenaceous form described and figured by Prof. Williamson (CX, p. 50, figs. 93, 94) under the designation *Rotalina inflata.* The subsequent extension of their inquiries has led them to separate it altogether from *Rotalia*, and to include in it a large series of arenaceous Foraminifera presenting very wide diversities both as to form and as to grade of development (LIV, p. 304); and it is on their conclusions that the following account of it is based.

207. *External Characters and Internal Structure.*—The principal feature that is common to all the forms of this apparently heterogeneous series, is the peculiar texture of the shell; which, although arenaceous, differs greatly from that of other genera whose shells are either partially or wholly formed by an aggregation of particles of sand. The shell consists of a dense ferruginous cement of an ochreous hue, obviously composed of an aggregation of very finely divided particles, in which are imbedded sand-grains of somewhat larger size; these last do not project above the surface, which is finished-off like a smoothly plastered wall; and thus the shell of *Trochammina* contrasts strongly with the wholly-arenaceous shells of the other genera of the same family, and with those partly arenaceous shells which sometimes present themselves in other genera (as *Nubecularia* and *Miliola*), in all of which the sand roughens the surface, its grains being larger, and the proportion they bear to the cement being greater. The simplest form of *Trochammina* (fig. 2) consists of a cylindrical tube, gradually increasing in diameter, attached by one of its surfaces, and spirally coiled, so as to bear a close resemblance in shape, on the one hand, to the cylindrical form of *Cornuspira*, and, on the other, to *Spirillina.* This form, already described and figured by D'Orbigny (XCII) as *Operculina incerta*, and by Prof. Williamson (CX, p. 93, fig. 203) as *Spirillina arenacea*, may be distinguished as *Trochammina incerta.* Now the undivided spiral tube may form a vertical spiral, instead of being complanate (fig. 3); and the resemblance it then presents to the "nucule" of *Chara* suggests the trivial designation *charoides.* In a third variety, *T. gordialis*, the tube presents in its early convolutions an irregular division into chambers; its later portion, however, is undivided, and may either continue to coil in the original plane, or may raise itself from this and pass over the earlier portion, forming loopings and twistings in various directions (fig. 4), resembling those of a *Gordius.* Again, the subdivision into chambers may become more complete, and the convolutions may assume a more regular disposition; so that the shell comes to present a series of lunate flattened chambers, several in a whorl, regularly increasing with the progress of growth, and communicating by fissures corresponding to those of *Rotalia* in position, so as strongly to resemble in general conformation the flatter varieties of *R. turbo* (fig. 1); this form may be distinguished as *T. squamata.* A still higher development on the same plan (fig. 5), gives the form already noticed as having been described under the designation *R. inflata*, which may be regarded as the highest type of this series.—But returning again to the original undivided cylindrical tube, we find that this may undergo another series of modifications, not at all less remarkable,

constituting the type distinguished by Messrs. Parker and Rupert Jones as *T. irregularis.* Thus the tube, which in this type is always adherent, and has a portion of its wall furnished by the surface on which it grows, may dilate into a large pyriform or oval chamber (fig. 6), of which also the surface beneath forms the inferior boundary, and which commonly shows a margined and semioval aperture at the opposite extremity; and before undergoing this dilatation the tube may bifurcate, so as to form another similar tube and dilated chamber. Again, from the farthest extremity of the first chamber, another tube may proceed, which again may dilate into a second chamber; this, in its turn, may put forth another that dilates into a third chamber; and thus we may have a moniliform series of ovoidal chambers, connected by cylindrical tubes, with every degree of variation as to the number of the chambers, the relative length of the tubes, and the straightness or curvature of their line of growth (figs. 8, 9, 10). This type was first observed by Cornuel ('Mém. Soc. Géol. France,' ser. 2, tom. iii, pl. iv, fig. 37), who described the moniliform series of chambers as eggs of Mollusks; but its Foraminiferous nature was recognised by D'Orbigny, who assigned to it the generic name *Webbina*, which he also applied to a few-chambered, uniserial, curved form of *Nubecularia* (¶ 87). It may undergo a further modification by an alternation in the direction in which the connecting tubes spring from the chambers; which gives to the series a loose Textularian character.

208. It is obvious from the foregoing description of the shell, that the primary form of the sarcode-body is a simple uniform cord or stolon, which may coil itself into a spiral, either horizontally or vertically, or may take upon itself any other direction; and that this primitive uniformity may give place to a differentiation of two kinds,—the spiral cord either undergoing segmentation, at intervals, by constrictions more or less complete, in such a manner as to show a tendency to the assumption of the Rotalian form,—or enlarging from time to time by the accumulation of sarcode at particular points, so as to become converted into the semblance of a string of beads, more or less closely set together.

209. *Affinities.*—The uniform undivided spiral tube which constitutes the lowest and simplest form of *Trochammina*, is obviously allied to the corresponding imperforate spiral of *Cornuspira*, the difference between them consisting simply in the material of the shell. But in the tendency of this type to attain, either by the segmentation or by the enlargement of its tube, a more or less regular multilocularity of shell, it ranges upwards in a line which may be considered parallel to *Nubecularia*, and thus comes to present a near approximation both to the simpler and to the more typical forms of *Lituola*, from both which it differs chiefly in the finely arenaceous texture of its shell.

210. *Geographical Distribution.*—We have examples of this type from all seas, arctic, temperate, and tropical; and the simpler of them are found at very considerable depths, the rotaline forms being apparently littoral, and sometimes occurring even in brackish waters.

211. *Geological Distribution.*—Simple adherent moniliform *Trochamminæ*, exactly resembling those which are met with at the present day, are found attached to the surfaces of shells occurring in the Chalk, and even in the Oxford Clay; and the spirilline forms can be traced back through the Gault and Lower Oolite (in which they abound) to the Permian deposits.

Genus II.—LITUOLA (Plate VI, figs. 39—47, and Plate XI, figs. 11—14).

212. *History.*—The genus *Lituola* was instituted by Lamarck (in the first instance, LVIII, under the designation *Lituolites*), for the reception of a minute crozier-shaped shell, common in the Cretaceous formation, which, resembling *Spirolina* (that is, the spiroline variety of *Peneroplis*) in external form, differs from it in having its principal chambers subdivided by secondary septa into chamberlets. The genus has been adopted in its original sense by D'Orbigny and most other systematists; but the recent inquiries of Messrs. Parker and Rupert Jones (LXXIX, LXXXI) have led them greatly to extend the application of this generic designation, and to bring under it a wide range of forms, which not only agree with each other in the peculiar composition of the shell, but are so closely linked together by continuity of varietal modifications in all their differential characters, as to evince the intimacy of their essential relationship.

213. *External Characters.*—The shell, in all the forms that have now to be described, is coarsely arenaceous; the particles of sand (which may be either calcareous or siliceous) being always large enough to be readily distinguished under a moderate amplification, and generally giving a very perceptible roughness to the surface. Sometimes, however, the larger particles are imbedded in a kind of mortar, which, as in the case of *Trochammina* (¶ 207), seems to be composed of finer particles, drawn from the like source, united by an adhesive exudation from the animal (Plate VI, fig. 42); and the shell is then very thick and clumsy, deriving its massiveness, however, entirely from the aggregation of foreign material, and in no degree (like the arenaceous varieties of *Nubecularia* and *Miliola*) from an abundance of the proper shell-substance. In other cases, again, the larger arenaceous particles are fitted together in a very regular manner, without the intervention either of smaller particles or of calcareous cement (Plate VI, fig. 41); so that it would seem as if the animal of *Lituola* had no power whatever of excreting calcareous matter for the consolidation of its envelope, but was altogether dependent for its protection upon its power of drawing to itself and of cementing together the materials brought to it by the ocean-waters amid which it lives. In its simplest form (Plate XI, fig. 11) *Lituola* is a mere string of suboval, plano-convex, successively enlarging chambers, more or less irregular in outline, attached by their flat side (which is usually imperfect) to the surface of shells, corals, &c.; and so closely resembling certain forms of *Trochammina*, as, like them, to have been first supposed by Cornuel ('Mém. Soc. Géol. France,' ser. 2, tom. iii, pl. iv, fig. 36) to be eggs of Mollusks. These two types, however, are readily distinguished by the texture of their shells. Very frequently this series of chambers commences in the form of a spiral coil (Plate XI, fig. 12), though it afterwards extends itself rectilinearly or irregularly; and this is the type which has received from M. D'Orbigny the designation of *Placopsilina cenomana*, under which it has been figured by Reuss (LXXXVIII). These adherent Placopsiline forms are often wild in their growth, spreading and bifurcating with great irregularity (Plate XI, fig. 14) and to a considerable extent, so as even to attain an inch in length. The spire, however, may continue to develope itself after a regular fashion, so that the shell (still adherent by its flat, and usually imperfect side) has very much the

conformation of that of *Truncatulina* (Plate XI, fig. 13). But we pass from these to a series of forms in which the shell becomes more and more symmetrical, completing itself on both sides, and at last detaching itself altogether, and assuming a regular nautiloid form (Plate VI, figs. 39, 40). This very interesting type is met with at the present time on our own coasts, and very abundantly in some northern seas; it possesses so exactly the characteristic form of *Nonionina*, that it has been unhesitatingly referred to that genus by Profs. Schultze (XCVIII) and Williamson (CX, p. 34); and yet I feel myself bound to agree with Messrs. Parker and Rupert Jones as to the place they have assigned to it, since, after a very careful examination, I have satisfied myself that the shell is altogether imperforate; and that the animal must therefore differ essentially from that of a *Nonionina*. The nautiloid spiral, moreover, frequently gives place, in the fossil forms of this genus, to a rectilineal mode of growth, so that the shell comes so strongly to resemble the "spiroline" form of *Peneroplis* as to have been mistaken for it, the *Spirolina agglutinans* of D'Orbigny (LXXIII, pl. vii, figs. 10, 11) being nothing else than a *Lituola* of which the chambers are undivided. The septal orifice, in all the foregoing varieties, is single, but varies in form from a simple, roundish passage, on the one hand to a narrow fissure (Plate VI, fig. 40), on the other to an oblong, lobed, or somewhat dendritine aperture. It varies also in position; for whilst in the "nonionine" varieties it is usually close to the inner margin of the chamber, it not unfrequently moves, even in them, towards the middle of the septal plane, at the same time becoming more crescentic (fig. 46), whilst in the straight portion of the "spiroline" variety it is commonly central.

214. From these simple varieties of conformation, we now pass to a more important modification of the fundamental type; that, namely, which consists in the subdivision of the chambers by secondary partitions, passing at right angles to the principal septa, as shown in Plate VI, fig. 44 A, which represents a specimen of the *Lituola nautiloidea* of Lamarck, partially laid open by the wearing-away of its outer layer. Now this subdivision varies so much in its kind and degree in different individuals—being most complete and regular in the largest forms, whilst it is only present in a rudimentary condition in those which are less developed, —that its existence cannot be fairly regarded as involving more than a varietal differentiation of the forms in which it occurs. The extent to which it is carried may be generally determined by an examination of the septal plane; which presents a multiplication of apertural pores corresponding to the subdivision of the chambers. It is worthy of note that in this labyrinthic variety even the secondary partitions, like the principal septa and the external wall, are formed of arenaceous material. One other remarkable variety remains to be noticed, in which the growth is rectilineal from the first (Plate VI, fig. 43), its chambers being subdivided, as in the preceding form. This is connected with the preceding by a series of intermediate gradations, in which the "nautiloid" or spiral commencement of the shell bears a smaller and smaller proportion to its straight or "nodosarian" extension, and at last comes to be altogether wanting. The septal plane is so extremely convex as to be almost conical, bearing at its summit the aperture, which is usually composite (fig. 45), or, if single, is a large dendritic fissure. This peculiar form is common in many Tertiary deposits, and also occurs in tropical seas at the present time.

215. *Affinities.*—The most intimate relationships which this type possesses, appear to be undoubtedly those by which it is connected with the other members of its own truly arenaceous family. We have seen how nearly its lower forms approximate to *Trochammina*; and we shall see that some of its higher are no less closely related to certain varieties of *Valvulina*. But it is curious to remark how many types, alike in the porcellanous and in the vitreous series, are represented as to form by the varieties of this single genus. In their attachment by one surface, the incompleteness of the shell on that side, the indefiniteness of their plan of growth, and the irregularity of aggregation of their chambers, the lowest forms present a striking parallelism to *Nubecularia*; whilst in proportion as the shell detaches itself and becomes complete on both sides, it comes to resemble in its nautiloid form and mode of growth the "dendritine" *Peneroplis*, whilst its crozier-like form is the exact parallel of the "spiroline" *Peneroplis*. The subdivision of the principal chambers by secondary partitions is an advance in grade of development corresponding with that which marks the difference between *Miliola* and *Fabularia*, or between *Peneroplis* and *Orbiculina*. In its rectilineal mode of growth, the "nodosarine" variety corresponds with the "articuline" variety of *Vertebralina*; but there is no member, either of the porcellanous or of the vitreous series, in which this plan of growth is combined with subdivision of the chambers. The types of the vitreous series represented by the several varieties of *Lituola* in plan of growth and in the form and place of the aperture, are, as we have seen, *Truncatulina* by the most regular of the attached forms, *Nonionina* by those free, symmetrical, nautiloid forms whose aperture is an elongated slit at the inner margin of each chamber, and *Nodosaria* by the straight forms with a very convex septal plane and central aperture.

216. *Geographical Distribution.*—The adherent or "placopsiline" varieties of *Lituola*, like their congeners the *Trochamminæ*, are inhabitants of our existing ocean, being chiefly brought up from considerable depths in warmer seas; the free "nonionine" forms seem to be common inhabitants of the littoral zone of northern temperate regions; the labyrinthic "nodosarine" have been obtained from the neighbourhood of Rio Janeiro, whilst the simplest forms are world-wide.

217. *Geological Distribution.*—The "spiroline" forms of *Lituola* are the earliest of which we have any knowledge; a minute and simple specimen of this having been found in the Triassic clay of Chellaston (LV). The "placopsiline" forms have been first noticed adherent to shells of the Lower Oolite; and in the Cretaceous period these come to be very abundant. It was at this epoch that the Lituoline type appears to have attained its greatest development, as we here meet with the nautiloid and spiroline forms in their greatest number, size, variety, and complexity. The "nodosarine" form first presents itself in the Miocene Tertiaries of San Domingo and Malaga, and in the Pliocene of Tuscany; in which last situation it attracted the observation of the accurate Soldani, being figured by him (C, pl. xix, fig 92 z, and CI, ii, pl. 3, fig. *cc*) under the names of *Orthoceras*, *Trochus*, and *Vermiculus*.

Genus III.—VALVULINA (Plate XI, figs. 15—26).

218. *History.*—The genus *Valvulina* was established by D'Orbigny (LXIX) to comprehend a group of multilocular shells, some fossil and some recent, which are distinguished by their turbinoid mode of growth, and by the partial occlusion of the single aperture of each chamber by a peculiar valve or tongue that projects from the umbilicus. The genus has of late been carefully studied by Messrs. Parker and Rupert Jones (LXXIX); and the account which I give of it may be considered as virtually theirs, while the illustrations of it given in Plate XI are drawn from typical specimens with which they have kindly furnished me. All the forms which they consider properly to belong to this genus are arenaceous; but several were included within it by D'Orbigny, which they consider to be varieties of *Rotalia turbo* and *R. repanda.*

219. *External Characters and Internal Structure.*—The impossibility of drawing definite lines of demarcation between even the primary groups of Foraminifera is remarkably shown in the type before us; since, although its shell is constantly arenaceous and is (for the most part) *practically* imperforate, yet it is formed on the basis of a perforated vitreous lamina, which is sometimes brought into view at the apex of the spire by the rubbing away of the arenaceous incrustation, and which also occasionally displays itself (especially in the large depressed variety) in the walls of the last-formed chambers (fig. 22), these having not yet been thickened to the same degree as the preceding by the aggregation of foreign particles. Thus in regard to the fundamental texture of its shell, *Valvulina* is obviously related to the vitreous series; and we shall see that to certain genera of that series its affinity in general characters is so close, as to render doubtful the propriety of its separation from them. But whilst the shells of those genera are often so arenaceous as strongly to resemble those of *Valvulina*, the fact that they are often entirely free from arenaceous incrustation shows the animal to possess the power of forming a regular shell of the ordinary vitreous substance; and their pores may generally, if not always, be distinguished, on a careful examination, in the intervals of the attached sand-grains; so that the exit of their pseudopodia is not interfered with. In *Valvulina*, on the other hand, the arenaceous incrustation consists not merely of sand-grains attached to the proper testaceous lamella, but, as in the case of *Lituola* and *Trochammina*, of a cement formed of very fine particles, in which larger grains are imbedded; and by this cement, wherever it is present in any amount, the perforations are so effectually closed-up, that the shell becomes actually imperforate, excepting in the wall of its last-formed chambers. Hence we have considered that the place of this genus is rather in the Sub-Order *Imperforata* than in that of *Perforata;* but it would, perhaps, be more correct to assign to it an independent position as the connecting link between the two.

220. It is more easy in *Valvulina* than in the two preceding genera to refer all the principal modifications to one central type; the *Valvulina triangularis* of D'Orbigny being the form of which the rest may be regarded as varieties. This is a triserial, three-sided, pyramidal shell (Plate XI, fig. 15), having three chambers in every turn of its spire, and presenting

on the convexity of its last chamber a large circular aperture, to which is applied a circular flap or "valve" of rather smaller diameter, so as to leave a fissure which would be completely circular but for the tongue-like process which connects the valve with the umbilical margin of the aperture. The shell may lose its trifacial compression, and assume an ordinary trochoid or conical form, without any departure from the triserial arrangement of its chambers. This form is sometimes extremely depressed, becoming so flat as to resemble a *Rotalia* (fig. 16); and its aperture is narrowed to an irregular slit (fig. 23), the valve being reduced to a slightly raised lip along its umbilical margin. Such a form has been described and figured by Prof. Williamson (cx, p. 55, figs. 114, 115) under the name *Rotalina fusca*. It is distinguished from Rotalia not only by the arenaceous character of the shell, but also by the uniformity with which each circuit of the spire is completed by three chambers, the last three being always exposed at the base of the cone. This depressed conical form attains a larger size than any other, and is the one most widely distributed. The cone varies considerably in its proportions, but always exhibits at its apex a relatively large, globular, primordial chamber, which is sometimes separated by a slight constriction from the chambers that succeed it. The preceding is often accompanied by a more aberrant variety, in which the triserial arrangement is altogether wanting; and the several chambers of which the shell is composed, failing to make even a single coil of the spire, form an obliquely semioval shell, having a broad, flat, oblique apertural plane, with a very large aperture, and a valve of extraordinary dimensions (figs. 21, 24). The crescentic fissure that surrounds the valve is crossed by numerous processes of shell, which pass from the margin of the valve to that of the aperture, and is thus converted into a series of separate passages; and the valve being itself perforated by large pores, the entire apertural surface has an almost cribriform aspect.

221. Another series of varietal forms results from the substitution of a new plan of growth for the original triserial arrangement, and the consequent entire departure in the last formed portion of the shell from the triangular form which its earlier portion exhibits. Thus, the proper "valvuline" may give place to a "bulimine" succession of chambers, the spire becoming rounded to the form of that of a *Bulimus*, and each coil being made up of several oblong, parallel segments (fig. 25). The characteristic form of valve in this variety is a tongue or flap formed by a curved prolongation of the turgid lip of the aperture (fig. 19); but this is frequently modified so as to give place to other forms, such as those represented in figs. 20, 26. In some specimens of this variety the early triangular growth is so completely masked, that it is by the presence of the valve alone that they can be distinguished from the sandy forms of *Bulimina*.—Again, the proper "valvuline" form may give place to an elongated, nail-like, or "claviform" shape; and it is on this modification, occurring not merely in *Valvulina*, but also in *Textularia* and *Uvigerina*, that D'Orbigny has founded his genus *Clavulina*. In the claviform *Valvulina* we find the primitive triserial arrangement of the chambers replaced by a uniserial, with little or no progressive enlargement of the chambers; sometimes with a marked distinction in external form, the uniserial portion being cylindrical, or nearly so (fig. 17); but sometimes with a retention of the triangular shape, which is here due to the triangular form of the chambers, the angles of which are strongly carinated (fig. 18). The mouth in either case is terminal, and is usually furnished with a regular valve (fig. 17, A). A still more aberrant claviform variety is occasionally met with, in which the uniserial

chambers are pentangular, with five prominent carinæ. And it is finally to be noticed that claviform specimens occasionally present themselves, in which the primitive triserial arrangement cannot be distinguished, so that nothing but their aperture indicates their "valvuline" character.

222. *Affinities.*—It will be evident, from what has been already stated, that if *Valvulina* is to be ranked among LITUOLIDA, it must be regarded as a very aberrant member of that family; its affinities being at least as close to the occasionally arenaceous members of the vitreous series, as they are to the typically arenaceous *Lituola*. In fact, it would be difficult to adduce a more apposite illustration of the indefiniteness that characterises the boundaries of even the primary subdivisions among Foraminifera, than that which is afforded by the singular combination of characters which this genus presents, and by the approximation to that combination exhibited by certain aberrant modifications of such genera as *Textularia* and *Bulimina*, whose proper place is unquestionably among the vitreous-shelled Foraminifera. Points of resemblance are not wanting, however, between *Valvulina* and certain porcellanous types: thus in the tendency of the spiral growth to give place to rectilinear elongation, even at a very early stage, we are reminded of the articuline elongation of *Vertebralina*; while the partial occlusion of the large aperture by a valvular flap (of which the small genus *Sphæroidina* and some varieties of *Rotalia* present the only examples in the vitreous series) is a remarkable link of affinity to *Miliola*, which is strengthened by the parallelism we have seen to be exhibited by the most developed forms attained by this valve in the two genera respectively.

223. *Geographical Distribution.*—The typical form of *Valvulina* is less common at the present time than it seems to have been at earlier periods; and the genus is now represented rather by its trochoid, clavuline, and other modifications. The former present themselves in all seas, being of smaller size and less frequency in the northern than in the southern; and it is along the Australian shores, and in shell-deposits among Coral-reefs, that we meet with the highest development of the trochoid and of the large-mouthed forms, whilst the clavuline occur not merely in the Australian but in the Indian and Atlantic Oceans, in the Red Sea, and in the Mediterranean.

224. *Geological Distribution.*—The earliest specimens of this type at present known occur in the Cretaceous period; but it is in the Eocene Tertiaries of the Paris basin that it seems to have first attained a high development, both as to number and variety of forms. It appears to have continued as a common inhabitant of the littoral zone through the successive periods of the Tertiary epoch; and the assemblage of forms presented by the Grignon deposits is almost exactly paralleled by that which may be collected at the present time near the coast of Australia.

CHAPTER VII.

OF THE SUB-ORDER PERFORATA.

225. A very large proportion of these types of Foraminifera which present themselves to general observation,—including nearly the whole of those inhabiting our own shores, with the exception of the *Miliolæ*,—belong to that division of the Foraminifera which is characterised by the possession of a shell perforated by tubular openings for the exit of pseudopodia. The reasons already specified (Chapter III) appear to justify us in ranking this division as a Sub-Order, equivalent in value to the "imperforate" division (¶ 75); but whilst the subdivision of the latter into families may be very naturally based on the differences in the material of the shell, no such characters are available in the present case, the shell being everywhere calcareous, and being composed of *vitreous* or *hyaline* substance, except in a small group in which it is occasionally, but not essentially, arenaceous. Notwithstanding the very close resemblance in external form and in general plan of growth (sometimes amounting to absolute *isomorphism*), which often presents itself between the members of the "porcellanous" and of the "vitreous" series (¶ 67), there is no real gradation between them. Such a gradation does exist, however, between the "arenaceous" forms of the PERFORATA and the IMPERFORATA respectively; for whilst, as we have just seen, it may be doubted whether *Valvulina*, in spite of the essentially arenaceous composition and imperforation of the external test in its fully developed condition, should not rank among the former in virtue of the perforated hyaline layer of shell which immediately covers its sarcode-body, there seems almost equal reason for ranking among the latter some of those *Textulariæ*, in which the pores, large and distinct as they are in the original shell, seem entirely blocked-up by arenaceous incrustation.

226. But although we do not find in this Sub-Order any such well-marked differences in the material of the shelly envelope, as those which serve to characterise the families of the Imperforate series, yet it does not seem very difficult to group its diversified forms around certain principal types, so as to assemble them into Families, of which the members are recognisable by their mutual relationship, and by their essential dissimilarity (except in the border forms) to those of other groups of equal rank. It is not possible, in the present state of our knowledge, to separate these families by precise definition; for they are so connected with each other by intermediate forms, that any definition which should be founded upon the

characters of the central types would have to be so greatly modified for the comprehension of the peripheral, as to lose all its precision. And all that can be here attempted will be to point out what seem to be the typical peculiarities of each group, and to trace the shading off of these as we pass in different directions from its central type towards the most aberrant modifications which it may present.

227. Starting in the first instance, as in the Imperforate series, from the *monothalamous* forms, we find among these a diversity of shape scarcely inferior than that which we have seen to exist between *Gromia*, *Squamulina*, *Cornuspira*, and *Trochammina*. For in *Orbulina* we have a perfect sphere, not only devoid of any projection whatever, but very commonly destitute of any principal aperture; in *Ovulites*, an egg-shaped spheroid, with an aperture at each end; in *Lagena*, a spheroidal body drawn out at one extremity into a projecting neck, at the end of which the aperture is situated: whilst in *Spirillina* the chamber consists of a very elongated tube, regularly coiled in a flat spiral. There is a yet greater difference, however, in the texture of these shells, than in their external form; for the substance of that of *Lagena* is very finely tubular, whilst that of all the others is coarsely porous; and the surface of *Lagena* is almost invariably rendered uneven by regular longitudinal costation, or by some other kind of symmetrical ornamentation, of which we scarcely find any traces in the others. Moreover *Lagena* is distinguished by the peculiarity of its aperture, which is very regularly circular, and has an everted lip, whose inner surface is commonly marked by radiating fissures.

228. Now it is not difficult to find a series of generic forms which naturally build themselves up (so to speak) on the basis of the fundamental type presented by *Lagena*. For if a new lageniform chamber be added by gemmation to the extremity of its predecessor, and this process be repeated indefinitely in a rectilineal direction, we have a *Nodosaria*,—a type which is characterised, like *Lagena*, by the finely tubular structure of its shell, by its central radiating aperture, and by its peculiar ornamentation; whilst a similar gemmation, repeated along a bent axis, will give rise to a series of forms, more or less curved, but possessing the same essential characters, bringing us at last to the flattened and symmetrical spiral of *Cristellaria*. On the other hand, an oblique alternating gemmation will give us the biserial *Polymorphina* or the triserial *Uvigerina*; both of which types are manifestly related to *Lagena* in their essential features, notwithstanding their striking isomorphism with *Textularia* and *Valvulina* respectively.—Now of the three principal families under which we shall range the members of the Perforated series, that to which we give the name of LAGENIDA is unquestionably the one which presents the nearest approximation to the Imperforate; for we shall find that, notwithstanding the elaborate condition of its shell, even its highest forms agree with the latter, rather than with the more elevated types of the former, as to the mode in which the segments are united each to the preceding (¶ 62), and in the absence of any trace whatever either of "intermediate skeleton" or of "canal-system" (¶ 63).

229. If, on the other hand, we take *Orbulina* as our starting point, and look for its nearest alliances in the perforated series, we shall have no difficulty in fixing upon *Globigerina* as its connecting link with higher types: the polythalamous shell of that genus being formed

by an aggregation of globular segments that are united to each other by external adhesion only, each segment possessing its own separate aperture. The shelly walls of the segments are composed of a coarsely porous substance, having little or no surface-ornamentation; and the aperture which leads to their cavity is a simple fissure, usually crescentic in form, without either prominence or lip. Now this simple "globigerine" type may develope itself, as we shall hereafter see, into a very remarkable form (*Carpenteria*), in which, without any departure from the essential characters of the original, a high degree of complexity is superinduced by the enlargement and sub-division of the later chambers (which completely include the earlier growth), and by the peculiar provision that is nevertheless made for the maintenance of the direct communication between each chamber and the exterior. But whilst this is, so to speak, a lateral offset, the tendency to a really higher elevation shows itself in the more intimate union of the chambers, which no longer have separate external apertures, but open sequentially, each into the one that succeeds it, the last alone having an external aperture. Now such a series of globigerine chambers, budded forth alternately on the two sides of a linear axis, becomes a *Textularia*; whilst if the succession follows the course of a spire resembling that of a *Bulimus*, a *Bulimina* is formed. These types accord closely with *Globerigina* in the characters of their individual segments; and their low grade of development is marked, like that of the *Lagenida*, by the incompleteness of the posterior wall of the new segment whenever the anterior wall of its predecessor can be used to complete the enclosure of the chamber, and by the entire absence both of "intermediate skeleton" and of "canal-system." Yet in some large forms of *Textularia* we find—as in *Carpenteria*—a partial subdivision of the chambers into chamberlets, which is decidedly a character of elevation; but there is no further progress in that direction, such forms marking the culmination of the Textularian type.

230. Reverting again to *Globigerina*, we see in the turbinoid plan on which its chambers are disposed an obvious foreshadowing of the turbinoid spire which is the essential characteristic of the *Rotalian* series; so that nothing more is needed to convert a *Globigerina* into a *Rotalia*, than that its chambers shall open successively each into the next, the last alone opening externally. We shall find ourselves required, by the absence of any natural lines of demarcation, to group together, under the generic name *Rotalina*, a series of forms that present very wide diversities in grade of development; the simplest presenting but a slight advance upon *Globigerina*; whilst the most elaborate exhibit the special features of the perforated series—namely, the double septum between the chambers, the intermediate skeleton, and the canal-system—in a highly characteristic aspect; the last two of these peculiarities being nowhere more conspicuous than in *Calcarina*, which is little else than a modified *Rotalia*. But whilst the development of the central stem thus takes place on the original type, that of the branches or offsets may follow a very different course. Thus there are low forms of *Rotalia repanda*, whose spire is so much flattened out, and whose chambers are so greatly elongated, that they come to resemble what a *Spirillina* would be, if its one continuous vermiculate chamber were partially divided by transverse constrictions. In some of these we find a tendency to the obliteration of the regular spiral mode of increase by a "wild" growth of the marginal chambers; but this substitution of an indefinite for a definite plan is more characteristically seen in the *Planorbuline* forms, which, commencing on the regular Rotalian

plan, are subsequently augmented, not only by the addition of new chambers to the whole margin of the spire, but also by a piling-up of similar chambers on its upper surface. In these *acervuline* forms there is no advance upon the simple Globigerine character of the individual segments; but we often find the surface of the aggregate mass remarkably modified by exogenous deposit. A still greater departure from the Rotalian plan of growth, without any considerable modification of the characters of the individual segments, presents itself in the highly composite organisms which will be described under the generic names *Tinoporus* and *Polytrema;* and in the former of these we shall meet with a development of the intermediate skeleton and of the canal-system, which curiously repeats in that acervuline type the like development which converts a *Rotalia* into a *Calcarina*.

231. Between the simplest and the most complex of the foregoing types, there is a continuity not less complete than that which we have seen to exist between the successive types of the porcellanous series; and since we nowhere find in the structure of the individual segments any considerable departure from the characters presented by those of the *Globigerina* which we took as our starting-point, we shall designate the entire series by the title of GLOBIGERINIDA.

232. Our third family contains those types of Foraminifera, the peculiar specialization of whose structure entitles them to the highest rank in the group, whilst their comparatively large size and extraordinary multiplication at the early part of the Tertiary period give them a place of no mean importance as members of its Fossil Fauna. Not being able satisfactorily to trace this family upwards from an elementary type to its most elaborate forms (although it is not without relations even to the lowly *Globigerinæ*), we shall find it more convenient to group its various members around a type which presents its characteristic features in their fullest development; and we select for that purpose the genus *Operculina*, which is characterised by the dense tubular texture of its shell, replaced in certain spots by still harder non-tubular substance, which often forms tubercles or ridges on the surface; by the symmetry of its spire; by the complete investment of the earlier convolutions by the later: by the narrow fissured aperture at the inner margin: by the complete enclosure of each segment in its own wall, causing a duplication of the septal lamellæ; and by the interposition of an intermediate skeleton and highly complex canal-system. All these characters present themselves equally in the genus *Nummulina*, with the addition (in the most characteristic forms of that type) of a set of chamberlets, derived from the alar prolongations of the principal chambers, between the successive turns of the investing portion of the spiral lamina. By the subdivision of the principal chambers into chamberlets, *Operculina* is modified into *Heterostegina;* and by the substitution of the cyclical for the spiral plan of growth, *Heterostegina* is converted into *Cycloclypeus*. So far as the metamorphic condition of the shell of *Fusulina* allows me to judge, it seems to have belonged to the Operculine type; its chamberlets being disposed around a longitudinal axis, instead of in a complanate spire, so as to give it the same relation to *Heterostegina* that *Alveolina* bears to *Orbiculina* (¶ 151). Again, the interposition of secondary chamberlets (as in the reticulate Nummulites) between the lamellæ of shell by which the disk of *Cycloclypeus* is successively overlaid, would convert it into *Orbitoides:* a type which, though now extinct, formerly rivalled *Nummulina* in importance. All these types closely

accord with each other in every point which concerns the characters of the individual segments, and differ only as to the plan in which those segments are disposed. Now, in *Amphistegina* we find the spire unsymmetrical, and the general development inferior, so that a certain approximation is presented to the Rotalian type. In *Polystomella* the texture of the shell is far inferior in density, and the spire is much simpler; but this type is remarkable for the large amount of exogenous deposit with which the proper walls of its chambers are overlaid, and for the extraordinary development of the canal-system provided for its nutrition. By the simpler or "nonionine" forms of this type, we seem carried down towards the Globigerinæ; the connecting link being afforded by the genus *Pullenia*, which presents a strong resemblance to the former, but seems essentially related to the latter.

Such is the grouping which seems most consistent with the present state of our knowledge of this important division of the Foraminifera. That it may hereafter require modification with the advance of knowledge, is by no means improbable; but it may be affirmed with considerable confidence that the principles on which it is founded are correct, and that alike in the affinities it indicates, and in the separations it establishes, it is a fair interpretation of the most important facts which a careful study of Nature has up to this time disclosed.

CHAPTER VIII.

FAMILY LAGENIDA.

232. A more marked example can scarcely be found of the contrast between the results of the system of classification adopted by M. D'Orbigny, and those of the method followed in the present work, than is presented by their respective modes of dealing with the members of the group here brought together under a designation indicative of their essential relationship to that minute Monothalam, which (as we have just seen) is one of the simplest forms of the "vitreous" series of Foraminifera. It may be freely admitted that no set of characters can be framed, which should equally apply to all these organisms, and should differentiate them from all other Foraminifera; but they will be found to be mutually connected by a strong family likeness in the most essential characters,—those, namely, which are most indicative of the physiological condition of the animal; and whilst we find one or other of these to be shaded off, so to speak, as we pass from each generic type to the next, the persistence of other features no less characteristic leaves no reasonable ground for doubt. Throughout the group we find the hyaline or vitreous shell-substance to be possessed of great hardness, and to be perforated by tubuli of extreme fineness; in young and feebly developed examples it is very thin and of almost glassy transparency; but in older specimens, if well developed, it is overlaid by superficial deposit, which in general not only adds to its thickness, but rises into exogenous growths, having the form either of tubercles, of prickles, or most commonly of linear *costæ*, which almost invariably run in a longitudinal direction, that is, parallel to the axis of the shell. These exogenous growths, not being perforated by tubuli, have an aspect that differentiates them from the general surface of the shell. The small circular aperture is situated in the centre of the septal plane, which is more or less prominent, and is sometimes prolonged into a tube; and it usually has an everted lip, divided by radiating fissures into denticulations. These characters are presented in their highest development by *Lagena*; and we shall see (¶ 239, 253) that so perfect a transition exists between that Monothalam and the polythalamous *Nodosaria*, as renders it impossible to doubt the close affinity of these two forms. From the rectilineal *Nodosaria*, through the gently curved *Dentalina* and the more strongly curved *Marginulina*, we are led, in a series so perfectly gradational as to forbid lines of demarcation from being anywhere drawn across it, to the spiral *Cristellaria*, which may be regarded as the highest manifestation of the lagenoid type. From this central

stem we find a set of offsets more or less divergent, presenting modifications of the typical characters on which generic distinctions have been founded, but which we cannot recognise as of higher than varietal importance.

233. Now it is to be observed that notwithstanding the large size and high development attained by many *Nodosariæ* and *Cristellariæ*, their plan of structure is so simple as to bear a stronger resemblance to that of the porcellanous series, than to that of the higher types of the vitreous. For each segment is simply joined on to the preceding, in such a manner that the posterior wall of the last segment is formed by the anterior wall of the penultimate; the septal plane of each segment is only that portion of its ordinary wall which is destined to be included by the next addition, and is not differentiated in structure from the rest; and the septa dividing the successive chambers are consequently not double but single. Hence there is not in this type any vestige of an "intermediate" skeleton, notwithstanding the extraordinary amount of "supplemental" deposit which forms the exogenous growths from the surface of these shells; and we find no trace whatever of any canal-system. Notwithstanding, therefore, the strong resemblance in plan of growth between *Cristellaria* and certain members of the *Operculine* series, there is a diversity in the most important features of their structure, which is quite sufficient to mark their essential distinctness.

234. Throughout the series which begins with *Nodosaria* and ends with *Cristellaria*, we trace the same characters of shell-substance, the same forms of surface-ornamentation, the same position of the aperture (modified only in appearance by the curvature of the axis), and the same tendency to radiation at its margin,—the eversion of the lip, however, being for the most part wanting. In *Orthocerina*, with the same uniserial arrangement of the chambers, we have an absence of radiation at the margin of the aperture, its form and position remaining normal; whilst the disposition of the exogenous growths resembles that of the preceding. In *Polymorphina*, on the other hand, the affinity to the lagenoid type is chiefly indicated by the central position of the aperture and by the marked radiation of its margin, as well as by the occasional existence of a tubular neck; the external ornamentation is so far obsolete as to be no longer characteristic; and the plan of growth is biserial. In *Uvigerina*, whose plan of growth is triserial, the radiation of the aperture is wanting; but its lagenoid nature is marked by its elongated neck and somewhat everted lip: whilst the ornamentation of the surface of the shell is highly characteristic.

235. In the classification of M. D'Orbigny, the closely-allied genera of this family are distributed under *four* different Orders, as follows:—

I.—Monostègues. Lagena.

II.—Stichostègues. Glandulina, Nodosaria, Orthocerina, Dentalina, Frondicularia, Lingulina, Rimulina, Vaginulina, Marginulina.

III.—Hélicostègues. Cristellaria, Flabellina, Robulina, Uvigerina.

V.—Énallostègues. Dimorphina, Polymorphina

The dissociation of closely-allied types, and the approximation of types altogether distinct, which result from the adoption of this scheme (and which do not less show themselves in the modification of it proposed by Prof. Schultze, XCVII) will become apparent as we proceed. The following arrangement of the genera is here offered as more truly representing their real relationship:—

FAMILY LAGENIDA.

LAGENA.

Orthocerina

Uvigerina — *Nodosarina.* — *Polymorphina*

Lingulina	Nodosaria	Glandulina
	Dentalina	
	Vaginulina	
Rimulina	Planularia	Frondicularia
	Marginulina	
Robulina	Dimorphina	Flabellina
	Cristellaria	

Taking *Lagena* as the primary form, it is shown to pass directly into *Nodosarina*, under which generic designation are brought together (for reasons to be stated hereafter) no fewer than *thirteen* forms which have been differentiated as generic by D'Orbigny. Of these, the seven which are ranked in the central column differ from each other only in the straightness or curvature of their axis of growth, the transverse or oblique direction of their septa, and the centricity or excentricity of their aperture. The three in the right hand column differ from the preceding in the mode of setting-on of the chambers; and the three in the left hand column have been differentiated on account of the form of their apertures. The genera *Polymorphina* and *Uvigerina* being related to *Lagena* in their essential characters, but differing from each other and from *Nodosarina* in their respective plans of growth, have positions assigned to them that are in harmony with their mutual affinities. The small genus *Orthocerina* may be considered as a connecting link between *Lagena* and the simplest conditions of *Uvigerina*, with relations of its own to *Nodosarina*.

Genus I.—LAGENA (Williamson, Figs. 5—32).

236. *History*.—The minute flask-shaped Monothalamia which have received from D'Orbigny the designation *Oolina*, had been so long previously recognised and distinguished, that it would be an act of great injustice to abandon without good reason the name originally given to them. An example of them was figured by Soldani (C, CI) under the inappropriate designation *Orthocera perfecte globularia*; but it was by Walker (IX) that attention was first particularly directed to them, several distinct forms having been figured under the generic

name *Serpula*, with *Lagena* appended in brackets, apparently as a sub-generic name. The designation *Vermiculum* was given to these by Montagu (LXV); but some subsequent writers on British shells went back to the comprehensive term *Serpula;* whilst others modified Walker's *Lagena* into *Lagenula*. The peculiar modification of this type which consists in the introversion of the flask-shaped neck (an example of which had been figured by Walker) was distinguished by Ehrenberg under the generic name *Entosolenia*. It was not until 1839 that this type was noticed by M. D'Orbigny; and he seems to have remained in entire ignorance that it had been previously described; no allusion being made in his latest enumeration of the genera of Foraminifera (LXXIV) to the Monograph of the genus *Lagena* published some years previously by Prof. Williamson (CVI), in which Walker's original generic name was restored, and the question of the value of specific distinctions in this group first treated (as I have already had occasion to observe, p. 9) in a truly philosophical spirit. The identity of *Oolina* and *Lagena* has been noticed by Pictet ('Paléontologie,' tom. iv, p. 483); who has not, however, substituted the original designation for that of D'Orbigny.

237. *External Characters, and Internal Structure.*—The typical *Lagena* is a minute globose shell with a prolonged neck and terminal aperture, very much resembling a Florence flask. It is frequently elongated, however, into an ovate form, and may even be pointed at its posterior extremity, being at the same time so much narrowed as to become fusiform in shape. In some of the slenderest forms there is a tubular aperture at each end; and such are occasionally somewhat bent. Like the *Entosolenia* figured by Prof. Williamson (CX, fig. 32 *a*) these are perhaps to be regarded as "double monsters." The aperture at the extremity of the neck is surrounded by a thickened rim; this is frequently notched or denticulated so as to form a set of radiating fissures; and sometimes the central portion of the aperture is filled up by a plug of calcareous matter. There is a large fossil *Lagena*, in which the neck has secondary tubular apertures arising from it laterally and almost at right angles to the main tube. The surface is sometimes smooth, but is more frequently marked with elevated *costæ*, which usually spring from the centre of the posterior extremity, and extend in a meridional direction towards the neck, sometimes, however, proceeding no further than the equator (CX, figs. 5—14). These costæ vary greatly in number as well as in length; when they are fewest they are usually most prominent; and when most numerous they are so closely approximated as to give a fluted character to the surface. They are distinguished, moreover, from the general surface, not merely by their prominence, but by their more glistening aspect: and this results from the fact that whilst the substance of which the shell generally is composed is finely tubular, that of the *costæ* is destitute of tubuli. In the strongly costated forms the tubuli are generally disposed in rows parallel to the costæ; and sometimes they are limited, like the costæ, to the posterior portion of the shell. There is seldom in the typical *Lagenæ* any considerable anastomosis of the costæ, though traces of it are sometimes observable.—The length of these little shells is generally between 1-45th and 1-100th of an inch.

238. The apertural tube or neck is sometimes prolonged internally instead of externally; and on this introversion the genus *Entosolenia* has been founded. The propriety of this distinction, however, was questioned in the first instance by Prof. Williamson (CVI), and still more strongly by Messrs. Parker and Rupert Jones (LXXXI), who have finally (LXXVI) come

to the conclusion that it cannot be maintained as of even specific value, on account of the variability of the degree of the introversion. It may be so complete that none of the neck appears externally, the shell having a nearly globular form, and the tube reaching almost to the posterior extremity of its cavity. On the other hand it may be so partial that the greater portion of the neck is extruded; and between these two extremes there are numerous intermediate gradations (cx, figs. 16*a*, 22, 25—28). In the entosolenian as in the ectosolenian forms, there is sometimes a tube at each extremity; and occasionally there is a second internal tube attached to the side of the principal.—The entosolenian form presents a yet greater variety of external ornamentation than the ectosolenian; for not only do we find the surface marked with longitudinal costæ, but these costæ may be connected by transverse bars, so as to cover the shell with a regular division into quadrangular areolæ; and this may give place to a hexagonal areolation, which may be of various degrees of fineness (cx, figs. 17, 18, 29—32). In certain cases the globular or ovate form gives place to one more or less compressed; and each margin is then usually elevated into a *carina* or keel. In a curious variety noticed by Prof. Williamson (cx, p. 11, fig. 24) the marginal carina contains numerous small detached cavities like microscopic water-bottles with straight necks, each of which opens by a minute aperture at the outer edge of the carina. In these compressed marginate forms the tubuli of the shell usually open for the most part in a broad band along the marginal ridge, although occasionally they are scattered sparsely over the whole surface. In these forms, moreover, the introverted apertural tube does not project axially into the cavity of the shell; but follows the curvature of, and is in contact with, one of its lateral walls, in some cases coalescing with it so that the tube is only complete on one side, the other side being formed by the shell-wall; and sometimes its direction is more or less sinuous.—The length of the Entosolenian variety is usually between 1-70th and 1-160th of an inch, corresponding closely with that of the typical *Lagena* when allowance is made for the introversion of the neck.

239. *Monstrosities.*—Besides the departures from the typical form which have been already noticed, an abnormality occasionally presents itself in this genus, which is of much interest, as showing how gradationally it passes into the polythalamous forms of the same family. Specimens are of no unfrequent occurrence, in which a superadded segment is attached obliquely to the side of the original one; but now and then it happens that the additional segment is formed in the axis of the original one, so as to imitate the mode of growth of *Nodosaria*. Sometimes the nature of such specimens may be decided by their surface ornamentation; their lageniform character being marked by a reticulation never presented in the Nodosarine group. But if the markings consist of a simple costation or furrowing, such as is common to both types, the decision may be difficult; as is the case with certain specimens found in the Tertiary sands of Bordeaux, rich in *Lagenæ* and small *Nodosariæ*; which specimens, being two-celled and furrowed, may be considered either as young individuals of *Nodosaria longicauda*, or as monstrosities of *Lagena sulcata* (Parker).

240. *Affinities.*—In the general simplicity of its structure, *Lagena* is related to *Orbulina*; differing from that type, however, in the possession of a single definite aperture and of the prolonged neck on which it is situated, as well as in the more elaborate structure and ornamentation of its shell-substance. On the other hand, *Lagena* is so intimately related to certain

forms of *Nodosarina*, that they might readily be taken either for their young, or for fragments of them accidentally disjoined; and D'Orbigny states that he actually regarded them in this light, until he found *Lagenæ* abounding in localities from which *Nodosaria* was altogether absent.

241. *Geographical Distribution.*—This generic type appears to be pretty widely diffused; having been found in marine sands from the coasts of Great Britain and Norway, Bombay, Singapore, Australia, and Patagonia; and also in dredgings from great depths. Generally speaking, the largest and most strongly marked *Lagenæ* are found at an average depth of about fifty (twenty-five to seventy-five) fathoms; the more delicate varieties being either from shallower or from deeper water.

242. *Geological Distribution.*—Large examples of *Lagena* present themselves in the upper Chalk of Maestricht: but this type does not commonly present itself until the Tertiary period, when it is met with abundantly in the Grignon and Bordeaux beds; also in certain Eocene and Miocene beds of Germany. It occurs, but not abundantly, in the Vienna basin, in the Sub-Apennine beds, at Baltjik, and in San Domingo. It is very large in the Crag of Suffolk; and it abounds in the Post-Tertiary clays beneath the fens of Lincolnshire.

Genus II.—NODOSARINA (Plate XII, figs. 1—7; and Williamson, figs. 33—67).

243. Under the generic designation *Nodosarina* an extensive series of forms will here be reunited, which have been grouped by D'Orbigny and the systematists who adopt his views, not only under several distinct genera, but under three different Orders. The propriety of this reunion has been insisted upon by Messrs. Parker and Rupert Jones on several occasions (LIV, LV, LXXVI, LXXVIII); and although in adopting their views on this point I am chiefly influenced by my knowledge of the thoroughness with which this group has been studied by them, yet I feel it right to state at the same time that the results of my own observations, so far as they go, are so completely confirmatory of theirs, as to leave in my mind no doubt whatever as to the correctness of their conclusions. Moreover the extraordinary tendency to variation which is exhibited by some of the commonest forms of this type, has been recognised by several of the ablest systematists who have treated of it, such as Linnæus, Fichtel and Moll, and Williamson; the group being one in which, as in *Miliola*, it is easy enough to establish generic differences when only a few strongly marked types are contrasted, whilst it becomes more and more difficult to maintain these, in proportion to the number of individuals compared, until at last the difficulty amounts to an impossibility.—It will be convenient, for the sake of avoiding repetition, to state *in limine* that we regard as the two extreme forms of this type the straight rod-like *Nodosaria* and the spirally-coiled *Cristellaria*; the remainder either forming part of the series by which one of these continuously graduates into the other, or being (so to speak) offsets from some part of that series distinguished by some peculiar varietal modification.

244. *History.*—Although the generic designations *Nodosaria* and *Cristellaria* were first introduced by Lamarck (LIX), yet numerous organisms of the type now before us had been

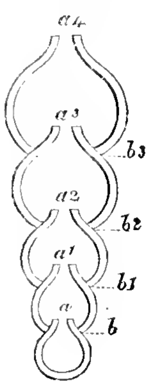
described and figured under other names by preceding systematists. Thus Linnæus (LXIII), under the all-comprehensive designation *Nautilus*, enumerated as distinct species no fewer than seven Nodosarian forms and one Cristellarian; pointing out in regard to the latter its special tendency to pass into varieties. Some of the Nodosarian forms were figured and described by Soldani (C, CL) under the designation *Orthoceratia*; while some examples of the Cristellarian were ranked under *Nautilus*, and others under *Lenticula*. Of the varietal forms of *Nautilus* (*Cristellaria*) *calcar* noticed by Linnæus, *seven distinct species* were made by Walker and Montagu (LXV). These varieties, however, with many more, were brought together again by Fichtel and Moll (XLV), who showed the same right appreciation of the value of subordinate differences in regard to this type, that they displayed with respect to others. Precisely the opposite line was taken, according to his wont, by De Montfort (LXVI), who made from the varieties of *Cristellaria calcar* no fewer than *thirteen new genera*, only one of which has been accepted by later systematists. Besides introducing the generic names *Nodosaria* and *Cristellaria*, Lamarck (LIX) revived the name *Orthocera* as the designation of certain Nodosarian forms, and applied the term *Lenticulites* to one of the varieties of *Cristellaria calcar*; his idea of the real nature of the genera which he created being so vague, that he assembled under the term *Cristellaria* examples of the genera *Peneroplis*, *Polystomella*, *Rotalia*, and *Planorbulina*, in addition to true *Cristellariæ*; whilst under *Nodosaria* he actually placed a *Serpula*. The genus *Frondicularia* was created by Defrance (XXIX); and he also erected two of the varietal forms of *Cristellaria* into the genera *Planularia* and *Saracenaria*, of which the former was for a time adopted by D'Orbigny, whilst the latter was adopted by Blainville (VI), who also adopted two of De Montfort's genera, *Oreas* and *Linthuris*, and added another of his own, *Crepidulina*. It was by D'Orbigny, however, that the greatest number of those generic distinctions were invented, which have passed into currency on his authority: his original 'Tableau Methodique' having included *Glandulina*, *Dentalina*, *Lingulina*, *Rimulina*, *Vaginulina*, *Marginulina*, *Robulina*, and *Dimorphina*, together with others which he subsequently abandoned, in addition to the *Nodosaria*, *Orthocerina*, and *Cristellaria* of Lamarck, and the *Frondicularia* of Defrance. The genus *Flabellina* was added to the foregoing in 1839 (LXXI). Of these, thirteen were ranked in his order *Stichostègues*, their line of growth being either straight or slightly curved: three as belonging to the *Hélicostègues*, their growth always commencing in a spiral, though it does not always continue on the same plan; whilst one is disjoined from its congeners and referred to the order *Enallostègues*, because in its early growth its chambers seem to alternate on three sides of a central axis. It is acknowledged by M. D'Orbigny (LXXIII), however, that between *Marginulina*, the last genus of his *Stichostègues*, and *Cristellaria*, the first genus of his *Hélicostègues* there is "un passage évident:" the most curved forms of the one passing into the least curved forms of the other: and Prof. Williamson (CX, p. 25) has expresssed himself as unable to separate these two genera; remarking that the *Cristellaria Berthelotiana* of D'Orbigny "has no greater curvature than his *Marginula Webbiana*; and in like manner his *C. cymboides* has even a smaller one than his *M. pedum*, or than occurs in numerous other species of the same genus." "The variations of the two English species of *Cristellaria*," he continues, "satisfy me that the characters which distinguish *Cristellaria* from *Marginulina* are insufficient to be specific, much less generic ones." So, again, Prof. Williamson (p. 22) expresses his conviction that the genus *Vaginulina* of D'Orbigny is not really distinguishable from *Dentalina*: the characters by which he differentiated it being presented by mere varieties of the British *D. legumen.* And he does not seem more inclined to retain the genus *Robulina,* which is founded on varietal forms of *Cristellaria.* Thus we see that, in so far as he had the opportunity of making a sufficiently extensive comparison of these protean forms, he was led to conclusions of the same kind as those here advocated on the basis of a more comprehensive study of them. In no group is the artificiality of M. D'Orbigny's method of classification more apparent; and there is none in which the results of painstaking research have been more fruitful in elucidating the close natural affinities of organisms, whose diversity of form at first sight appears to require their wide separation from each other.—It will be convenient in the first instance to describe the typically *straight* and the typically *spiral* forms of this genus; and then to notice the intermediate links by which the two are connected, and the chief varietal modifications which diverge from them in different directions.

245. Nodosaria: *External Characters.*—The elongated shell of this organism consists of a series of segments joined end to end in a straight line; these segments sometimes exhibit a progressive increase, so that the entire shell has somewhat of a conical form; whilst in other cases each segment has the same diameter as the preceding, so that the general form of the shell is cylindrical; and it occasionally happens that the middle segment is larger than those which precede and follow it, or even that the primary segment may be the largest, and that the size of the succeeding segments progressively diminishes. The primordial segment is often furnished with a more or less prolonged *mucro.* The segments are marked externally by more or less definite constrictions, which are transverse to the axis of growth; sometimes these constrictions are simple bands, the successive segments being in contact with each other over the whole of their septal planes (cx, figs. 36, 38); whilst in other instances the segments are nearly globular in form and are connected together by narrow necks, so that the entire series looks like a string of beads (Plate XII, fig. 2). That such differences have no specific value, is fully proved by the fact that they occasionally present themselves in the several segmental divisions of one and the same individual. The septal plane is circular, and the aperture occupies its centre: that of the last segment is sometimes situated at the extremity of a long neck resembling that of a *Lagena,* and is surrounded by a row of triangular denticles (cx, figs. 36, 37); but the margin is usually rather inverted than everted, and such a broad, smooth lip as is common in *Lagena* and in *Uvigerina* is rare in this type. Although the surface is sometimes smooth, yet it is more frequently rendered uneven by longitudinal flutings or ribbings (cx, figs. 36—38), or by the projection of numerous spines from every part of the exterior (Plate XII, fig. 2). The number and degree of these inequalities are extremely subject to variation; sometimes the costæ or spines do not show themselves equally on all parts of the shell, and they are generally stronger on old than on young individuals.—The large *Nodosariæ* of the Sub-Apennine tertiaries sometimes attain a length of more than an inch; but the recent forms are far smaller, few of them much exceeding 1-10th of an inch in length.

246. *Internal Structure.*—When the shell of *Nodosaria* is examined by sections taken in various directions, it is found that the greater part of it is penetrated by tubuli of extreme minuteness, which pass directly from the interior of the chambers to the external surface; these tubuli, however, do not extend into the costæ or the spines, which are everywhere composed of

an apparently homogeneous shell-substance. In those forms which have the segments closely applied one to the other, the outer wall of each chamber partly invests the outer wall of the preceding, and the invested portion serves as the septum between the two (Fig. XXX). This septum has the ordinary structure of the outer wall, and is not differentiated from it by being non-tubular, as is ordinarily the case in other shells of the *vitreous* series; a point, as we shall presently see, of some consequence in regard to the position of the aperture in *Cristellaria*. The apertures a, a^1, a^2, a^3 between the successive segments correspond precisely in form and position with that of the last segment a^4 which is seen externally.

Fig. XXX.



247. Cristellaria: *External Characters*.—The typical form of this organism may be considered as a nautiloid spiral, each whorl of which has its chambers extended by alar prolongations so as to reach the centre, and thus entirely to enclose the preceding whorl. The number of chambers in each whorl is much smaller than in most other nautiloid Foraminifera, being seldom more than eight or nine, and often less. The division of the chambers is always strongly marked externally by septal bands, which are sometimes elevated into continuous ridges, sometimes into rows of tubercles, whilst sometimes on the contrary they are depressed; but they are always differentiated by their peculiar appearance from the ordinary surface of the shell. The direction of these septal bands is somewhat oblique to the axis of the spire; and they are generally convex anteriorly (cx, figs. 52—54). They meet in the umbilicus, which is usually raised into an elevated tubercle. The margin of the shell often rises into a sort of keel or *carina*, which may even be extended into a *cultro* or knife-blade projection; and sometimes this gives off a variable number of radiating prolongations (Plate XII, fig. 3), as in the form distinguished as *C. calcar*. The surface of the segments between the septal bands is sometimes regularly marked by ridges passing in the direction of the axis of growth, so as precisely to correspond with those of *Nodosaria*, as in the *Robulina ariminensis* of D'Orbigny; whilst it is sometimes studded with little spinous tubercles, as in the *R. echinata* of D'Orbigny; and the one condition may give place to the other in different segments of the same shell, as is shown in Plate XII, fig. 3. The form of the septal plane is sagittate (Plate XII, fig. 3); and the aperture, which exactly resembles that of *Nodosaria*, is situated at its extreme point, so as to be at the outer margin of the convolution. When the shell is looked at laterally (Plate XII, fig. 3), however, it is seen that the aperture is really situated nearly in the centre of the anterior wall of the last segment, as in *Nodosaria*. —The diameter attained by the fossil *Cristellariæ* of the Sub-Apennine Tertiaries occasionally exceeds 1-5th of an inch; the recent examples of this type, however, are usually far smaller, the diameter of the British specimens not usually exceeding 1-15th of an inch, and being frequently much less.

248. *Internal Structure*.—The texture of this form of shell precisely corresponds with that of *Nodosaria*; being very finely tubular, not only in the lateral walls, but also in the septal divisions between the chambers, which are here strictly continuations of the lateral walls over the anterior face of the chambers, instead of being completely differentiated from them as in the higher types of the vitreous series. That the real position of the aperture is nearly in the centre of the anterior wall of the chamber, is made very apparent by a careful examination of

its relations in a section passing through the median plane; its position, however, is always more or less outside of the axis of the spiral, so as to be nearest to the convex border. The elevated septal bands or rows of tubercles, the central umbilical tubercle, the marginal *carina* or *cultro* with its radiating prolongations, and the longitudinal ribs or scattered spines with which the surface is beset, are all composed of non-tubular shell substance. No additional feature of any importance is revealed by sections of the shell. Even in the most highly developed examples of it, I have not detected the least vestige of a canal-system; and the wall of each chamber seems to be simply joined-on to that of the chamber which preceded it, so that each septum is formed not of two laminæ, but only of a single one.

249. Thus the differences between these two extreme forms reduce themselves to these,—that the axis of growth changes from a straight line to a spiral, that the divisions between the segments cross that axis obliquely instead of transversely, and that the aperture leaves its exactly central position to become excentric. Now, among the varied forms of the Cristellarian type, we meet with every gradation between such as persist in the spiral plan of growth through their whole lives, and such as, after forming one or more convolutions, thenceforth increase along a nearly rectilineal axis, still having their aperture at the convex margin. From these last we pass by an equally continuous gradation (exhibited in the varieties of the single British species *C. subarcuatula*, CX, p. 30) to forms in which the increase is from the first along a line so slightly curved that the primordial segment remains terminal, as in *Dentalina*; it was to these intermediate forms with a central aperture, that the name *Marginulina* was given by D'Orbigny. In proportion as they approach the rectilineal mode of growth, they become more and more like *Nodosaria* in their general aspect, and especially in the replacement of the *carina* or *cultro* of the convex margin by a set of longitudinal *costæ* that repeat one another at regular intervals around each segment, and are continued from one segment to another,—this being especially the case in those varieties in which the compressed form has most yielded to the conical or cylindrical, whilst the costæ along the two margins are usually the strongest in the compressed forms, which thus show an interesting link of transition to certain examples of that modification of *Nodosaria* which has been distinguished as *Lingulina* (Plate XII, fig. 1). In *Dimorphina* (the true nature of whose growth was entirely misunderstood by M. D'Orbigny) the early growth is truly Cristellarian, though the form of this part of the shell is somewhat spheroidal; but the direction of the axis suddenly becomes rectilineal or nearly so, and the aperture, from being on the convex margin, becomes central, so that the plan of growth is thenceforth truly *Nodosarian*.

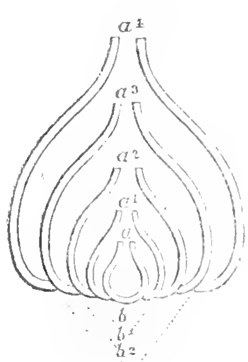
250. Returning now to the *Nodosarian* or rectilineal type, we find that this is subject to like variations, both as to general plan of growth, and as to minor details. Those varieties in which the axis is slightly curved, the segmental divisions somewhat oblique, and the aperture slightly excentric,—its displacement, however, being towards the concave margin,—have been distinguished by the generic name *Dentalina* (CX, figs. 40—44). The variations which have been mentioned as presenting themselves in the form and mode of connexion of the segments, and in the superficial inequalities, of *Nodosaria*, so precisely repeat themselves in *Dentalina* (compare together figs. 38 and 42 of CX, or Plates I and II of LXXIII), as to excite surprise that these two types should ever have been separated,—especially since it is made perfectly clear by the comparison of a sufficient number of forms, that a complete gradation exists between

the perfectly straight *Nodosaria*, and the most arcuate *Dentalina*. On the other hand, an increased obliquity of the segmental divisions, accompanied with a lateral compression of the shell, and with a greater or less degree of curvature of its axis, constitutes the varietal modification to which the generic name *Vaginulina* has been given (cx, figs. 45—48). When this form becomes extremely flat and broad, it receives the name *Planularia*.

251. The form of the aperture, again, is often modified in accordance with that of the septal plane; and on this modification (of which we have seen marked examples in *Miliola* and in the "dendritine" variety of *Peneroplis*) other genera have been founded. Thus *Lingulina* (Plate XII, fig. 1) is nothing but a compressed *Nodosaria*, whose transverse section is oval, and whose aperture (fig. 1, *a*) has undergone a corresponding elongation, sometimes becoming crescentic or reniform. The low value of this modification as a differential character is curiously evinced by the fact, that in the *L. mutabilis* of D'Orbigny, the last chamber, instead of being compressed and bicarinated like those which preceded it, is triangular and tricarinated, and is furnished with a triangular aperture. In the various forms of *Lingulina*, again, it is curious to see how precisely the superficial inequalities of *Nodosaria* and *Cristellaria* repeat themselves; the costate varieties usually having the ribs of the two margins raised into carinæ.—The varietal modification on which the generic term *Rimulina* has been conferred by D'Orbigny, is merely a compressed or vaginuline form of *Dentalina*, in which the aperture, instead of being circular and nearly central, is an elongated fissure extending through a large part of the convex side of the anterior wall of the chamber (Plate XII, fig. 4).—And the varieties of the Cristellarian type in which the aperture, instead of being round, is triangular (Plate XII, fig. 3, *a*), have been distinguished by the generic term *Robulina*. The gradational transition from one form of aperture to the other, is seen in the varieties of the common *Cristellaria calcar*.

252. Another set of varietal modifications of the Nodosarian type, arises out of the diversities in the mode in which the segments are applied one to the other, and in the degree in which the later segments extend themselves backwards so as to enclose the earlier. Thus in the *Glandulina*, of D'Orbigny, not only is the anterior wall of each chamber prolonged forwards as in *Nodosaria*, but the posterior portion of each segment is so far prolonged over the preceding as to conceal a large part of it (Plate XII, fig. 5). This prolongation is carried to a much greater extent in the well-marked form known under the designation *Frondicularia*; of which the shell is extremely compressed, and of which the segments are so prolonged backwards along the two margins, that the chambers have a sagittate form, the aperture being at the point of each (Fig. XXXI). The extent of these prolongations, however, varies considerably; for sometimes the *alæ* of the newer segments meet beyond the primordial cell, so as completely to enclose it (cx, fig. 50), whilst in other instances the posterior prolongation is not greater than in many *Glandulinæ* (cx, fig. 51). When the early growth of this frondicularian variety takes place along a spiral instead of a rectilineal axis, (Plate XII, fig. 6), it is referred by D'Orbigny to the genus *Flabellina*. The relation of this form to *Frondicularia* is precisely that of *Cristellaria* to *Nodosaria*: that general physiognomy of the two which depends upon the peculiarity of their later growths.

FIG. XXXI.



being so strikingly similar as at once to suggest their close affinity, (notwithstanding that they are referred by D'Orbigny to different Orders); and this affinity being distinctly proved by the existence of a continuous series of gradational forms, in which the spiral of *Flabellina* uncoils itself more and more, until its axis assumes the rectilineal direction of that of *Frondicularia*.

253. *Affinities.*—The relationship of the universally-rectilineal or slightly-curved *Nodosaria* to the unilocular *Lagena* is extremely obvious; many forms of *Nodosaria* being in all essential particulars *Lagenæ*, of which the segments that are successively formed by gemmation have remained in continuity with each other. The intimate structure of their shells, moreover, is precisely the same; and the surface-marking of the simple is often precisely repeated on the composite forms. The Cristellarian or flat spiral forms do not seem to graduate into any other type, being (so to speak), the culminating group of the series to which they belong; so that it is only through its simpler or more elementary forms, that these are related to the genera to which we have assigned a parallel rank in the family *Lagenida*.

254. *Geographical Distribution.*—Under some or other of its protean forms, the Nodosarine type is very generally diffused through the seas of various parts of the globe. Nearly all these forms are well represented in the Rhizopodal Fauna of the Mediterranean (LIV); and the Adriatic Sea is particularly rich in them, *Cristellariæ* being found there of large size, and in greater variety and abundance than elsewhere, and *Planulariæ* being almost peculiar to that locality. The Nodosarines are not so common in littoral deposits as they are in those of moderate depth.

255. *Geological Distribution.*—Not only can the Nodosarine type be traced back in geological time to a very remote antiquity—as far even as the Carboniferous epoch—but its leading varieties are recognisable in the earlier strata, as well as in a succession of later formations. The Triassic clay of Chellaston has been shown by Messrs. Rupert Jones and Parker (LV), to contain not merely typical representatives of the Nodosarian, Dentaline, Glanduline, Linguline, Vaginuline, Frondicularian, Flabelline, Marginuline, and Cristellarian forms, but also a number of those connecting links between these, of which mention has been made in the preceding pages. Similar varietal modifications present themselves in the Foraminifera of this type from the Lias-clay of England and the Continent (see Bornemann, 'Liasformation, Göttingen'). The clays of the Oolites also are rich in them; and in the Cretaceous series we meet with a peculiar abundance and variety of Nodosarine forms. In the remarkable development of the Rhizopodal fauna which seems to have taken place at the commencement of the Tertiary period, the Nodosarine type appears to have had its full share, at least as regards the abundance of individuals and the large size they attained; but we do not find any well-marked new varieties. The Vienna Tertiaries present us with an almost complete sample of the entire series; and it is in those and in the Sub-Apennine Tertiaries that we find the largest specimens, especially of the Cristellarian sub-type, that are anywhere to be met with; the nearest approach to these at the present time being afforded by specimens collected on the Abrolhos Bank. From a comparison of the Rhizopodal fauna of the Siennese clays with similar recent collections from various localities in the Mediterranean, it is concluded by Messrs. Rupert Jones and Parker (LIV) that those clay beds were deposited at a depth of not less than 40, and not

more than 100 fathoms. The marine Tertiaries of other regions are scarcely less rich in Nodosarine forms; so that we may consider this type to have an equally wide diffusion in time and in space.

Genus III.—ORTHOCERINA (Plate XII, fig. 7).

256. *History.*—This is one of the numerous genera created by D'Orbigny in 1825 for the reception of the various modifications of the Nodosarine type; and it is the only one which we do not at present see adequate reason for reuniting with the rest, its combination of characters being so peculiar as to differentiate it from every form of that series, as well as from the other genera of the family *Lagenida.*

257. *External Characters and Internal Structure.*—The shell of this genus is formed of a succession of segments arranged in a straight line, without any intermediate constrictions; these segments usually increase pretty regularly in size, and are either square or triangular in their cross section, so that the whole shell has the form of an inverted pyramid, either four-sided or three-sided, the faces being generally concave (Plate XII, fig. 7). The septal planes are sometimes nearly flat, but are more often very convex. The aperture, which is a simple circular perforation without radiating fissures or equal and regular denticulations, is somewhat pouting, but does not generally project as a distinct tube. The angles sometimes become sharply carinated by exogenous deposit; and thick, rounded, longitudinal costæ may exist also midway between the angles, as in the form designated *Rhabdogonium anomalum* by Reuss (XC *b*), these, however, being formed rather by the sudden convexity of the walls of the chambers midway between the carinated angles, than by any great excess of exogenous deposit.

258. *Affinities.*—This genus is obviously a member of the family *Lagenida,* to the composite forms of which it is allied in its general mode of growth, the character of its aperture, and the disposition of exogenous deposits on its surface. Its nearest relationship seems to be to certain feebly-developed forms of *Uvigerina;* but in the rectilineal disposition of its segments it conforms to the Nodosarian type.

259. *Geographical and Geological Distribution.*—The only recent example of this type at present known is that mentioned by D'Orbigny (LXXIII) as having been obtained from the West Indian seas. So far as we yet know, the earliest appearance of *Orthocerina* is in the Oxford Clay; it is afterwards met with in the Chalk formation and in the Paris Tertiaries.

Genus IV.—POLYMORPHINA (Williamson, Figs. 145—157).

260. *History.*—The earliest notice of the shells of this very common but extremely variable type, occurs in the work of Boys and Walker (IX); in which the generic name

Serpula, with the description *tenuis ovalis lævis*, is given to the well-known form afterwards named by Walker *S. lactea*; under which designation it has been cited by several among the earlier writers on British Conchology. Certain aberrant forms distinguished by the 'stag-horn' processes to be presently described, were described and figured by Soldani (CI) under the name *Polymorphia corcula spinosa*; and upon his figures of this and certain other forms of the same type, De Montfort (LXVII) founded his genera *Canopus*, *Cantharus*, *Misilus*, and *Arethusa*, of which none but the last has been adopted by any other systematists, and of which all are now entirely disused. For the objectionable name *Serpula*, the scarcely less objectionable name *Vermiculum* was substituted by Montagu (LXV), who associated under that generic designation examples of *Miliola*, *Lagena*, and *Polymorphina*; and this, again, has been adopted by British Conchologists, though it has not been admitted by continental authorities. The name *Polymorphina* was used by D'Orbigny in 1825 to designate a portion of the series of forms which we now include under that generic type; other portions being separately ranked by him under the genera *Globulina* and *Guttulina*, which, together with *Dimorphina*, made up his family *Polymorphinidæ*. The absence of any valid generic or even specific distinction between the ordinary forms of *Polymorphina*, *Globulina*, and *Guttulina* became apparent to Prof. Williamson from the comparison of only the British species which had fallen under his special observation; and we can not only entirely endorse his excellent remarks (CX, p. 73,) upon the specific identity of the forms which he brings together under the designation *Polymorphina lactea*, but can extend them also to those other more divergent modifications of which his *P. myristiformis* is an example.

261. *External Characters and Internal Structure.*—The essential characters of *Polymorphina* consists in the biserial alternation of lageniform chambers, each with a radiating mouth, along the two sides of a longitudinal axis. The form and disposition of the chambers, however, may vary so much as to give to the entire shell such marked diversities in shape, that, unless the intermediate gradations were traced out, there would seem adequate ground for specific if not for generic differentiation. Starting from what may be regarded the typical form of the common *P. lactea* (CX, fig. 145), we observe that the segments are arranged very obliquely to the central axis, and that each is prolonged in some degree over the penultimate segment on the opposite side (so as to render the shell unsymmetrical), whilst it also extends itself backwards over the antepenultimate segment on its own side; the entire shell thus presenting a somewhat fusiform shape. Now there may, on the one hand, be a greater elongation of the shell, arising out of a predominance of the forward over the backward growth of the segments, so as to make the entire shell resemble a wheat-ear or grass-spike; whilst, on the other hand, by a predominance of the backward growth of the newer segments, the earlier ones may be almost or completely concealed by them, and the entire shell may come to present the form of a drop or a tear (CX, figs. 147, 153—155). Again, its two opposite surfaces may be more or less compressed; and this compression may proceed to such an extent that the proportions of the shell resemble those of a thick fleshy leaf. The most remarkable departure from the ordinary type is seen in those forms in which the last chamber extends itself over all the preceding, so as completely to include them; this is especially the case in some forms, which, from their peculiar mode of growth, appear to have been adherent (CX, figs. 151, 152). The outermost segment may develope itself into numerous irregular expansions and tubular growths,

known from their appearance as "stag-horn processes" (cx, fig. 150); and these seem to be homologous with the lobate extensions occasionally met with in "wildly-growing" *Globigerinæ* (¶294), and still more remarkably in *Carpenteria* (¶ 308). Although it is probable that these processes are generally closed, as is surmised by Professor Williamson (cx, p. 72), yet from the absence of any proper aperture to the segment from which they proceed, and from their special grouping about the spot at which the aperture should be, it seems likely that some of them are normally open at their extremities, and give exit to pseudopodial extensions. Such "wildly-growing" specimens are probably always parasitic.—Although we have spoken of the arrangement of the segments as normally biserial, yet they are sometimes so loosely piled together, that three or more of them would be brought into view by a transverse section.

262. The form of the aperture, except in the cases in which the last segment takes on the "wild" growth just described, is usually extremely characteristic; being circular, with a plicated margin, so as to present a regularly radiating form. Sometimes the centre of the aperture is filled up by a plug of calcareous matter (as occasionally happens in *Nodosarina*), so that the stoloniferous processes must pass out through a set of radiating fissures. We seldom find the aperture situated at the extremity of a prolonged *ecto*solenian neck; but the earlier chambers of the most transparent forms may not unfrequently be seen to be furnished with an *ento*solenian neck; and in the later chambers, whose apertures are not prolonged in either direction, it is generally to be observed that the plicæ extend as far inwards as they do outwards. It is a very curious fact that when an outer "wild-growing" segment extends itself over the whole of the preceding series, its cavity communicates, not merely by the usual radiated aperture with the antepenultimate chamber, but also by a double row of openings with all the chambers which it overlaps. It is difficult to suppose that these openings existed anteriorly to the overgrowth; and we can scarcely account for their presence in any other way, than that they have been formed *de novo* by absorption.—The appearance of the shell in the younger specimens is peculiarly glassy: the walls of the chambers being thin, and the pores which traverse their vitreous substance not being so closely set as to render it opaque. And it is a distinguishing characteristic of this type, that its surface-character is but little modified by that exogenous deposit, which gives such marked features to the exterior of *Lagenæ*, *Nodosarinæ*, and *Uvigerinæ*. The shell may be simply thickened, so as to became opaque: or it may be rendered scabrous by minute granules, and these may either run together into fine parallel short longitudinal riblets, or they may enlarge into beads; or they may be prolonged into aciculi, which may render the surface bristly:—but all these kinds of surface-ornament are met with far more strongly marked in the other genera of the family LAGENIDA.

263. *Affinities.*—From the preceding description it would seem obvious that the true affinity of *Polymorphina* is on the one hand to the uniserial *Nodosarina*, and on the other to the triserial *Uvigerina*. But it has a strong relation of analogy to *Textularia*, the mode of growth being essentially isomorphic in these two types; so that if we were to place our chief reliance on that character, these two genera would have to be brought into close approximation. For reasons already assigned, however, we consider the plan of increase

of the aggregation of segments to be quite subordinate in essential importance to those characters which appertain to each segment in detail; such as, in this instance, the strongly marked peculiarity of the aperture, and the surface-ornamentation, by both of which the real affinities of *Polymorphina* are shown to be with the group of genera of which we have taken *Lagena* as the type.

263. *Geographical Distribution.*—This genus shows itself under some or others of its protean forms on nearly all the coasts which have been yet explored, alike in arctic, temperate, and equatorial seas. It does not often present itself in the deepest dredgings or soundings, but is most common in shore-sands and in dredgings from shallow waters.

264. *Geological Distribution.*—The earliest appearance yet recognised of *Polymorphina* is in the Upper Trias. It is common in the Chalk-marl, in which several of its varieties have been met with; in the Chalk itself it occurs more rarely. It is extremely plentiful in many of the Tertiary deposits, as those of Grignon, Tours, Bordeaux, Vienna, and Palermo; and in the Post-tertiary clays of Lincolnshire.

Genus V.—UVIGERINA (*Williamson*, Plate V, figs. 138—140).

265. *History.*—With the exception of Soldani, who figured certain fossil forms of this genus (CI) under the name of *Polymorphina pineiformis*, no systematist appears to have noticed it previously to the characterisation of the genus by D'Orbigny (LXIX) in 1825. The name which he gave to this type appropriately indicates the resemblance of some of its forms to a bunch of grapes.

266. *External Characters and Internal Structure.*—The essential character of this type consists in the triserial arrangement of its lageniform chambers, which are disposed somewhat irregularly around an elongated axis, so as to form a spire having the proportions of that of a *Mitra*. The aperture (CX, figs. 138, 139) is a distinct round passage, with an everted lip, generally set upon a tube more or less prolonged outwards, and sometimes faintly toothed. When the tubular mouth is much elongated, and the chambers are globular and distinct, the entire shell presents a well-marked racemose shape; but in other forms the surfaces of the segments are flattened against each other and are also compressed externally, so that the transverse section of the shell becomes triangular. The triserial arrangement, however, is not always maintained; for in certain elongated forms of feeble growth we find the later chambers loosely set on, and approaching a biserial or even a uniserial arrangement; such forms are figured by Soldani, and present themselves also in *Uvigerinæ* at present existing in the Mediterranean. There are even cases in which the triserial mode of growth seems altogether wanting, and the biserial almost obsolete; Messrs. Parker and Rupert Jones having specimens from shell-beds in the tropical and sub-tropical parts of the Indian Ocean which might be easily mistaken for *Nodosarinæ*, but whose Uvigerine character is marked by the short, wide, strongly labiate aperture. It seems to have been a specimen of the biserial type, that was figured by D'Orbigny (LXXIII) under the name of *Sagrina*

pulchella: and other connecting links are met with. In large, well-developed individuals, whether of typical or of dimorphous growth, the surface of the segments is generally marked by elevated costæ running parallel to the axis of the shell (cx, fig. 138); but in place of these we not unfrequently find the surface rendered hispid by prickles, especially in specimens brought from great depths. In these forms of exogenous deposit there is a manifest parallelism to *Lagena* and *Nodosarina*. In specimens of more feeble growth, however, the ribbing becomes obsolete on the newer chambers: and in some of the dimorphous forms it is scarcely perceptible even on the earliest.

267. *Affinities*.—On the principles of classification here adopted, the nearest relationships of *Uvigerina* are obviously to *Polymorphina* and *Nodosarina*. We shall hereafter find, when we come to speak of *Textularia*, that the dimorphism of *Uvigerina* is very strikingly paralleled in that type, as it is also in *Valvulina* (¶ 221): but the relation thus indicated is one of analogy or isomorphism, not of affinity.

268. *Geographical Distribution*.—The home of this type seems to be in warm seas, at depths of from 100 to 300 fathoms; it ranges, however, in regard to depth both upwards and downwards, and in regard to latitude towards both polar and equatorial regions, being found in shore-sands from all quarters of the globe, and also in deep-sea dredgings and soundings.

269. *Geological Distribution*.—This genus has not been recognised in any deposit older than the Middle Tertiary period: but it thenceforward presents itself abundantly in various localities.

CHAPTER IX.

OF THE FAMILY GLOBIGERINIDA.

270. Under the general designation GLOBIGERINIDA we bring together, for the reasons already stated, all those hyaline or vitreous Foraminifera which have their shell-substance *coarsely perforated* for the exit of pseudopodia, so as to resemble that of *Globigerina*; a character by which they are differentiated from the LAGENIDA on the one hand, and from the NUMMULINIDA on the other. They are further differentiated from the former of these families by the form and character of their aperture; for although there are instances in which the chambers communicate with each other, and the last chamber with the exterior, by circular pores, yet this is only in aberrant forms of the group; and the typical aperture is a crescent, which may either be contracted to a narrow fissure, or which may open-out so as to have the proportions of a gateway. There is not a like difference in the form of the aperture between *Globigerinida* and *Nummulinida*; but generally speaking, it is of much larger size, so as to permit a much freer communication between the segments of the body in the former group than in the latter.

271. The series of forms whose agreement in these fundamental characters may be considered as justifying their association in the same family, presents varieties of configuration, dependent upon differences in their plan of growth, which are even greater than those we have encountered in the preceding case; and widely separated places have accordingly been assigned to them by those Systematists who adopted "plan of growth" as the basis of their arrangements. Thus, in the classification of D'Orbigny, our genera would be distributed as follows:

Order I.—MONOSTÈGUES. Orbulina, Ovulites, Spirillina.

Order II.—CYCLOSTÈGUES. Tinoporus (Orbitolina, *D'Orb.*), Patellina.

Order IV.—HÉLICOSTÈGUES. Globigerina, Carpenteria, Pullenia (part of Nonionina, *D'Orb.*), Bulimina, Chrysalidina, Rotalina (including Rosalina, Planorbulina, Anomalina, Calcarina, and part of Asterigerina, *D'Orb.*)

Order V.—ENTOMOSTÈGUES. Cassidulina.

Order VI.—ENALLOSTÈGUES. Textularina, Cuneolina.

Order VII.—AGATHISTÈGUES. Sphæroidina.

A nearer approximation to what we consider the true view of their affinities is presented by the system of Prof. Schultze (XCVII); who separates *Orbulina* and *Spirillina* (*Cornuspira*, Sch.) from his other MONOTHALAMIA, and brings together *Rotalida*, *Textilarida*, and *Cassidulinida*, with *Uvellida*, as sub-families of his family TURBINOIDA, which holds very much the same relation to his family NAUTILOIDA, that our family GLOBIGERINIDA holds to our NUMMULINIDA. If Prof. Schultze had expunged his *Uvellida* from the former, and his *Cristellarida* from the latter, and had united these with his family NODOSARIDA, his general arrangement would have differed in this part but little from ours, except in the complete line of demarcation which he draws between the monothalamous and the polythalamous forms characterised by essentially the same type of structure. On one point, however, we are altogether at variance with him; namely, the value he assigns to his Family ACERVULINIDA, which consists of what is in our view but an aberrant form of the Rotaline type, that is distinguished by its "wild" or acervuline growth, the segments being piled one upon another without any definite plan.

272. Taken as a whole, our family GLOBIGERINIDA may be considered as holding an intermediate rank between our LAGENIDA and our NUMMULINIDA. In common with the former, it has its root (so to speak) among the Monothalamia, from which it extends itself upwards in various directions, like a tree whose trunk early subdivides into branches. But whilst the development of the LAGENIDA is checked at a low grade, so that even their most elevated forms present very little real advance upon the most simple, that of the GLOBIGERINIDA goes on so much further, that we find in the highest types of this family a complication of structure scarcely inferior to that which characterises the highest NUMMULINIDA. When we come, however, to consider the relations of the principal generic types of this family, both among themselves and to other groups, we find that they cannot be expressed by any linear arrangement; and the only practicable method, therefore, is to follow that which seems to be the line of most intimate relationship so far as it may lead, and then, returning to the original starting-point, to take a fresh departure in some other direction.

273. There can be no hesitation in regarding the monothalamous forms as being those which present the fundamental or essential "idea" of this group under its simplest aspect; and yet these are differentiated from each other by very marked characters:—*Orbulina* being often destitute of any principal aperture, but having numerous secondary apertures of larger size than the ordinary pores; *Ovulites*, on the contrary, presenting an aperture at each end of its egg-shaped chamber; whilst in *Spirillina* the single chamber is elongated into a nearly cylindrical tube, coiled upon itself into a spire, which, closed at its central extremity, is freely open at its peripheral. In the two former, as in the *Gromida* and in *Lagena*, the act of gemmation consists in the production of a segment, which (except in certain cases of monstrosity) detaches itself from the original body and forms its own separate investment; but in the latter it consists in a simple elongation of the sarcode-body and continuous extension of the shell, without any appearance of segmentation. It is obvious that from either of these monothalamous types an ordinary polythalam may be derived: for, on the one hand, the segments successively budded off from a globular *Orbulina* may remain in continuity with

it and with each other, producing either a spiral or some other figure, according to their direction of increase; whilst, on the other, the continuous tube of a *Spirillina* may contract itself at intervals so as to form a succession of chambers, just as we have seen a *Cornuspira* convert itself into a spiroloculine *Miliola* (¶ 104). Now we find among the lowest of the Polythalamous forms exactly such as might be the resultants of each of these modifications; for in *Globigerina* we have a spiral aggregation of segments which are really disconnected from each other, although united by mutual adhesion; whilst in certain vermiculate forms of the Rotaline type we shall be very strongly reminded of what a *Spirillina* would be if segmentally divided at intervals by partial constrictions.

274. In immediate structural relation to *Globigerina*, but diverging from it in plan of growth, we find the two small genera *Pullenia* and *Sphæroidina*, of which the former, in the finely porous texture of its shell, and in the equilateral disposition of its spire, conducts us towards the simplest "nonionine" forms of *Polystomella*, a member of the family NUMMULINIDA; whilst the latter, though essentially "globigerine" in the character of its segments, has them applied one to another in a manner that reminds us of some forms of the Milioline type, to which it also bears a further curious resemblance in having its aperture furnished with a kind of "valve."—The Globigerine type evolves itself, however, without any departure from its essential character, into a much more complex form, *Carpenteria;* which, on the one hand, presents us with a singular feature of approximation to Sponges, whilst, on the other, it exhibits, in the duplication of its septal laminæ, and in the presence of a canal-system, an elevation of type which is not a little remarkable as based on a foundation so humble.

275. Although we might very naturally pass from *Globigerina* to the Rotaline series, yet it seems desirable, in the first place, to notice the *Textularine;* because, although the lower types of the two may be considered as on the same grade of development, the highest types of the former rise far above those of the latter. The genera of which the Textularine series is composed, are characterised by the alternating arrangement of their chambers upon an elongated axis: the successive chambers freely communicating with one another by (usually) crescentic apertures; but each being so applied to the preceding that the septum is single, so that there are neither intraseptal spaces, intermediate skeleton, nor canal-system. This group thus represents in its own series both the Uvigerine type of the vitreous-shelled family LAGENIDA, and the Valvuline of the arenaceous LITUOLIDA; and its relationship to the latter seems to be even more intimate than to the former; since both in *Textularia* and in *Bulimina* it frequently happens that the proper substance of the shell is replaced to a great extent by an aggregation of sandy particles, in the midst of which, however, the pseudopodial pores are still traceable. It is unquestionably in these *aberrant* modifications of their respective series, that the great primary groups of Perforate and Imperforate Foraminifera show the most intimate relationship; the *typical* forms of those groups, even when most resembling one another in external configuration, being most completely differentiated in essential characters.—In the ordinary *Textularia* the alternation of the chambers is essentially *biserial:* but in some of its subgeneric modifications it is triserial, whilst, on the other hand, it may become uniserial. In *Bulimina*, again, the chambers are disposed, without any definite number, in a spire which strongly resembles that of a *Bulimus;* but in some of its subgeneric

modifications it becomes biserial. These two generic types differ essentially, however, like *Uvigerina* and *Polymorphina*, in the setting-on of the chambers, and in the form of the aperture. In *Chrysalidina* and *Cuneolina*, whose plan of growth is Textularine, the large, single aperture is replaced by a multiplication of pores. And in *Cassidulina*, of which the aperture is Bulimine, and the chambers alternate biserially, the elongated axis is itself coiled into a spiral, affording the only real example of that complex plan of growth on which D'Orbigny founded his order ENALLOSTÈGUES.* As the Nodosarine type culminates in *Cristellaria*, so may we consider the Textularine as culminating in *Cassidulina*; and the latter of these genera, like the former, is altogether destitute of those peculiar features which characterise what may be unmistakeably recognised as the most elevated forms of the family *Globigerinida*.

276. To such forms we can only ascend by returning again to those simpler derivations from the Globigerine and Spirilline types, which constitute the lowest forms of the *Rotaline* series: this consists of a group of genera whose typical character consists in the arrangement of the chambers in a turbinoid spiral, and in their communication with each other by an aperture (usually more or less crescentic in form) situated at its inner and lower margin. Now the simplest forms of this Rotaline spire present a close parallel to the Textularine series in the manner in which each segment applies itself to the preceding; but the same type may be traced upwards, through successive grades of development, until we arrive, in the highest form of *Rotalia Beccarii*, at a condition scarcely inferior to that of *Operculina* in regard to the differentiation and duplication of the septal laminæ, the system of intraseptal canals, and the supplemental skeleton. In the genus *Calcarina* we find an exogenous development of the supplemental skeleton, and of the portion of the canal-system provided for its nutrition, which is unparalleled elsewhere; but it is not a little singular that this modification is related rather to the higher than to the lower forms of the Rotaline series; the septal laminæ being for the most part single, so that the intraseptal portion of the canal-system is but little developed. It is further worthy of note in this genus, that the narrow, crescentic, apertural slit is divided by cross-bars into separate circular pores.

277. The greatest departure from the normal development of the Rotaline type is shown in the entire cessation of the regular plan of increase, observable in all but the earliest stage of growth of certain forms, which, in the structure of their individual segments, are entirely conformable to the Globigerine type. The essentially Rotaline character of these organisms is marked by the turbinoid spiral in which they usually commence; whilst the forms they present in their fully developed condition are so far from suggesting their real relationship, as to seem in many instances to claim for them a completely separate place in the series. By the

* The genera *Asterigerina* and *Heterostegina*, which were placed by D'Orbigny in this order, have no claim whatever to be thus differentiated from their congeners; and although in *Amphistegina* there is often a want of equality between the alar extensions of the chambers on the two lateral surfaces, with a separation of the umbilical extremities of those extensions into secondary chamberlets, there is no really biserial alteration.

flattening out of a Rotaline spire, and the cyclical or concentric growth of chambers from its margin, it takes on the form known as the *Planorbulina*; and this may undergo a further modification, on the one hand, by that irregular heaping up of chambers one upon another which constitutes the "acervuline" mode of growth; on the other, by the interposition of a large amount of solid shell-substance between and upon the chambers. This acervuline mode of growth is carried still further in the genus *Tinoporus* (*Orbitolina*, D'Orb.), some forms of which also present an extraordinary development of the exogenous portion of the intermediate skeleton, strongly resembling in external aspect that of *Calcarina*, and accompanied, like it, by a corresponding development of the peripheral part of the canal-system. And it is a most interesting indication of the mutual relationship of these two types, notwithstanding the complete dissimilarity of their modes of growth in their adult condition, that in their early Rotaline state they are absolutely undistinguishable from each other. In *Tinoporus*, moreover, as in *Calcarina*, the setting on of the chambers follows the plan of that of the lower Rotalines, not that of the higher. We are probably to rank the genus *Patellina*, whose plan of growth tends early to become cyclical, as a still more aberrant member of the Rotaline series. Finally, in *Polytrema* the growth becomes so "wild" that the aggregations of chambers present a zoophytic form; and as their origin in a Rotaline spire cannot be demonstrated with certainty, their relationship to this type is established only by their conformity in structure and mode of growth to the acervuline portions of *Tinoporus*; which conformity will be shown to be so complete as to leave no room whatever for doubt as to their true nature.

The following arrangement of the genera may help towards the understanding of the principal relationships that have been indicated among them; but no such arrangement can give more than a partial view of those relationships:—

FAMILY GLOBIGERINIDA.

Ovulites . . . . . . *Orbulina* . . . . . . *Spirillina*

TEXTULARINÆ

Bulimina
Virgulina
Bolivina
Cassidulina
Ehrenbergina

Textularia
Bigenerina
Gaudryina
Verneuilina
Grammostomum
Cuneolina
Chrysalidina

GLOBIGERINÆ

Globigerina
Sphæroidina *Pullenia*
Carpenteria . . *Rotalia*

ROTALINÆ

Discorbina
Planorbulina
Truncatulina
Planulina
Anomalina
Pulvinulina
Rotalia

Cymbalopora
Calcarina
Tinoporus
Patellina
Polytrema

Genus I.—ORBULINA (Plate XII, fig. 8).

278. *History.*—The little spherical bodies to which the appropriate name *Orbulina* was first given by D'Orbigny in 1839 (XCII), had been described and figured by Soldani (CI) under the names *Sphærula petræa* and *S. hispida;* but they do not seem to have received any attention from intervening authors. Subsequently to its recognition by D'Orbigny, this type has been generally adopted by systematists as a distinct genus until a recent date, when its claim to that rank has been called in question, on grounds which will be presently explained. Not being as yet satisfied of the invalidity of that claim, but not, on the other hand, feeling able to affirm that the objections to it are altogether groundless, I have thought it best to retain the genus provisionally; especially since I find that my friends Messrs. Parker and Rupert Jones are in accordance with me as to the propriety of this course.

279. *External Characters and Internal Structure.*—The shell of *Orbulina* is usually an almost perfect sphere, varying in diameter from 1-35th to 1-200th of an inch. Its surface is usually roughened by minute tubercles, presenting an appearance which is described by Professor Williamson (CX, p. 2) as "arenaceous;" but I am satisfied that its substance is not made up of any such aggregation of foreign particles as constitutes the material of the truly "arenaceous" shells; whilst, on the other hand, it is only in the earlier stage of its formation that it has the hyaline transparency characteristic of the truly "vitreous" shells. The shell is pierced (Plate XII, fig. 8) with a number of large pores, the average diameter of which is about 1-1500th of an inch; their distance from each other varies considerably, but is seldom less than about 1-750th of an inch. Between these there are very numerous minute pores, not above 1-10,000th of a inch in diameter, and closely set together, so as to be pretty uniformly distributed. In the large majority of specimens these constitute the only apertures in the globular shell; but we frequently meet with one of larger size, normally round, but sometimes irregular, its diameter averaging 1-500th of an inch. I am much disposed, however, to question how far this can rightly be regarded as comparable to the aperture of ordinary Foraminifera; since, on the one hand, it is often absent;* whilst, on the other, when it exists, it is only one among the very numerous large pores by which the shell is fenestrated, distinguished from the rest only by its pre-eminent size. I believe the truth to be that the sarcode-body puts forth its prolongations indifferently from any or all the pores; and that, when this organism multiplies itself by the formation of detached gemmæ, these are budded off from the gelatinous mass which the coalescence of these prolongations will form on the exterior of the

* It is remarked by M. D'Orbigny (LXXIII, p. 21) that as the aperture is frequently invisible, not showing itself in above one-sixth of the freshest specimens, the animal may possibly possess the power of closing it. Prof. Williamson (CX) confirms D'Orbigny's statement of the infrequency of the aperture; but thinks that "its frequent closure is more probably due to the inspissated animal matter of its internal cavity." My own observations satisfy me that the existence of a single aperture of any considerable size is the exception rather than the rule.

shell. In the *Orbulinæ* of comparatively shallow waters, the shell seems to retain through life its hyaline aspect, not appearing to receive any augmentation in thickness subsequently to its first formation. In those brought up from deeper waters, on the other hand, we commonly find the original hyaline shell to be encrusted by an exogenous deposit of coarser texture and of a reddish hue, having a peculiar sculptured surface (fig. 8, *a*) which reminds the observer of that of some of the hispid pollen-grains.

280. Not unfrequently this exogenous deposit, instead of closely adhering to the surface of the shell which it encloses, forms a distinct sphere that is exactly fitted to it without being continuous with it,—a circumstance which seems first to have been pointed out by Mr. Pourtales,* who supposed that the inner shell is the more recent or younger, and that the outer one is the older and is destined to be cast off. Of this, however, I see no evidence whatever: whilst, on the other hand, not only is it found that a more delicate hyaline layer always exists within the outer less transparent coat (as may be easily shown by removing the latter by the careful application of dilute acid), but this outer layer is occasionally so loosely applied to the interior, that a considerable space remains between them over a larger or smaller portion of the surface of the sphere, so that the outer layer forms a protuberance enclosing an additional chamber, which is sometimes of small proportionate size, but sometimes has nearly the dimensions of the original sphere. (This seems to be the form described by D'Orbigny, LXXIII, as *Globigerina bilobata*.) In one specimen in my possession, the sphere bears two such protuberances, both of them small. It is particularly worthy of note that the secondary cavity thus formed has no other communication with the single cavity of the original sphere, than that which is afforded by the ordinary pores of the shell-wall; there being no apertural passage between the two. Hence, although such an excrescence may in some sense be regarded as a sort of attempt at the formation of a new chamber, the rarity of its presence seems to forbid the idea that its formation is anything but abnormal. In fact the perfection of the spherical form in all but such extraordinary specimens of *Orbulina* is extremely remarkable; there being not the slightest indication on any part of their surface of ever having been attached by adhesion to any other organism, still less of ever having been continuous with any other fabric and having been separated from it by fracture.

281. It is affirmed, however, by Mr. Pourtales (loc. cit.), that in nearly one half of the *Orbulinæ* which he examined among the large number of well-preserved specimens obtained from the bottom beneath the Gulf Stream by the U.S. Coast Survey, he found "young *Globigerinæ* more or less developed, and attached to the inside of the *Orbulina* by numerous very slender spicules. Only one *Globigerina* is developed in an *Orbulina*, whose cavity it gradually fills up, and whose shell it finally bursts to make its escape. At that time the *Globigerina* has already nearly attained its full size; and I have counted as many as sixteen cells in a specimen having yet room for several more before filling up the parent *Orbulina*." It is not rare, continues the same observer, to find *Orbulinæ* with the double shells just described containing young *Globigerinæ*. Further, it is stated by Prof. Schultze (XCIX), that Dr. August Krohn has seen exactly the same thing in living *Orbulinæ* captured with the

* 'Silliman's Journal,' July, 1858, p. 96; and 'Annals of Natural History,' September, 1858, p. 236.

tow-net (?) at the surface of the sea near Madeira; and Prof. Schultze thinks it the most probable supposition that the last chamber of the *Globigerina*, when it has attained a certain age and size, separates like the proglottis of a *Tænia*, and, after living in a free state for a longer or shorter period, effects the reproduction. Now I have very carefully laid open by the application of dilute acid the spheres of a considerable number of *Orbulinæ*; and I have not met with a *Globigerina* in the interior of a single one. Without wishing to affirm that my negative observation necessarily invalidates the statements just quoted (since it is quite possible that, supposing *Orbulinæ* to be generative segments of *Globigerinæ*, the contents of my specimens may not have been sufficiently advanced towards maturity at the time they were gathered, to be recognisable in the dry state), it derives support from the following facts: —1. The marked difference in size between the *Orbulinæ* and the *Globigerinæ* of the same "gathering," the diameter of the former averaging 1-40th of an inch, and the smallest being 1-85th, whilst the diameter of the largest chamber in the latter averages 1-100th of an inch, seldom exceeding 1-80th.—2. The perfect sphericity of *Orbulina*; whilst the larger chambers of *Globigerina* almost invariably depart considerably from the spherical form.—3. The entire absence of any indication whatever that *Orbulinæ* have been attached to, or continuous with, any other organisms.—4. The constancy of a large aperture in the segments of *Globigerina*; whilst it is deficient in so great a proportion of *Orbulinæ* that its presence may be considered as exceptional.—5. The absence in *Globigerina* of the larger pores by which the shell-wall of *Orbulina* is so abundantly pierced.—Taken in mutual connection, therefore, the facts I have adduced *at present* seem to me sufficient to justify the retention of *Orbulina* as a substantive genus; the only fact that occurs to me in support of its asserted relationship to *Globigerina* being the generality of their association. Even this, however, does not appear to be universal; for although at the present epoch the two forms generally occur together, this association is by no means constant; and, moreover, *Globigerina* presents itself much earlier in Geological time than *Orbulina*.

282. *Affinities*.—If we consider *Orbulina* to be entitled to rank as a substantive genus, we cannot hesitate in regarding it as the simplest conceivable form of the hyaline Foraminifera; since it corresponds with that globular primordial segment, in which, as a rule, even the most complex among them has its origin. In this way it may be said to be related to all the higher forms; but its nearest affinities are of course, on the one hand, to the monothalamous types *Ovulites*, *Lagena*, and *Spirillina*; and, on the other, to *Globigerina*, as being that one of the polythalamous forms which most resembles an aggregation of monothalams.

283. *Geographical and Geological Distribution*.—This genus, as Prof. Williamson remarks, is a true cosmopolite; being an inhabitant of all seas through a great range of depths. It seldom presents itself, however, in shore-sands; as it does not frequent shallow waters. On bottoms of fine sand or mud, at depths of from 30 to 2350 fathoms, *Orbulinæ* have been found in abundance in every maritime region. Such a range in *space*, according to general experience, would indicate a corresponding range in *time*; but the rule does not seem to hold good in this instance, for *Orbulinæ* have not been detected in any formation earlier than the Miocene Tertiaries. It is especially abundant in the Vienna and Sub-Apennine deposits.

Genus II.—OVULITES (Plate XII, figs. 9, 10).

284. *History.*—The name *Oveolites* was applied by Lamarck in 1801 (LVII) to a minute fossil, abundant in the "Calcaire grossier," which has very much the aspect of a bird's egg in miniature; and this name was subsequently (LIX) altered by him to *Ovulites.* Under this latter designation the genus has been adopted by various systematists, most of whom, however, have seemed uncertain as to its true place, which has generally been supposed to be among Zoophytes. And even D'Orbigny has included it among Foraminifera only in his most recent systematic publication (LXXIV); ranking *Dactylopora* (¶ 187) in close proximity to it!

285. *External Characters.*—This beautiful little fossil type is the largest of the monothalamous Foraminifera; its one segment, which is usually about the size of a mustard seed, equalling in bulk the entire polythalamous shells of ordinary *Miliolæ, Rotaliæ,* &c. The typical form of the shell is ovate, with an aperture at each end, so as to give it a striking resemblance to a "blown" bird's egg (Plate XII, fig. 9); while the pearly aspect which it often presents caused Lamarck to confer upon it the specific name *margaritula.* Various aberrant forms, however, present themselves; most of them being the result of elongation with or without occasional constriction. Thus a moderate degree of elongation with constrictions at intervals (a sort of foreshadowing of division into chambers) gives to some specimens the aspect of sausages; whilst a greater degree of elongation will produce a long straight tube (the *O. elongata* of Lamarck); and this tube may be clavate at one or both ends, so as to resemble a drumstick or a life-preserver (fig. 10). In every case there is a large round aperture at each end; and this is the most distinctive character of the genus. The cavity is simple and undivided, though sometimes narrowed by the constrictions which show themselves externally. The shell-wall is perforated by large sparse pores; and these very commonly open on the surface into minute superficial depressions, which, in some of the elongated forms, are so regularly arranged as to give rise to a delicate hexagonal areolation, having a pore in the centre of each areola (fig. 9, *a*),—the superficial resemblance thus presented to *Dactylopora* (¶ 124) having probably influenced D'Orbigny in his approximation of that most complex type to the simple *Ovulites.* Specimens that have escaped molecular change present the clear, smooth, glassy appearance characteristic of the hyaline Foraminifera.

286. *Affinities.*—The close relationship between *Ovulites* and *Orbulina* is sufficiently obvious; as is also that between *Ovulites* and *Lagena,* especially through the distomatous varieties of the latter (¶ 237),—the coarser texture of the shell, however, and the absence of anything like an everted lip with radiating notches, being marked features of difference. The elongated forms may be considered as related on the one hand to *Spirillina,* and on the other to these vermiculate forms of the Rotaline *Pulvinulina* which have wildly growing, attenuated, and prolonged chambers.

287. *Geological Distribution.*—This genus, so far as is at present known, was limited to the earlier portion of the Tertiary period; making its first appearance in the Eocene deposits of Grignon and Hauteville, in which it is extremely abundant; and lingering, under its attenuated forms, in the Miocene of St. Domingo. In no deposits of subsequent date has it been recognised.

Genus III.—Spirillina (Williamson, Figs. 202, 204).

288. *History.*—Through the marked isomorphism between this genus and *Cornuspira* (¶ 82), it cannot be affirmed with confidence to which type we are to refer the figures and descriptions of minute spiral monothalamous shells given by Soldani and after him by other authors, who did not clearly distinguish between such as are imperforate and porcellanous, and such as are perforated and hyaline. It is probable, however, that while the "albocalcareæ" of Soldani (ci) belong to the former, his "margaritiferæ," which he describes as iridescent, belong to the type now before us. The generic designation Spirillina was originally conferred upon the perforated hyaline spiral monothalams by Prof. Ehrenberg (xl *a*); but it has not gained general acceptance. It was set aside by Prof. Schultze (xcvii) for the term *Cornuspira*; but this name was in its turn set aside by Prof. Williamson (cx) in favour of Ehrenberg's name, which, however, he applied to the porcellanous and arenaceous as well as to the hyaline forms. For the reasons already given, we think it better to appropriate Schultze's generic name as the designation of the porcellanous type (¶ 82), to adopt the new name *Trochammina* for the arenaceous (¶ 206), and to retain Ehrenberg's name for the type on which he originally bestowed it, notwithstanding that he has since expressed his belief ('Monatsber. der Akad. der Wiss. zu Berlin,' 1857, 1858) that this type really belongs not to the *Foraminifera* but to the *Polycystina*. (See also xcix.) Examples of this type have been figured by Reuss (lxxxvi) as low forms of *Operculina*.

289. *External Characters and Internal Structure.*—The shell of *Spirillina* is a simple undivided cylindriform tube of hyaline substance, usually perforated with rather large foramina, and coiled spirally on a horizontal plane; the successive coils do not increase rapidly in size, and show but little tendency to flatten themselves out, retaining for the most part their circular section (cx, fig. 202). The principal variety presented by this type results from the modification imparted to its surface by exogenous deposit; for specimens not unfrequently occur, in which all save the last-formed portion is studded with pearly tubercles, while the foramina are so small and inconspicuous as not to be seen without close examination (cx, fig. 204). The diameter attained by this shell does not usually exceed 1-50th of an inch.

290. *Affinities.*—According to the view on which our classification of Foraminifera is based, there is no real affinity between *Spirillina* and either *Cornuspira* or *Trochammina*, notwithstanding the precise resemblance in the forms of their shells; since in the first of these types the pseudopodia may be put forth from any part of the sarcode-body, whilst in the two latter they can only be extended from the mouth of the spire. The real affinity of *Spirillina* is with

the monothalamous forms of the Globigerine family; and it cannot fail to be obvious to any one who accords with us in regarding the external form of such protean creatures as of little account, that if one of the chambers of a *Globigerina* were to elongate itself indefinitely, instead of closing itself in and budding off another segment, we should have *Spirillina*. As already remarked (¶ 62), this genus, like *Cornuspira* and *Trochammina*, though actually monothalamous, is "potentially" polythalamous, in virtue of its power of unlimited extension.

291. *Geographical and Geological Distribution.*—This genus is very generally diffused at the present time, and seems ordinarily to inhabit shallow waters, being found rather in shore-sands than in deep-sea dredgings. It makes its first appearance in the Calcaire Grossier; and is met with in various Tertiary deposits.

SUB-FAMILY GLOBIGERINÆ.

Genus IV.—Globigerina (Williamson, Figs. 116—118; and Plate XII, fig. 11).

292. *History.*—The only distinct notice of the shells belonging to this type, that has been detected in the writings of the earlier authors who have treated of Foraminifera, occurs in the great work of Soldani (CI); who has figured and described the form now known as *Globigerina bulloides* under the names *Polymorphia tuberosa* and *P. globulifera*. The genus was first characterised by D'Orbigny (LXIX) in his earliest classification of Foraminifera; and it has been adopted by all subsequent systematists.

293. *External Characters and Internal Structure.*—The name given by D'Orbigny to this type is very expressive of the globose aspect which its segments generally present. In its typical form, the *G. bulloides* of D'Orbigny, the shell consists of a series of eight or ten such segments, increasing rapidly and pretty regularly in diameter from about 1-2000 to 1-80th of an inch, and arranged in a turbinoid spire, forming from two to three convolutions. The segments are always somewhat flattened against one another at their planes of junction; and sometimes this flattening extends over a pretty large surface. The entire series of segments shows itself on the upper side; but on the lower side only the segments forming the latest convolution are prominent, these being usually four in number, and being arranged symmetrically around a deep umbilical depression or "vestibule," the bottom of which is formed by the segments of the earlier convolution. Into this vestibule each segment opens by a large crescentic orifice, the several chambers having no direct communication with each other. The entire shell of the ordinary type may attain a diameter of about 1-30th of an inch, but it is usually much smaller.—This typical form, however, is subject to very considerable modifications. Thus in the *G. helicina* the later chambers lose their spheroidal form, and become flat, outspread, and loosely lobulate or palmate (Plate XII, fig. 11); thus exhibiting a manifest tendency to that remarkable departure from the ordinary plan of growth, which reaches its full development in *Carpenteria* (¶ 308). On the other hand we observe in certain *Globigerinæ* (as the *G. hirsuta*) a decided tendency towards the symme-

trical plan of growth, so as to give them somewhat of a nautiloid aspect, their essentially globigerine character, however, being still marked by the distinctness of the apertures of the several segments: and other forms are flat, with raised edges and elevated septal bands.

294. The newly formed segments of *Globigerina* have their chamber-walls composed of a hyaline shell-substance, which is perforated by minute tubuli of uniform size arranged at pretty regular distances. The diameter of these tubuli varies in different specimens from about 1-10,000th to 1-5000th of an inch; but we nowhere meet with any pores at all approaching in size to the large pores of *Orbulina*, nor do we find pores of two very different dimensions coexisting in the same individual. In the *Globigerinæ* of shallow waters, the walls of the chambers retain through life their original thinness and transparence; but in those of deeper seas they are generally thickened by exogenous deposit, the surface of which is raised sometimes into minute tubercles, and sometimes into ridges, in the depressions between which are seen the orifices of the pores; and specimens are frequently met with, in which the ridges form a regular reticulation, with the opening of one of the pores in each areola. Sometimes the ridges bear acicular prolongations; as is well seen in some of the symmetrical specimens that abound in the Red Sea, in which the needles are so long as to subdivide the large arched aperture of the later chambers. In other instances, again, the entire ridge surrounding each areola rises so high from the surface, as actually to form a tube that encloses the pseudopodium in its course outwards from the pore of the chamber-wall; this peculiar condition has been observed in nautiloid (symmetrical) specimens from 1600 or 1700 fathoms' depth between Malta and Crete and from the deeper parts of the Red Sea.

295. Each chamber is occupied during life by a reddish-yellow segment of sarcode, from which pseudopodia are seen to protrude; and it seems probable that the sarcode-body also fills the umbilical vestibule, since without some such connecting band it is difficult to understand how the segments which occupy the separate chambers can communicate directly with each other, or how new segments can be budded off. It has been noticed by Dr. Wallich (CIV *a*) that in the *Globigerinæ* brought up from great depths the hue of the sarcode-body is dingy, and inclines rather to brown than to yellow; whilst its particles are less united into a viscid mass, and more disinclined to coalesce again after being crushed asunder, than they are in the specimens obtained from shallower waters. Moreover, he has in no instance seen the pseudopodia extended in deep-sea specimens; but their surface, when they are newly taken out of the water, is studded with little yellow-coloured masses, closely applied to, and somewhat larger than, the apertures from which they emerge; and these masses are not unfrequently visible even on the surface of the dry shell.

296. *Affinities.*—This genus stands alone among the polythalamous Foraminifera of the hyaline series, in having its shell composed of an aggregation of segments which are merely connected by external adhesion, and have no internal communication with each other. In this respect it corresponds with *Dactylopora* and *Acicularia* among the porcellanous forms; bearing, like them, a really stronger resemblance to its monothalamous than to its polythalamous congeners (¶ 203). If the new segments of *Orbulina*, instead of detaching themselves (as they ordinarily seem to do) previously to the formation of their investing shell, were to

remain in continuity with that from which they are put forth (as they do in exceptional cases), we should have the likeness of *Globigerina*, differing solely in the presence of the large pores which constitute the distinctive feature of *Orbulina*. Again, the wildly growing forms of *Globigerina* obviously tend towards *Carpenteria*, as will be evident when the remarkable structure of that genus shall have been explained. By its symmetrical variety, *Globigerina* is shown to be related to those nautiloid Foraminifera which are the highest types of the hyaline series. But its nearest relationships are to its congeners *Pullenia* and *Sphæroidina*, and to the Rotaline genera *Discorbina* and *Planorbulina;* the smooth-walled compact *Globigerinæ* (such as have been named *G. inflata* by D'Orbigny, v) presenting a close approximation to specimens of *Pullenia obliquiloculata* of Parker and Rupert Jones (a variety of the *Nonionina sphæroides* of D'Orbigny) brought up from great depths; the large, extremely thick-walled, compact *Globigerinæ* of the deepest waters approaching in like manner to the equally abyssal solid *Sphæroidinæ;* and the moderately depressed flat-chambered forms presenting a strong resemblance to certain modifications of the Rotaline type.

297. *Geographical Distribution.*—This genus ordinarily inhabits the deeper waters of the ocean, through which it is very extensively distributed, although not as universally as has been represented. It is not common in shore-sands or in dredgings from shallow waters; but often presents itself in extraordinary abundance in deep-sea dredgings, and in the contents of the scoop attached to the deep-sea sounding-apparatus. Thus Mr. Parker found it to constitute 97 per cent. of the soundings brought up by Capt. Dayman from a depth of 2000 fathoms in the Mid-Atlantic; and Dr. Wallich (CIV *a*) met with a like proportion in soundings taken between Cape Farewell (Greenland) and the island of Rockall, at depths respectively of 1260 and 1607 fathoms. The surface-layer of the "ooze" seems to be formed of living shells; whilst its principal mass consists of the *exuviæ* of preceding generations. It is a remarkable fact that the occurrence of *Globigerinæ* in any quantity in the deep-sea deposits of the Northern Atlantic Ocean is associated in an intimate manner with the presence of the Gulf Stream or its offshoots. Thus they abound in the soundings taken between Ireland and Newfoundland, in those taken between the Faroe Islands and Iceland, and in those taken midchannel between Iceland and Greenland,—diminishing, however, towards the latter coast; whilst from the soundings taken between Greenland and Labrador they are entirely absent. Again, they have been found in the deep waters off Shetland more abundantly than in the neighbourhood of any other portion of the coast of Great Britain; and they are also met with on the northern coast of Norway. This association appears to be wholly irrespective of the direct drifting action of the Gulf Stream, which can scarcely extend to the profounder depths of the ocean; and it would rather seem to depend on the presence in it of a large quantity of organic particles, derived from the Gulfs of Mexico and Florida, or from the Sargasso fields, which afford nutriment to the *Globigerinæ*. The genus is also met with, frequently in such abundance as to constitute 50 per cent. of the "ooze," in the deeper waters of the Mediterranean and the Adriatic, in the Red Sea, and in the neighbourhood of the Canaries, the West Indian Islands, the eastern and western coasts of South America, St. Helena, and the Isle of France. On the other hand, in the deep sea-soundings taken in various parts of the great "Coral Sea," *Globigerinæ* do not seem to occur.

298. *Geological Distribution.*—As far as is yet known, this genus first presents itself in

the Gault, in which it is small and not abundant. It is, however, extremely abundant in the Chalk-marl and Chalk, forming a considerable proportion of some specimens of those deposits; and it occurs in nearly all Tertiary beds of deep-sea origin,—the Vienna and Sub-Apennine Tertiaries yielding it in greater amount than the basins of Paris and Bordeaux.

Genus V.—PULLENIA (Plate XII, fig. 12).

299. *History.*—The generic designation *Pullenia* is applied by Messrs. Parker and Rupert Jones to a minute form which has been represented by M. D'Orbigny (Modèles, No. 43) under the name of *Nonionina sphæroides*, and has been subsequently described by him (LXXIII) under the name of *N. bulloides*. It differs so widely from the ordinary *Nonioninæ* (which we shall hereafter see to be low forms of *Polystomella*), and presents such features of approximation to *Globigerina*, as to justify its being ranked as an aberrant form of the group of which the latter is the type; whilst it is differentiated from all other forms at present known by characters that are of sufficient importance to justify its being ranked as a distinct genus. The place here assigned to it will be found to harmonise in a remarkable manner with the peculiarity of its geographical distribution.

300. *External Characters and Internal Structure.*—The shell of *Pullenia* has a globose form, the distance between its two poles being nearly or quite as great as the diameter of the spire (Plate XII, fig. 12). It is formed of a series of segments following one another in a symmetrical or nautiloid spiral, the number of these segments in each turn of the spire being usually four or five; each whorl is normally invested by that which succeeds it, the chambers of the latter being prolonged on either side to the centre of the spire; and the last chamber is usually large, occupying about one third of the lateral aspect of the spire. The septal plane is a narrow crescent (fig. 12, *a*); and the aperture is a very elongated fissure, extending almost from one point of that crescent to the other. The segments are in general but slightly convex, without any considerable depressions at their junctions; but sometimes they are turgid or vesicular, and obliquely coiled, like the chambers of *Globigerina;* and it may then happen that they do not so far extend themselves over the preceding whorl as to conceal it, so that the whole spire remains visible. These minute shells are extremely glassy in their texture, and their pores are fine. They are among the smallest Polythalamia at present known; their diameter averaging 1-50th and never exceeding 1-30th of an inch.

301. *Affinities.*—This type is related to *Globigerina* in the simplicity of its structure, and in the occasionally globigerine character of its chambers, as well as in the wideness of their aperture; whilst among true *Globigerinæ* there are some forms which approach it in mode of growth. On the other hand, it is related to *Nonionina* in its plan of growth, and in the comparative fineness of its porosity.

302. *Geographical and Geological Distribution.*—The home of this genus—like that of *Globigerina*, but unlike that of *Nonionina*—is in the deep seas, especially those of warm

climates; its occurrence being rarer and its examples smaller in shallower waters, and in the seas of northern temperate or arctic regions. It makes its first appearance in the Chalk-marl, and has been recognised also in the London Clay; but it is most abundant in the Vienna, Grignon, Sienna, and other Tertiary deposits.

Genus VI.—SPHÆROIDINA (Plate XII, fig. 13).

303. *History.*—The first account of the very peculiar type known under the name of *Sphæroidina* seems to have been given by M. D'Orbigny in 1825 (LXIX); but he confesses himself to have so far misunderstood its plan of growth, as to have erroneously placed it among his *Enallostègues*. Subsequently (LXXIII) he was induced to place it among his *Agathistègues*, in immediate association with the *Miliolinæ* series, to which its relationship, according to our view, is analogical only.

304. *External Characters and Internal Structure.*—The shell of *Sphæroidina* is most distinctly vitreous and perforated; but its porous texture is finer than that of *Globigerina*. It consists of a series of segments which succeed one another in a loosely turbinoid spire, having but four or five chambers in each turn. These segments are turgid and vesicular, like the chambers of *Globigerina;* but each invests a large part of the preceding, so that only three segments are usually visible (Plate XII, fig. 13). The aperture is generally more or less crescentic in form, and is situated at one side of the last chamber close to the exterior of the oldest visible segment; it is partly occupied by a projecting tongue or valve, which strongly resembles that of *Miliola;* and while its form sometimes approaches that of a *Spiroloculina* (Plate VI, fig. 18), it as frequently approaches that of a *Biloculina* (Plate VI, fig. 7). Sometimes its margin has deep radiating notches.—A curious variety is presented by certain examples of *Sphæroidina*, whose chambers, instead of being in close contact with one another, are separated like the segments of a dehiscent fruit; the intervals, however, being partly bridged over by shelly bands.

305. *Affinities.*—It will be obvious, from what has now been stated, that both in the structure of the individual segments, and in the general mode in which they are arranged, there is a very close resemblance between *Sphæroidina* and *Globigerina;* the difference between these types chiefly consisting in the continuous communication of the chambers of the former, one with another, and in its valvular aperture, as also in the degree in which its earlier segments are overgrown by its later. There is no real correspondence in plan of growth between *Sphæroidina* and *Miliola;* so that the only point of resemblance between them consists in the valvular aperture that is common to both.

306. *Geographical and Geological Distribution.*—It is not a little confirmatory of the correctness of the place we have assigned to this type, that its *habitat* should remarkably correspond with that of *Orbulina, Globigerina,* and *Pullenia;* the home of these four types being at depths in the ocean at which other Foraminifera are comparatively rare. It is found especially, but not exclusively, in the seas of the warmer regions of the globe.—The first

appearance of *Sphæroidina* in geological time is in the Chalk of Bohemia and Westphalia (LXXXV, XC *b*); and it occurs in various Tertiary formations, especially those of Vienna and Sienna.

Genus VII.—CARPENTERIA (Plate XXI).

307. *History.*—The genus *Carpenteria* was established by Dr. J. E. Gray in 1858 ('Proceedings of the Zoological Society,' April 27) on the basis of a remarkable set of specimens collected by Mr. Cuming in the Philippine seas, which had been supposed by several experienced Conchologists to be sessile Cirripedia. Dr. Gray was led by his examination of them to regard these organisms as a connecting link between Sponges and Foraminifera; the shell being multilocular and minutely foraminated like that of the Rotaline family of Foraminifera, whilst the fleshy substance occupying its chambers is strengthened with spicules like those of Sponges.—The larger number of the specimens of this type in the collection of Mr. Cuming are attached to the surface of a piece of *Porites* (coral); other specimens, however, are adherent to the shells of *Pecten* and *Cardita;* and Mr. W. K. Parker has met with them on the surface of other Bivalves, especially *Chama gigas.*

308. *External Characters.*—The ordinary external aspect of *Carpenteria,* as represented in Plate XXI, figs. 6, 14 (taken from a group on the surface of *Porites*, of which the individuals are in close proximity to each other), at once suggests a resemblance to the Balaniform type; the shell being conical, attached by its broad base, furnished with a single definite aperture at its apex, and presenting an appearance of irregular divisions into triangular segments, which might easily be supposed to be "valves" bounding a single undivided cavity. On breaking into the interior of the shell, however, it immediately becomes apparent that the foregoing resemblance is superficial only; the entire cavity of the shell being divided into numerous chambers, which are completely separated from each other by septa, whose lines of junction with the external wall (indicative of the successional additions which the shell has received) give rise to the appearance of valvular divisions. And a closer examination reveals that these chambers are disposed upon a spiral type, each whorl completely investing (save on the adherent base) that which preceded it, so that only the external wall of the last whorl is anywhere seen on the surface. In the specimen represented in fig. 7, which is one of the isolated individuals occurring on the valve of a *Pecten*, the shell has a much less regular form, owing to the more or less complete divergence of the basal portions of the chambers of the last whorl, and the partial subdivision of some of those chambers into lobes which exhibit the like divergence. The shelly surface of the wall of each chamber presents a somewhat areolated aspect, which depends upon its being raised into a multitude of low rounded elevations (fig. 10); and under a sufficient magnifying power these areolæ are seen to be pretty uniformly marked with minute punctations (fig. 12, *a*, *a*). The form of the aperture at the summit of the cone, of which two examples are shown in figs. 8, 9, presents a striking resemblance to that of the aperture of the *Milioloid* Foraminifera. In some of Mr. Parker's specimens, the oral ring is extended upwards into a tube or syphon at least equal in length to the radius of the cone.

309. *Internal Structure.*—On breaking away a portion of the external wall of the last-formed chamber, so as to lay open its interior (as shown in fig. 10), we find that its cavity is closed-in on every side by its shelly walls, except where it has communications (*b*, *c*) with the apical aperture; and each principal chamber is partially subdivided by a system of shelly septa, of which some are more and others less complete. The more complete of these secondary septa (fig. 10, *e*, e^1, e^2) resemble the principal septa (*d*, d^1, d^2) which separate the cavities of the chambers, in running from the base towards the apex of the cone; they divide the lower portion of each chamber into three, four, or more digitations, which are sometimes marked by an external lobulation, as shown in fig. 7; they stop short, however, about half or two-thirds of the way towards the apex, leaving the upper third or half of the chamber undivided. Some of these septa do not reach the opposite surface of the chamber; and the least complete (*f*, f^1, f^2) form a sort of network of ridges slightly projecting from the inner surface of the outer wall into its cavity (as shown in vertical section at *b*, *b*, *b*, fig. 18), and there marking out an areolation which corresponds to that of the external surface. The areolæ of the internal surface, however, are concave instead of convex; and the punctations, which are wanting on the ridges, are set more closely on the depressions between them (fig. 12, *b*, *b*, fig. 16). The reason of this peculiarity in their distribution will be presently seen.

310. The cavity of the last chamber communicates with the external orifice by a passage of considerable size; and the wall of this passage is distinctly continued as an irregular ring around the apical aperture, so that this aperture may be considered in one sense (as described by Dr. Gray) to belong to the last chamber alone. But it would be more correct to say that each chamber as it is formed *conceals*, than (with Dr. Gray) that it *closes*, the aperture of the preceding chamber; for a careful examination shows that the external aperture or vent is the termination of an irregular vertical canal, formed by the superposition of the oral rings of successive chambers; and that through this canal the previously formed chambers retain their original connexion with the exterior. The general disposition of the chambers around the central canal is well shown by sections of the cone taken parallel to its base (fig. 11); such sections, however, may only bring into view the last or superficial whorl; and they will generally show only one or two chambers in communication (as at *b*, *c*) with the vertical canal *a*, the communicating passage of each chamber being on a different plane.

311. The foramina which pierce the outer wall of each chamber are of considerable size, as compared with the minute tubuli characteristic of the *Nummulinida*, and they are not nearly so closely approximated; in both respects they correspond closely with the foramina of the ordinary *Rotaliæ* and *Globigerinæ*. In fig. 13 they are shown as they appear in a section traversing the wall somewhat obliquely to its surface, whilst in fig. 18 they are shown as they appear in vertical section; and in each case they are seen to present an annulated appearance, which is due to constrictions of the tubes at tolerably regular intervals. These tubes generally pass direct from one surface to the other; but at *a*, *a*, fig. 18, it is seen that in the neighbourhood of the ridges which project from the inner wall into the cavity of the chamber, the tubes either bend or incline themselves in such a manner, that, whilst their external orifices are pretty uniformly distributed (fig. 12, *a*), their *internal* orifices do not show themselves upon the ridges, but are crowded together along their bases (fig. 12, *b*, and fig. 16). The septa, whether *primary*

(separating the chambers from each other) or *secondary* (partially subdividing the chambers), are obviously formed by a doubling-in of the outer wall, so as to make each septum consist of two laminæ (fig. 13, *a*, *a*); this is seen also in sections of the incomplete septa (fig. 13, *b*), as well as of the ridges which may be considered as rudimentary septa (fig. 18, *b*, *b*, *b*). The two layers sometimes separate from each other, as shown in these figures, so as to leave intraseptal spaces; and these form a tolerably regular canal-system, which may be traced throughout the network of ridges that covers the inner wall of each principal chamber, and, through the primary septa, into the ring that surrounds the vertical canal (fig. 11, *g*, *g'*).

312. Notwithstanding these marked peculiarities in the general plan of conformation of *Carpenteria*, a comparison of specimens in different stages of evolution, and the removal from the older specimens of one whorl after another until the original nucleus is arrived at, make it evident that the early condition of this organism essentially accords with that of the Globigerine type of Foraminifera,—its approximation being the closest to *Rotalia* in general form, but its tendency being rather towards *Globigerina* in the circumstance that its chambers do not seem to communicate directly with each other, but that each has a separate external orifice directed towards the umbilicus. Various aspects of this first-formed portion of the shell, three of them showing the animal substance contained in the chambers, are seen in Plate XXI, figs. 1—5. Now supposing that a *Globigerina* were to grow in such a manner, attached by one of its surfaces, that the walls of its successively-formed chambers came into mutual contact, and that these chambers were so shaped and so piled one on the other as to give to the entire shell a conical form, each chamber opening by its own separate orifice into an umbilical funnel, we should have the essential type (so far as its shell is concerned) of *Carpenteria;* and this is really the mode in which the latter type is superinduced upon the former, as the development of the organism advances. It is further interesting to observe that the great size of the chambers which form the superficial whorl of *Carpenteria*, has every appearance of being due to the deficiency of that complete segmentation, in the later stages of growth, which characterises the earlier; for every one of the *loculi* marked out by the ridges projecting into the interior corresponds so closely both in size and general aspect with an entire chamber of the earlier whorl, that the areolation of the outer wall may be regarded as a sort of attempt at that complete subdivision of the cavity, which we shall see to be fully carried out in *Heterostegina*.

313. The animal substance which occupies the chambers (figs. 1—4) is peculiarly spongeous in its texture; not only possessing (according to the evidence afforded by the dry specimens which alone I have had the opportunity of examining) far more consistence than the sarcode-body of the Foraminifera, but being supported, in the larger chambers at least (fig. 11), by sponge-like spicules (fig. 17), whose form resembles that of the simplest spicules of *Halichondria*, and whose composition is siliceous.—It may be undoubtedly urged that as the surface of dead Coral and the valves of living as well as dead Shells are frequently covered with Sponges, any multilocular organism growing on such surfaces might be so penetrated by the sponge, that all its chambers would be filled by the parasite. The following considerations, however, seem to me strongly to militate against the applicability of such an explanation to the present case:—1st. That neither on the surface nor in the substance of the specimen of

Porites covered with the cones of *Carpenteria*, nor on that of the valves of the *Pecten* and *Cardita* on which isolated specimens of *Carpenteria* occur, is there the least trace of spongy structure:—2nd. That, notwithstanding this marked difference in their *habitats*, all the specimens of *Carpenteria* yet examined have their cavities occupied by the same spongy substance: —3rd. That a firm brownish-yellow substance of far greater consistence than the sarcode of other Foraminifera is found to occupy even the smallest and earliest chambers of *Carpenteria* (figs. 1—4, *a*), filling them so completely that it can scarcely be supposed to be anything but the animal body properly belonging to them; and that although the substance in question is *there* destitute of spicules (the chambers being too small to accommodate them, as will be seen by the comparison of figs. 4 and 17, allowing for the difference of magnifying power), yet it is obviously the same with that in which spicules are copiously imbedded in the larger and later chambers:—and 4th. That notwithstanding the multitudes of sections of various Foraminiferous shells which I have made during the last ten or twelve years, I have never found their chambers to be occupied by a parasitic Sponge of any description, even where they have been completely overgrown by Sponge externally.

314. *Affinities.*—Although, from the account I have given of the structure of this polythalamous shell and its contained body, it will be seen that I can only partially admit the correctness of Dr. Gray's original comparison of the organism to the papilla of a sponge enveloped in a shelly case with a single terminal oscule, yet we seem fully justified in regarding it as a very interesting link of connection between Foraminifera and Sponges. Its nearest relationships are (as just now stated) to the genera *Globigerina* and *Rotalia*; and the peculiar modification of their plan of growth which its shell presents, although by no means removing it from the category of ordinary Foraminifera, certainly gives it an analogical resemblance to the Poriferous type, and thus renders it additionally probable that the spongeous body which is found in its interior is really its own. If this body be not parasitic, its presence obviously establishes a near and direct relationship between *Carpenteria* and the Spongiadæ.

315. *Geographical and Geological Distribution.*—All the recent specimens of *Carpenteria* hitherto known have been obtained from the Indian Ocean. The wide departure which some of them present from the typical form makes it not unlikely that we are to refer to this genus certain minute fossils, such as the *Chrysaora* (*Neuropora*, Bronn) *damæcornis* of Lamouroux from the Oolite, the *Thalamopora vesiculosa* of Michelin from the Greensand, and the *Ceriopora* (*Thalamopora*, Rœmer) *cribrosa* of Goldfuss from the Chalk, all of which present characters that differentiate them from the Corals and Sponges with which they have been usually associated, and suggest their relationship to *Carpenteria*.

SUB-FAMILY TEXTULARINÆ.

Genus VIII.—Textularia (Plate XII, figs. 14, 15, and Williamson, Figs. 158—168).

316. *History.*—Under the comprehensive name *Polymorphium* various examples of what is now known as the Textularian type were described and figured by Soldani (c1); but they

were not differentiated by him from other types associated under the same designation. This differentiation was first made by Defrance (XXIX), to whom we owe the establishment of the genus *Textularia*, which has been adopted by all subsequent systematists. With this genus we find the *Bigenerina*, *Gemmulina*, *Gaudryina*, *Verneuilina*, and *Vulvulina* of D'Orbigny (the last being the *Grammostomum* of Ehrenberg) to be not less intimately connected by gradational links than are the thirteen reputed genera which we have reunited under the genus *Nodosarina*: and we therefore regard them as merely varietal forms of *Textularia*. The *Candeina* of D'Orbigny appears to have more claim to rank as a sub-genus.

317. *External Characters.*—The shell of *Textularia* essentially consists of a binary series of segments arranged symmetrically on the two sides of a longitudinal axis; the segments of one side alternating with those of the other, and each segment communicating with the segments anterior and posterior to it on the opposite side (Plate XII, fig. 14). As the size of the segments usually increases progressively, the outline of the shell is generally more or less triangular; the apex of the triangle being formed by the first segment, and its base by the last two. Sometimes, however, the later chambers do not exhibit any progressive increase, so that the previously diverging sides of the triangle become parallel; and sometimes they even undergo a progressive decrease, so that the sides converge again. The two lateral faces of the shell usually show more or less of compression; being sometimes nearly flat, with rounded margins, so that its transverse section is more or less oblong (cx, Figs. 162, 163, 168); whilst in other instances the shell is more compressed, but is most prominent along the axial line, thinning away at the margins (cx, Figs. 158, 159, 164, 165), which may even be sharply carinated, as in the *T. carinata* of D'Orbigny. Sometimes, on the other hand, the two lateral faces, instead of being compressed, are so rotund that the transverse section becomes nearly circular, so that the form of the shell is almost conical (cx, Figs. 160, 161). The mode in which the segments are applied one to the other, also, is subject to considerable variation. In some instances they are almost spheroidal in shape, and are merely flattened against each other where they come into mutual contact (cx, Figs. 162, 168); but in general they are more or less depressed and elongated; and whilst the direction of their longer axes seems to be typically at right angles, or nearly so, to the axis of growth (cx, Fig. 158), it is sometimes considerably inclined to this (cx, Figs. 164, 166). It is usually in those very compressed forms which are thinnest at the margins, that the obliquity of the long axes of the segments is the greatest; and sometimes the outer margin of each chamber is prolonged into a sort of spine (cx, Figs. 166, 167). In these also we often find the inner margin of each segment prolonged across the longitudinal axis, so as to interdigitate with the alternate segments on the other side. Between all these forms there is a completely gradational series, as Professor Williamson has already pointed out (cx, p. 75). Again, some *Textulariæ* commence with a *flat* Operculine spire, and subsequently change to a *high* one; just as certain small long-spired Gasteropods begin like a Planorbis. Further, in certain attenuated *Textulariæ* from the Red Sea, the axis of growth slowly twists upon itself, so that the later pairs of alternating segments are at right angles with the earlier. Thus it is clear that in this type there is no less variety in regard to external configuration, than we have seen to exist elsewhere.—The aperture is very constant as to form and position, being a crescentic slit in the inner wall of each chamber close to its junction with the antecedent segment of the opposite side (cx, Figs. 159, 161, 163, 165, 167).

In the *Textulariæ* whose segments are most globose, the crescentic aperture may increase in breadth so as to become semilunar or even gibbous; whilst in those whose segments are most depressed it may be narrowed to a mere slit.

318. The proper substance of the shell is hyaline, with large pores usually not very closely set, though in some varieties more minute and more nearly approximated; it is occasionally to be observed that the pores open at the surface into deep hexagonal pits. It very commonly happens, however, that the shell, as it increases in size, becomes incrusted with arenaceous particles, which are commonly large and coarse, and which may entirely conceal the pores from superficial observation; and in some of the smallest examples from deep water, the shell-substance appears externally to be almost as completely replaced by an aggregation of fine sand-grains as it is in *Lituola* or *Valvulina*. In the coarsest *Textulariæ*, however, I have never failed to bring the pores distinctly into view by examining the shell by transmitted light when rendered sufficiently transparent by the removal of the wall on one side; and in the smallest and finest I have been able to distinguish the pores in the interspaces between the sand-grains, when I have made use of a sufficient magnifying power.—It is in some of the large fossil *Textulariæ* that the arenaceous incrustation is the coarsest in its texture, so as to give the greatest roughness to the surface.

319. *Internal Structure.*—When the shell is laid open by section, we find that its structure is of the simple type that might be expected from its external configuration. Each segment is so applied to those which preceded it, that its inner wall is partly formed by the inner wall of the alternate segment which it follows, whilst its posterior wall is formed by the anterior wall of the penultimate segment of its own series. Thus the septal lamella is always single; and there is no differentiation between its texture and that of the rest of the chamber-wall. The apertural passages by which each chamber communicates with that which precedes and with that which follows it, are very near to each other; as is well shown in Plate XII, fig. 14, which represents the body of the animal and the membranous basis of the shell after the removal of its calcareous substance by dilute acid, and in Plate XXII, fig. 9, which represents a siliceous cast of the body of a *Textularia* from the Greensand. It thus becomes obvious that the plan of growth depends upon the oblique gemmation of the successive segments of the animal body, alternately towards one side and then towards the other; and it is very easy to see how such a bi-serial arrangement may become either uni-serial or tri-serial. —In some of the largest fossil *Textulariæ*, the principal cavities of the chambers are irregularly subdivided by secondary partitions, as in *Lituola*.

320. *Sub-generic Modifications.*—The genus *Bigerina* of D'Orbigny is nothing else than a *Textularia* which passes from the bi-serial to the uni-serial plan; the alternating arrangement of the segments giving place to a single rectilineal succession resembling that of *Nodosaria;* and the aperture becoming central and circular, sometimes with a lip that may even be slightly elongated outwards into a tube. A like change in the plan of growth, the aperture remaining marginal, gives rise to the form distinguished by D'Orbigny as *Gemmulina*. In the *Gaudryina* of D'Orbigny, again, the arrangement of the chambers is at first tri-serial, as in the typical *Valvulina* (¶ 220); but in the course of growth, the tri-serial alternation gives place to the

bi-serial. And in the *Verneuilina* of D'Orbigny, the arrangement may either remain tri-serial through all the stages of growth, or may become "bulimine," or may give place to a uni-serial succession, in which last case the shape becomes nail-like, so nearly resembling that of some *Valvulinæ* (¶ 221) as only to be distinguishable by the want of the valve characteristic of the latter. The genus *Clavulina* of D'Orbigny is made up of these clavuline varieties of *Valvulina* and *Verneuilina*.—The *Vulvulina* of D'Orbigny (the *Grammostomum* of Ehrenberg), on the other hand, is a very obliquely chambered *Textularia*, of which the aperture is a narrow fissure, situated at the most anterior portion of the segment, and lying parallel to the plane of compression (Plate XII, fig. 15). This form, too, may become uni-serial.—In all these modifications of the Textularian type, the shell is as frequently arenaceous as it is in the typical *Textularia*; it is an arenaceous example of the Verneuiline type, which is figured by Professor Williamson (cx, Figs. 136, 137) under the designation *Bulimina arenacea*.—Lastly, the *Candeina* of D'Orbigny is a form in which the chambers present the "globigerine" shape and looseness of aggregation, and are disposed with something of a tri-serial or "verneuiline" arrangement in a turbinoid spire; the aperture is represented by him (LXXIII) as an elongated fissure bridged over by bars of shell so as to be divided into a row of pores; but these pores do not represent the true aperture, being only the ordinary pseudopodian passages of the shell-wall, which are peculiarly large and crowded together along the side of the septal line of the newest chamber. In its mode of growth this sub-genus is so closely paralleled by *Verneuilina* (*Bulimina*, Egger) *pygmæa*, that it may be questioned whether its distinctive modification is of more than varietal importance.

321. *Affinities*.—It is obvious from the intimacy of the relationship between the tri-serial, bi-serial, and uni-serial forms of *Textularia*, that we are to regard it as essentially a trochoid spire, of which the chambers may be three or two in each turn, or which may straighten itself out by the rectilineal instead of the zig-zag gemmation of its segments. In some of the small loosely-piled varieties of *Textularia*, there is obviously a very near approach to *Globigerina* in the form and disposition of the segments. On the other hand, its larger tri-serial and more trochoid forms tend on the one hand towards certain aberrant forms of the *Bulimine* series, and on the other towards the arenaceous *Valvulina*, to which genus, as already explained, their relationship is extremely close.

322. *Geographical Distribution*.—This type is among the most cosmopolitan of Foraminifera; presenting itself under some of its forms in sands from all shores and in dredgings from shallow or moderately deep waters. It occurs in greatest abundance, and attains its largest size, in the tropical and warmer temperate seas; its finest examples ranging from shallow waters to a depth of 200 or 300 fathoms.

323. *Geological Distribution*.—The Textularian type can be traced very far back in geological antiquity, being recognisable even in the Palæozoic period. It becomes much more abundant and varied, however, towards the end of the Secondary period; its siliceous casts being common in the Greensand, and its shells being frequently met with in the Chalk. It is in the Tertiary strata, however, that its fossil forms present their greatest multiplication and diversity; and the various modifications of this type at present existing are closely

paralleled by those which occur in the Miocene and Pliocene deposits of Vienna and Palermo.

Genus IX.—Chrysalidina (Plate XII, fig. 16).

324. *History.*—This genus was created by D'Orbigny in 1846 (lxxii), for the reception of a peculiar modification of the Textularian type, which, so far as is at present known, is not connected with it by any intermediate gradations.

325. *External Characters and Internal Structure.*—The name of this genus expresses the pupoid form of its shell, which results from the tri-serial arrangement of its chambers, and from the peculiar oblique mode in which they are set one upon another, as shown in Plate XII, fig. 16. The essential difference of this type, however, from *Textularia* appears to consist in the mode of communication of the chambers; for the apertural passages by which each chamber of one series communicates with the alternating chambers of the adjacent series in the tri-serial *Textulariæ* seems to be here wanting; being replaced by a set of very large "orbuline" pores, which are dispersed over nearly the whole anterior wall of the last chamber. These pores, which have fully twice the diameter of the ordinary pores of the shell, are sometimes continued externally into short tubes, which project fully the length of their own diameter from the convex septal plane. From the mode in which the older segments are partially overlapped by the newer, the communication between each chamber and that which succeeds it in the spiral alternation will be maintained by those pores which pass through that part of the anterior wall which forms the posterior wall of the next chamber.—The most characteristic specimens of this type present themselves only in the Lower Chalk, near the mouth of the river Charente; but small dimorphous examples of it are met with in the Indian Ocean and Panama Bay, which, commencing tri-serially, soon take on a uni-serial mode of growth, continuing to maintain their triangular form to the end, and progressively increasing the size of their segments, which is contrary to the rule of uni-serial growth in other bi- or tri-serial types.

Genus X.—Cuneolina (Plate XII, fig. 17).

326. *History.*—The first and only original account of this curious type is that which was given by M. D'Orbigny (lxxi) in 1839, on the basis of specimens found only (like those of the preceding type) in the Lower Chalk, near the mouth of the Charente.

327. *External Characters and Internal Structure.*—The form of this shell (Plate XII, fig. 17) is that of an almost equilateral triangle with a curved base; and its two flattened surfaces are marked by a succession of parallel curved septal bands, apparently indicating a uni-serial succession of chambers whose breadth bears an unusually large proportion to the distance between the septa. When the shell is viewed edgeways, however, it is seen that the two external surfaces belong to two different series of chambers, whose internal surfaces are closely applied to each other; and it is further to be noticed that the chambers of the two series

alternate with each other. The aperture consists of a number of distinct pores arranged in a single series along the whole extent of the apertural plane, as in the most flattened form of *Peneroplis;* and these are so obliquely disposed, that each chamber communicates by their means with the alternating chambers below and above it in the opposite series.

328. *Affinities.*—It is obvious from the preceding description, that *Cuneolina* is nothing else than a *Textularia* which is extremely compressed in a direction transverse to the normal direction of its compression; for if we could imagine a *Textularia* with globose chambers to be composed of a plastic substance, it can be easily conceived that whilst by pressure applied to the two axial *faces*, those two faces might be extended and thinned out until they presented the flat triangular shape which distinguishes *Cuneolina*—each face being divided by the axial line, on the two sides of which the two series of chambers would still be disposed,—a like pressure applied to the two *margins* would flatten the two series of chambers against one another, so as to convert what were before the margins into lateral faces, and to bring to what were before the axial faces into the condition of margins, as occurs in certain aberrant *Biloculinæ*. The same change would convert the wide crescentic aperture of the ordinary *Textularia* into a narrow elongated fissure; and it is obvious that the conversion of this into a row of detached pores does not in itself remove *Cuneolina* further from the Textularian type, than *Peneroplis* is distant from *Dendritina*, or *Calcarina* from *Rotalia*. Intermediate gradational forms being here wanting, however, *Cuneolina* must, for the present at least, be ranked as distinct from *Textularia*, though in close proximity to it.

Genus XI.—Bulimina (Plate XII, figs. 18—22; and Williamson, Figs 124—135).

329. *History.*—The peculiar type to which the name *Bulimina* (expressive of the Bulimus-like form of its spire) was given by D'Orbigny (LXXIII) in 1825, does not seem to have been recognised by any preceding systematist. It has been since generally adopted in the sense in which it was originally employed; but we shall use it as the generic designation not merely for the forms included under *Bulimina* proper, but also for those belonging to the sub-genera *Virgulina* and *Bolivina*, which were instituted as genera by D'Orbigny, but were regarded by him as allied rather to *Textularia* than to *Bulimina*.

330. *External Characters and Internal Structure.*—In its typical form the shell of *Bulimina* is composed of a series of spheroidal segments progressively increasing in size, and so applied to one another by their flattened faces as to form a "bulimine" spire (Plate XII, fig. 18). The aperture is a loop-like notch in the convex wall of the last chamber, extending forwards and outwards, usually with more or less obliquity, from its umbilical margin; its shape is such that it seems as if it were formed by the folding over and convergence of the two halves of the anterior wall of the chambers (Plate XII, fig. 18), and it is noticeable that these do not commonly meet at the umbilical angle, but that one passes obliquely behind the other. The margin of the aperture is usually somewhat lipped externally; on the other hand, it is sometimes prolonged externally into a little narrow tubular neck. The shell of the smaller forms and younger specimens of *Bulimina* is hyaline and very translucent, and its

porous structure is considerably finer than that of *Textularia;* the hyaline surface is never lost in the recent examples of this type; but the larger and older fossil specimens very commonly have the shell incrusted by an adherent layer of arenaceous particles. Such arenaceous forms are very common among the *Buliminæ* of the Cretaceous deposit, of which an example is here figured (Plate XII, fig. 18). In the *Buliminæ*, as in the *Textulariæ*, the aggregation of segments takes place upon the simple plan which is common to the lower forms of the vitreous series with the whole of the porcellanous; the anterior wall of each chamber serving as the posterior wall of that which succeeds it, and the septal laminæ being single and not differentiated from the ordinary wall of the chamber. There is therefore neither intermediate skeleton nor canal-system.

331. Departures of greater or less extent from the typical character of this genus are extremely common; and such departures are especially liable to occur in regard to the plan of growth, to the form and setting-on of the chambers, and to their surface-ornamentation. Thus the obliquely spiral succession of the segments may be so modified that they come to present a more or less distinct tri-serial arrangement, of which we have a striking illustration in the *B. Buchiana* of D'Orbigny (Plate XII, fig. 19), whilst the ordinary *B. pupoides* (cx, Figs. 124, 125) presents it in a less obvious degree; and in a variety of this last form termed *fusiformis* by Prof. Williamson, the segments are chiefly added in *two* instead of in three oblique series, so that the form becomes compressed (cx, Figs. 129, 130). A still greater modification is effected by the uncoiling of the spire, so that the later segments present a uni-serial rectilineal succession, and the form of the entire shell becomes "spiroline;" of this we have an example in the varietal form described by Prof. Williamson as *convoluta* (cx, p. 63, Figs. 132, 133), of which he remarks that "it presents almost as many modifications as individual specimens."* The same condition sometimes presents itself in the *B. elegantissima* of the Indian seas; which also sometimes puts forth a few feeble "wild" segments out of the regular axis of growth. In other varieties, again, the ventricose form of the segments is modified in a greater or less degree by flattening or by drawing out in some particular direction. Thus the earlier segments may be more or less completely enclosed by the backward extension of the later. Of such backward extension we have an incipient example in *B. marginata* (xc, Figs. 126, 127), but it is carried to its fullest extent in *B. pyrula* (Plate XII, fig. 20), in which the later segments so completely enclose the earlier, that only the last three are at any time visible. By a lateral elongation of the segments, the obliquity of their setting in relation to the axis of the spire, and the flattening of their borders one against the other, that peculiar varietal form is produced which has been distinguished by M. D'Orbigny under the generic designation *Robertina* (Plate XII, fig. 21); and it is a singular instance of that want of power to discern the real affinities of the types he described, which I believe to have been induced by his misplaced confidence in plan of growth as the only trustworthy guide in the classification of Foraminifera, that he has not only separated this well-marked Bulimine type

* This form is regarded by Prof. Williamson as a *bi*-serial *B. pupoides* partly rolled upon itself; but he seems to us to have been misled by the split appearance which the shell acquires from the succession of the fissured apertures of a *uni*-serial row of segments; and we consider it, as above stated, rather as an uncoiled than as an abnormally convoluted form.

generically, but has even transferred it from his order *Helicostègues* to that of *Entomostègues*, under the influence of a misconception as to the real arrangement of its segments, without giving any other hint of its relationship to *Bulimina* than that which is afforded by his likening of the form of the entire shell to a minute *Bulimus*. In our view *Robertina* is only one of the numerous varieties presented by the *B. elegantissima* of D'Orbigny; in some of which the segments are extremely elongated laterally, and are set very obliquely to the axis of the spire, so that its last turn, consisting of from seven to ten segments, almost completely encloses the preceding, and the whole shell may have much more the form of an *Oliva* than that of a *Bulimus* (cx, Figs. 134, 135); whilst in its largest and best developed forms, which occur in Arctic regions, the alternating segments interdigitate with each other.

332. A general ornamentation of the surface is not common in this type, though we sometimes meet with a longitudinal costation (Plate XII, fig. 19) strongly resembling that of *Uvigerina*. This costation may be confined to the earlier segments, the later being quite smooth. The more usual kind of exogenous growth in this type consists in the prolongation of the posterior margin of the segments, in those varieties which are characterised by their backward extension; this prolongation may consist in a mere serration, as in the *B. marginata* (cx, Figs. 126, 127), or it may go so far as to produce a fringe of long transparent spines, the several segments of the same shell often exhibiting intermediate gradations between these two extreme conditions. In the most spinous varieties the shell itself is generally stronger than in the smooth forms; on the other hand it is thinnest in the most elongated examples, which seem to be starved out.

333. We have seen that even in the ordinary Bulimine type there is sometimes a tendency to a binary or Textularian alternation of the segments; this, however, is much more marked in certain extremely elongated forms, having a thin delicate shell that is never arenaceous, and the aperture greatly elongated but still preserving its Bulimine character. To such forms the generic name *Virgulina* has been applied by D'Orbigny; but their degree of departure from the Bulimine type is not even of specific importance, as Prof. Williamson has shown himself to have perceived, by ranking them as varieties of his *B. pupoides*.—A more decided modification of the Bulimine type is presented by those forms which have been ranked by D'Orbigny in his genus *Bolivina*, the arrangement of the segments being here regularly bi-serial and alternating, as in *Textularia;* but the aperture never loses the elongation and the inversion of its lips characteristic of the Bulimine type, and its direction is usually somewhat oblique. In the *B. costata* of D'Orbigny (Plate XII, fig. 22) there is a set of eight parallel costæ, running continuously from one segment to another along the entire length of the shell, giving to it a very peculiar aspect.

334. *Affinities.*—It is obvious from what has just preceded, that the affinity of *Bulimina* to *Textularia* is very close; since *Bolivina* will rank under one or the other of these generic types, according as we attach the greatest value to the *character of the aperture* or to *plan of growth*, as an indication of natural affinity. That the former has a far stronger claim to acceptance than the latter, appears obvious from the fact that, as we have seen, the plan of growth may vary in unquestionable *Buliminæ* from a continuous succession of segments in a bulimine spire

to a tri-serial or bi-serial alternation, and that in unquestionable *Textulariæ* the bi-serial arrangement may give place to the tri-serial or even to the bulimine; whilst through all these variations the form of the aperture characteristic of each type is constantly maintained. The relation of the large sandy *Buliminæ* to the "bulimine" *Valvulinæ* (¶ 221) is extremely intimate; the form of the segments and their mode of aggregation being the same; the originally porous texture of the shell being common to both, and being liable in both to be afterwards more or less completely occluded by arenaceous aggregation; and the difference of type being marked only by the aperture. The feebler forms of *Bulimina* are related, like those of *Textularina*, to *Globigerina;* and in some of the loosely piled tri-serial *Buliminæ* there is a strong general resemblance to certain *Uvigerinæ*, the chief differentiation being in the aperture. On the other hand, in *Bolivina punctata*, which combines a crescentic curvature of the entire shell with a bi-serial arrangement of the segments and a very oblique aperture, we have an obvious tendency towards *Cassidulina*, in which form the series appears to culminate.

335. *Geographical Distribution.*—There seems to be a close correspondence between *Bulimina* and *Textularia* as to the conditions most favorable to their development, as they are generally found under the same circumstances; the latter, however, being commonly much more abundant than the former.

336. *Geological Distribution.*—This genus has not as yet been traced, however, quite so far back in geological time as *Textularia*, its earliest appearance, so far as we at present know, having been in the Upper Trias, in which small examples of it are found; it occurs in the Oolitic formation and in the Chalk-marl, in which last deposit and in the Chalk some of its finest examples present themselves. It occurs under some or other of its forms through the whole Tertiary series, from the London Clay to the most recent formations; some of its most remarkable varieties being found in the Vienna and San Domingo deposits.

Genus XII.—Cassidulina (Plate XII, fig. 23; and Williamson, Figs. 141—144).

337. *History.*—This genus was first established by M. D'Orbigny in 1826 (LXIX) for a peculiar type, which does not seem to have been recognised by any previous observer.

338. *External Characters and Internal Structure.*—This genus is distinguished from all other Foraminifera in combining the bi-serial and the convolute arrangement of its segments: for although several other genera are associated with it by M. D'Orbigny in his order *Entomostègues*, yet in no one of them (as will hereafter appear) does this combination really exist. The texture of the shell of *Cassidulina* is hyaline and finely porous, like that of the smaller *Buliminæ;* and it resembles that type also in the characters of its aperture. In fact, if we imagine a bi-serial *Bulimina* to be completely rolled upon itself, so as to form an equilateral or nearly equilateral spire, we should have the essential features of a *Cassidulina*. The arrangement of the chambers, as it shows itself externally, has a semblance of irregularity which does not really belong to it; the apparent irregularity being really due to the interdigitation of the

chambers of the two alternating series, some of which may be made to appear by the obliquity of the spire as if they were small and intercalated (cx, Fig. 141). The earlier turns of the spire are in general completely enclosed by the later; but sometimes the axis of the spire is so oblique, that much more of the earlier portion is seen on one side than on the other. The septal plan is flat and oblique, facing alternately towards opposite sides; and the aperture is a curved slit, commencing at the junction of the septal plane with the preceding convolution, and extending about half way across the septal plane, usually in a direction parallel to its lower edge (cx, Figs. 141, 142), but sometimes becoming crozier-shaped, as in some of the uncoiled varieties, or even doubling abruptly back upon itself, so as to form a kind of valve or tongue, as in the *C. crassa* of D'Orbigny (LXXIII). The general form of the shell is subject to variations similar to those which we have seen to present themselves in *Bulimina* and *Textularia*; the segments being ventricose in some instances, and flattened in others; and the margin being obtuse and rounded in some instances, thin and carinate in others.—A much greater departure from the typical shape is presented by the *Ehrenbergina* of Reuss (LXXXVII), which is a *Cassidulina* in every essential particular, but has the later portion of its spire uncoiled, showing very clearly the bi-serial interdigitate arrangement of the segments (Plate XII, fig. 23). After the evidence which has been given in such genera as *Peneroplis* and *Nodosaria* of the little reliance to be placed on the direction of the axis of growth as a differential character, it is impossible to regard *Ehrenbergina* as anything but a varietal form of *Cassidulina*.

339. *Affinities*.—This genus may be regarded as the culminating form of the Textularian series, which nowhere graduates into any type of a character more elevated than its own. In the finely porous texture of its shell and its slit-like aperture, it is obviously more allied to *Bulimina* than to *Textularia*; whilst, in the bi-serial interdigitate arrangement of its chambers, it is more closely akin to *Textularia* than to the typical *Bulimina*.

340. *Geographical and Geological Distribution*.—Like the preceding genus, *Cassidulina* seems to have a world-wide distribution in shallow, moderately deep, or even very deep waters; being found at depths of from thirty to seventy fathoms on the west coast of Greenland, also off Norway, Shetland, and various parts of the British and Irish coasts; whilst the larger and thicker forms with smooth shining walls occur in tropical seas at depths of from thirty to one thousand fathoms.—This genus presents itself in the Tertiaries of New Zealand (Eocene?), Vienna, Sienna, and Palermo; but it has not been recognised in any older formations.

SUB-FAMILY ROTALINÆ.

341. The assemblage of forms which constitute in our view the *Rotaline* sub-family or series is the most numerous and the most varied that is presented by any corresponding group; and as a consequence of that variety, the relations of these forms to each other have been singularly misconceived. Misled by superficial differences masking real resemblances, M. D'Orbigny created several genera for their reception, which in our view have no title whatever to that rank. On the other hand, his ignorance or his want of appreciation of differences of far greater importance, led him to associate in the same genera types which

Messrs. Parker and Rupert Jones have been brought by a careful study and extended comparison to regard as essentially distinct. Thus a new distribution of the entire group becomes requisite, neither of *our* genera having the same value with any one of D'Orbigny's; and as the whole group constitutes an extremely natural series, of which there is much to be said in common, it will be convenient to treat of such generalities under this head, rather than to disperse them among the separate sections which will treat of the peculiarities of individual genera.

342. *History.*—Every systematist who has attended to such minute shells, has had his notice attracted by examples of the Rotaline series. Thus the world-wide typical *Rotalia Beccarii* and the tropical *Calcarina Spengleri* were both described in Gmelin's edition of the 'Systema Naturæ' under the generic designation *Nautilus*. A large number of Rotaline forms were described and figured in the great works of Soldani (C, CI), under the generic designations *Nautilus* and *Hammonia;* many plates being devoted to the protean varieties of the Mediterranean shell since known as *Truncatulina variabilis.* Boys and Walker (IX) described as British species of *Nautilus* not only the *N. Beccarii* (of the common "reversed" form of which they made a distinct species), but also *N. lobatulus* and *N. umbilicatulus*, which are varieties of the form since generally known as *Truncatulina lobatula.* Montagu (LXV) also enumerated *N. Beccarii* among British species; but he gave the generic name *Serpula* to two Truncatuline forms which we now place with *T. variabilis* and *T. lobatula* in our genus *Planorbulina.* The admirable work of Fichtel and Moll (XLV) contains numerous figures of the varieties of *Nautilus* (Calcarina) *Spengleri;* they distinguished as *N. repandus* the Rotaline form which we now differentiate as the typical *Pulvinulina repanda*, other varieties of which they designated as *N. sinuatus* and *N. auricula;* and they gave the name of *N. farctus* to the Rotaline form which we shall differentiate as *Planorbulina farcta*, another variety of which they designated as *N. tuberosus.* The name *Rotalites* was first introduced by Lamarck (LVII), who subsequently (LVIII) modified it to *Rotalia;* and from that time it has met with general acceptance amongst systematists, having been sometimes further modified into *Rotalina.* Particular Rotaline forms were further distinguished by Lamarck (LVIII and LIX) under the generic names *Discorbites*, *Discorbula*, and *Pulvinulus*, for the last of which he afterwards (LX) substituted *Placentula.* Although neither of these names has been generally adopted (*Discorbis* having been only employed by Blainville and by some British conchologists), yet, for reasons to be presently stated, *Discorbina* and *Pulvinulina* will be employed in the present work as generic designations. A fossil Rotaline form which occurs in the Upper Chalk of Maestricht received from Lamarck the generic name *Siderolites*, under a total misapprehension of its nature; this name, although admitted by D'Orbigny, must now be dropped, since I shall show that the type which was designated by it is only a variety of the long previously known *Nautilus* (Calcarina) *Spengleri.* It was of course to be expected that Montfort should institute many new genera for the varietal forms of this group; and accordingly we find the names *Cidarollus*, *Cortalus* (?), *Cibicides*, *Eponides*, *Storilus*, and *Polyxenes*, applied to as many Rotalines; whilst the name *Tinoporus* was conferred upon a peculiar type which he seems to have been the first to distinguish from *Nautilus* (Calcarina) *Spengleri.* All these names have long since been discarded as unnecessary synonymes; but we shall revive the last, for reasons which will be stated hereafter (¶ 390).

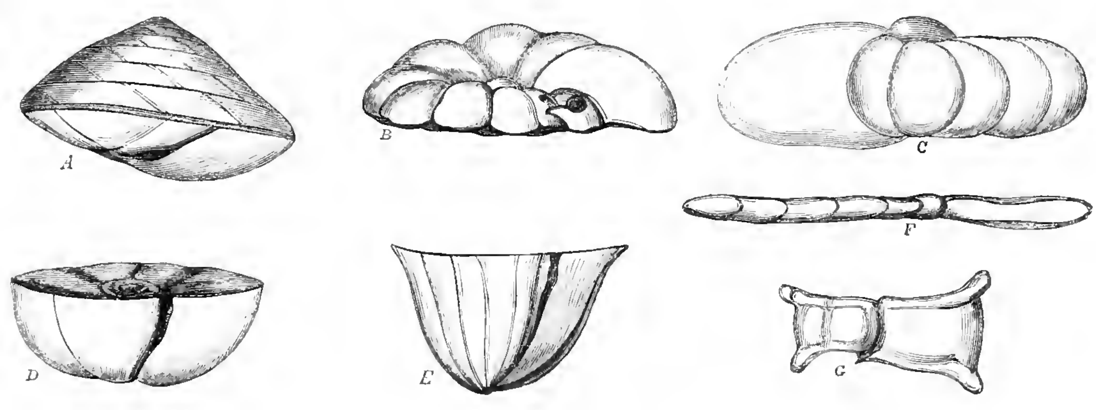
343. Such was the nomenclature of the group when it was first taken up by D'Orbigny; who, in his first systematic arrangement of the Foraminifera (LXIX) created, in addition to *Rotalia*, the genera *Gyroidina, Planorbulina, Truncatulina, Anomalina, Rosalina, Calcarina,* and *Turbinolina;* to which he subsequently added *Asterigerina* (LXXI), whilst he abandoned *Gyroidina* as not sufficiently differentiated from *Rotalia,* and *Turbinolina* as not sufficiently differentiated from *Rosalina.* To these the genus *Siphonia* has been added by Reuss (LXXXVII); and the genus *Acervulina* by Schultze (XCVII).—On the other hand, by Prof. Williamson (CX) the genera *Rotalina* and *Rosalina* have been reunited, for the excellent reason that their distinctive characters are such as a mere difference of age suffices to destroy; and he further correctly stated that (as had been in some degree divined by M. D'Orbigny himself) certain shells ranked by D'Orbigny under the genus *Valvulina* are true Rotalines.

344. The Rotaline type has been specially studied by Messrs. Parker and Rupert Jones, who have found it requisite to throw together again all the genera *Rotalia, Planorbulina, Truncatulina, Rosalina, Asterigerina, Anomalina, Planulina,* and *Calcarina* of D'Orbigny, together with several species of his *Valvulina,* as well as the *Siphonia* of Reuss, and the *Acervulina* of Schultze; and to rearrange the resultant aggregate of forms upon entirely new principles under six genera,—viz., *Rotalia, Calcarina, Planorbulina, Pulvinulina, Discorbina,* and *Cymbalopora;* for the first three of which they employ the names previously given by D'Orbigny, but in a different sense. Regarding *Rotalia Beccarii* as the type of the true *Rotalia,* and *Calcarina Spengleri* as the type of the true *Calcarina,* they arrange under those genera respectively such forms as correspond with their types in all essential particulars; and thus it comes to pass that the *Rotalia* of Messrs. Parker and Rupert Jones corresponds with parts of the *Rotalia, Rosalina, Gyroidina, Asterigerina,* and *Calcarina* of D'Orbigny; whilst their *Calcarina* includes part of the *Rotalia* of D'Orbigny with part of his *Calcarina.* The *Planorbulina* of Messrs. Parker and Rupert Jones has a scope very different from the *Planorbulina* of D'Orbigny; for it reunites parts of D'Orbigny's *Rotalia, Rosalina,* and *Anomalina,* together with *Truncatulina, Planulina,* and *Acervulina* (Schultze), to part of D'Orbigny's *Planorbulina.* The genus *Pulvinulina,* of which the type is the *Rotalia repanda* (the *Pulvinulus repandus* of Lamarck), includes parts of the genera *Rotalia, Planorbulina,* and *Valvulina* of D'Orbigny; and in like manner the genus *Discorbina,* of which the type is the *Rotalia turbo* (of which one variety had been named *Discorbites vesicularis* by Lamarck), is made up of parts of the genera *Rotalia, Rosalina, Valvulina, Asterigerina, Anomalina,* and *Globigerina* of D'Orbigny. Lastly, the genus *Cymbalopora* consists of a small group of very peculiar forms which had been included by D'Orbigny in his genus *Rosalina.*

345. The typical genera of the Rotaline series are those in which the shell essentially consists of a succession of coarsely porous or Globigerine segments, arranged in a turbinoid spire, and communicating with each other by a cresentic aperture situated at the junction of the septal plane with the free surface of the convolution. The pores (Plate XIII, fig. 1), in characteristic examples of the Rotaline series, are from 1-2000th to 1-5000th of an inch in diameter; they are usually larger on the external surface than on the internal, as is shown by sections which traverse the thickness of the shell (fig. 1, *b*); and it very commonly happens that each external orifice lies at the bottom of a sort of funnel that is formed by a

circular ridge of shell, so that the whole surface is marked out into minute areolæ (fig. 1, *a*). The segments progressively increase in size, and the earlier whorls are scarcely at all invested by the later; so that the whole spire remains visible on one lateral surface, whilst on the other side nothing is seen except the last convolution. Generally speaking, the former (as in a *Turbo* or *Trochus*) is more or less conical or convex, the primordial chamber occupying its highest point, whilst the latter or growing side is more or less flattened; and as it is ordinarily by the latter that the shell is adherent to the sea-weeds, zoophytes, shells, or stones, to which the animal commonly attaches itself during life, this may appropriately be called the *lower* surface, whilst the former, which is free, is distinguished as the *upper* surface (Fig. XXXII, A, B). We agree with Prof. Williamson (cx, p. xvi) in thinking it desirable to retain these terms as morphologically correct, in cases in which the side whereon the whole spire is visible is the flattest (Fig. XXXII, D, E), the spire having more the form of a *Conus* than of a *Turbo or Trochus;* notwithstanding that, the shell being attached by the flatter side, the position of the animal is (so to speak) inverted.—As a general rule in this series, the anterior portion of the wall of each segment forms the posterior wall of the chamber that succeeds it, the septal layer being single and not being differentiated in texture from the ordinary chamber wall, so that there is neither intermediate skeleton nor canal-system: to this rule, however, there is a marked exception in the genus *Rotalia*, which approaches the *Nummulinida* in the duplication of its septal laminæ and in the existence of intraseptal spaces; and there are many other cases in which the usual porous texture of the shell gives place, in the portion of the chamber wall forming the septal plane, to a hyaline plate that displays none but large perforations.

FIG. XXXII.



Various forms of Rotalines. A, *Pulvinulina badensis*, Czjek; B, *Discorbina dimidiata*, Jones and Parker; C, *Anomalina punctulata*, D'Orbigny; D, *Truncatulina lobatula*, Walker and Jacob: E, *Truncatulina refulgens*, Montagu; F, *Planulina Ariminensis*, D'Orbigny; G, *Discorbina bi-concava*, Jones and Parker.

346. The form of the spire, and that of the segments of which it is composed, may differ very widely. As already stated, the *turbinoid* form, in which the spire is somewhat depressed and more or less spreading, and in which the individual segments are more or less ventricose, may be considered as the one most characteristic of the group (Fig. XXXII, B). But, on the one hand, the spire may be as high, as regular, and as compact, as that of a *Trochus;* the shape of the segments being such that the outer surface of each is

"flush" with that of the cone as a whole; whilst they are so closely applied to each other that their septal planes become nearly flat. On the other hand, the depression of the spire may be so great that its superior lateral surface becomes completely flattened; and in this case it may happen that, if the inferior surface remains flattened, the shell may become almost exactly symmetrical (C), and in extreme cases complanate (F), or even bi-concave (G); whilst the segments may be so disposed as to render the inferior lateral surface convex (D), or even conoid (E). Again, the segments may be so ventricose and so loosely attached to each other, that the spire is scarcely closer than that of a *Globigerina;* and there are even cases in which their arrangement approaches that which is characteristic of *Textularia.* In most of the forms in which the spire is elevated, the chambers of the later convolutions do not extend inwards so as to reach the axis, but leave an "umbilical vestibule," which is sometimes of considerable dimensions (CX, Figs. 91, 102); this, however, does not ordinarily communicate (as in *Globigerina*) with the cavities of the chambers; and it is frequently filled up by solid shell-substance.

347. The external aspect of the shell in this genus is often considerably modified by an exogenous deposit of non-porous shell-substance, sometimes translucent, sometimes opaque. Such a deposit very commonly presents itself along the septal bands, converting what would otherwise be fossæ into elevated ridges, which may become continuous at their extremities with a similar deposit that forms the outer border of the spire (CX, Figs. 101, 103, 106, 112); in many instances, again, a like deposit forms a sort of columella in the axis of the spire, which shows itself more or less prominently on the inferior lateral surface; whilst in other cases its presence is chiefly marked by tubercular elevations on the general surface, which are usually more abundant on the lower side than on the upper. The marginal deposit occasionally extends itself, as in *Cristellaria,* into radiating spire-like prolongations; but these, in the ordinary Rotalines, are neither large nor numerous. In the genus *Planorbulina* we occasionally find the general surface beset with prominent tubercles, between which the pores are crowded together (Plate XIII, fig. 15). It is in the genus *Calcarina,* however, that this exogenous deposit is most remarkable (Plate XIV); the whole of the spire being invested with an extraordinary thickness of homogeneous shell-substance, which sends out numerous large extensions, and for the nutrition of which an elaborate canal-system is provided. It is not a little singular, however, that this canal-system does not extend to the interior of the spire, which is constructed upon the simplest Rotaline type, and which, although externally masked, is usually very regular.

348. A very curious feature presented by several modifications of the Rotaline type, is the development of "asterigerine" flaps of shell-substance (Plate XIII, fig. 3), which radiate to a greater or less distance from the umbilical depression on the lower surface, and apparently serve to cover-in secondary lobes of sarcode-substance. These flaps are sometimes so complete, and are disposed so regularly, as to inclose a set of secondary chambers alternating with those of the primary spire; whilst in other cases they are merely rudimentary.

349. In many forms of the Rotaline series, the typically spiral mode of growth gives place either in an earlier or a later stage of existence to the cyclical. Some approach to this is seen in the flat vermiculate forms of *Pulvinulina;* it is very evident in the advanced condi-

tion of *Cymbalopora;* but it is in *Planorbulina*, among the typical Rotalines, that the cyclical plan most completely prevails over the spiral, and replaces it at the earliest period. The truly Rotaline character of this type is evidenced by the frequency of its "truncatuline" and "anomaline" forms, these being merely *Planorbulinæ* whose development has been arrested. In this genus, moreover, the growth may become altogether "wild," the segments being heaped up, one on another, in an irregular or "acervuline" manner; and thus we are led to the genus *Tinoporus*, in which the primordial spiral is recognisable with difficulty, and the piling of segments is combined with a mode of horizontal extension that seems properly cyclical; whilst in the genus *Polytrema* all trace of the primordial spiral seems lost, and the mode of growth seems almost indefinite. In these cyclical and acervuline forms of the *Rotaline* type the aperture of communication undergoes a complete alteration in shape, being no longer a crescentic fissure, but a circular passage, which is sometimes furnished with a pouting lip that may be elongated into a tube.—A still more remarkable departure from the ordinary type will be found in the genus *Patellina;* of which the primitive form seems to be a hollow conical spire with only two segments in each turn, but each of these segments subdivided into chamberlets; this gives place, in the more developed examples, to a regular cyclical increase, and the hollow of the cone (which corresponds to the umbilical vestibule of the ordinary Rotalines) is filled up by a more or less regular growth of secondary chambers.

350. The intimacy of the relationship that exists between the several genera which normally constitute the Rotaline series, is evidenced by the fact, that among their very numerous varietal forms *isomorphs* are frequently met with; these isomorphs often so closely resembling each other, that it is only after a careful examination of the gradational affinities of each that its proper position can be assigned. The largest number of such varietal forms is presented by *Planorbulina*, which has yielded several scores of pseudo-species to authors; next to it comes *Discorbina;* then *Pulvinulina*, which has from forty to fifty such forms; then *Rotalia;* then *Calcarina;* and lastly *Cymbalopora*, from whose varieties only four species have been erected.—Of the more aberrant genera, *Tinoporus*, *Polytrema*, and *Patellina*, the first and third will probably yield a large number of varietal forms when they shall have been adequately studied; the second appears essentially amorphous. Even these genera are not without examples of the isomorphism just alluded to: thus the *Tinoporus baculatus* so extremely resembles *Calcarina Spengleri* as to be readily mistaken for it by such as are not familiar with the special peculiarities of each; and we shall see that in the early stage of growth there is no essential dissimilarity between them.

Genus XIII.—Discorbina (Plate XIII, figs. 2, 3; and Williamson, Figs. 104, 105, 109—113).

351. *External Characters and Internal Structure.*—The genus *Discorbina* may be regarded as presenting the characteristic features of the Rotaline series in their simplest, as *Rotalia* does in their most developed, condition. Its shell is typically a turbinoid spire, formed by a succession of vesicular segments, every one of which bears a strong resemblance to a

segment of a *Globigerina* (CX, Fig. 104 *); the only essential difference between the two types consisting in this, that each chamber of *Globigerina* has a distinct communication with the umbilical vestibule, whilst in *Discorbina* each chamber communicates only with that which precedes and follows it. The aperture is a large fissure, more or less arched, reaching to the lower edge of the umbilical margin of the septal plane; and it is nearly always more or less occluded by an "astral flap," which may be a mere projection of the exogenous substance deposited on the umbilicus, or may be part of the more developed "asterigerine" plates to be presently described. The general form of the shell is conical, with a rather sharp margin and a nearly flat base.

352. These characters are typically shown in the *Rotalia turbo* of D'Orbigny, of which fossil varieties had been described by Lamarck (LVIII), under the names *Discorbites vesicularis*, *Rotalites trochidiformis*, and *R. lenticularis*. Of these the *R. trochidiformis* of the Grignon Tertiaries is the largest and most strongly developed, but it is scarcely the most characteristic; the peculiar features of this type being more conspicuously exhibited by the *Rotalites vesicularis* of Lamarck, which is the *Rotalia Gervillii* of D'Orbigny's models and the *Discorbina vesicularis* of Parker and Rupert Jones, and which is very common at the present time on the Australian coast. The form of this shell (figs. 2, 3) is plano-convex, or concavo-convex, its umbilical surface being flattened, or even concave, whilst its upper surface is moderately arched. Its segments are vesicular externally, so that its septal bands are furrowed; and they commonly retain their globose form on their anterior extremity, which forms the posterior boundary of the next segment, and is not differentiated save by the loss of its pores from the remainder of the chamber-wall. The upper surface may show the spire from its very commencement; but as it commonly happens that each later whorl in some degree overgrows the one which precedes it, the primordial chamber is sometimes concealed. The character of the upper surface is for the most part but very little altered by exogenous deposit; though sometimes the apex of the spire is crowned by a glistening boss of hyaline substance. The vesicular form of the segments is sometimes retained on the lower or umbilical surface, but more commonly it gives place to a flattening; in either case, however, there is a deep furrowing at each septal junction, leading towards the umbilical depression. This depression, with its radiating furrows, is covered in by a sort of tent of hyaline non-tubular shell-substance, which sends an astral prolongation to attach itself to the wall of each of the surrounding segments (fig. 3); and thus a space is enclosed, which (it can scarcely be doubted) is filled in the living state with sarcode-substance. Under some condition or other, this "asterigerine" growth is found in almost every variety of the genus *Discorbina*: but it may be reduced on the one hand to a mere rudiment, as in the *D. globularis* of our own shores; whilst, on the other, it may be exuberant enough to form a solid mass, as in the fossil *D. trochidiformis*, where we find the surface of that mass covered with hemispherical granules, which especially run along the margins of the septal junctions, so as to give to this variety a curious analogical resemblance to *Rotalia Beccarii* (369).

* This very characteristic figure of the coarsely perforated *Discorbina globularis* is erroneously given by Prof. Williamson as the young of the finely perforated *Rotalina* (*Pulvinulina*) *concamerata*.

353. This type keeps very strictly, as a rule, to its regular mode of increase; though sometimes in the larger examples of the *D. vesicularis* we find the spire terminating in a few irregular or wildly-growing chambers. These may be either unusually large, or may become suddenly small; and they may either intercalate themselves along the border of the preceding segments, or they may grow over the older part of the shell without any definite direction. The smallest and feeblest varieties of *Discorbina* form a high cone, which may be flattened on two surfaces, so as to present a very "textularian" aspect; on the other hand, the spire may be so much depressed that the shell comes to have a complanate or even a scale-like form. It is for the most part in the small complanate varieties that we find an elevation of the septal bands and of the margin of the spire, which, common as it is in *Pulvinulina*, is of rare occurrence in this group; of this an example is shown in the *Rotalina ochracea* of Williamson (cx, Figs. 112, 113). One of the most curious modifications of structure in this type consists in the existence of deep fissures between the successive segments, the walls of which are complete on either side of these fissures; as we see in many recent examples of the *D. vesicularis* of Australia, but still better in the *D. rimosa* (Parker and Rupert Jones) of the Grignon Tertiaries and the Australian coral reefs. In this variety we not only find the asterigerine flaps so much developed as to form a regular series of secondary chambers alternating with the primary, but we also find the exogenous deposit partially bridging over the superficial entrance to the interseptal fissures, dividing it into a row of little passages; and thus is produced a sort of sketch of that intraseptal system of canals, which we shall see to be more fully elaborated in *Rotalia*, and to attain its most complete development in *Polystomella*.

354. Although, as a general rule, the walls of the chambers are coarsely perforated, yet in some of the smaller and more delicate varieties the pores are very fine. There are some instances in which a considerable portion of the external surface of each segment is destitute of pores, these being limited to the margin, where they are unusually large and closely set, giving rise to the peculiar appearance represented by Prof. Williamson (cx, Figs. 109, 111) as characterising his *Rotalina mamilla*, a variety of the *Rotalia rosacea*, D'Orb. In some varieties these marginal pores are prolonged into short tubes, which give to the edge a prickly character. The diameter of the shells of this genus ranges from 1-6th (*D. trochidiformis*) and 1-7th (*D. vesicularis*) of an inch to as little as 1-200th of an inch, which is the diameter of some of the specimens brought up from the deeper recesses of the ocean.

355. *Affinities.*—It has been already remarked (¶ 341) that all the genera constituting the proper *Rotaline* series are intimately connected by mutual affinity; but each of them has also relations of its own to other types. Thus, as we have seen, the simplest forms of *Discorbina* connect themselves with *Globigerina*, and even with *Textularia*; whilst among its more developed forms we find approximations to the lower types of the family *Nummulinida*, the complanate varieties reminding us of *Operculina*, and those in which the "astral lobes" are most complete bringing us almost into contact with *Amphistegina*. In general configuration this genus is closely paralleled by certain forms of the protean arenaceous type *Lituola* (¶ 213).

356. *Geographical and Geological Distribution.*—The Rotaline group as a whole may be

said to be universally diffused, and to have a very wide bathymetrical as well as climatic range. But its several generic forms are by no means equally developed under different conditions. Thus *Discorbina*, though presenting itself on the British coasts, in the Mediterranean, and in the East India seas, is there comparatively small; attaining a much larger size near the Australian shores. Its most congenial home seems to be in the Algal and Coralline zone, the deep-water examples of this type being smaller and rarer; a sandy bottom seems to suit it best, the specimens found in mud being small and delicate.—These peculiarities of habit must be taken into account in estimating the geological range of this genus; for it is quite possible that its absence from all strata in which it has been searched for, earlier than the Maestricht beds, may be due to the fact that these strata were deposited for the most part in deep seas. In the Maestricht beds this genus is represented by specimens of medium size; its largest fossil forms (which equal or even exceed those found recent on the Australian coast) are furnished by the Bracklesham and Grignon deposits; whilst in the later Tertiaries its varieties cloely correspond in size and character with the ordinary existing forms of the genus.

Genus XIV.—PLANORBULINA (Plate XIII, figs. 13—15; and Williamson, Figs. 119—123).

357. *External Characters and Internal Structure.*—The modification of the ordinary Rotaline type of which we have next to treat, is one that departs more widely from it in plan of growth than it does in the character of the individual segments; these retaining very much of their simple Globigerine condition, but being disposed in such a manner that their originally continuous spiral succession gives place to a cyclical arrangement not unlike that of *Orbitolites*, whilst this again may give place to an irregular heaping-up or "acervuline" disposition of the segments. It will be convenient in the first instance to describe a characteristic example of this type, and then to examine on the one hand the links which connect it with the ordinary *Rotalines*, and on the other those (so to speak) exaggerated forms by which it comes into relation with the genera *Tinoporus* and *Polytrema*.

358. Such a characteristic example is presented by the *Planorbulina mediterranensis* of our own coasts (described and figured by Prof. Williamson, cx, p. 57, Figs. 119, 120), which attains a considerably larger size in the Mediterranean and in other sub-tropical and tropical seas, and which has also received the name of *P. farcta*. The growth of this shell, which is always attached on one side, commences in a very depressed rotaline spiral; the successive segments of which open into one another by a wide fissure that is close to the inferior lateral surface, which (by the inverted position of the shell, ¶ 345) is here its free surface. After the spiral has made from one and a half to two turns, however, the segments begin to be added in a manner altogether different; the change being made in the first instance by the formation of segments which bud forth new ones from their peripheral as well as from their umbilical margins; and from these a succession of segments is produced, which passes round the original spire, and then returns into itself. Each of the chambers thus formed has an oval opening at either extremity,

as is shown in several of the marginal segments of Prof. Williamson's figure (CX, Fig. 120). From the time that a complete ring of chambers has been thus formed around the original spiral, the continued growth of this organism takes place upon the cyclical plan; each new chamber being formed (as a rule) by a tent of shell thrown over the interspace between two chambers of the preceding annulus, with each of which it communicates through its oval aperture; whilst in its turn it forms two apertures which will communicate with the two chambers to be formed in alternation with it in the succeeding annulus. Thus in plan of growth *Planorbulina* bears a considerable resemblance to that of the simple type of *Orbitolites* (¶ 157); but nothing can be more different than the texture of the shell in the two cases; that of *Planorbulina* being the most coarsely porous of any of the *Rotalines* (Plate XIII, fig. 14), so that its animal can send out large pseudopodia from every one of its segments; while that of *Orbitolites* is everywhere unperforated save by the marginal apertures. The segments of the cyclically growing portion usually elongate themselves in a direction which is oblique to that of the surface whereon they grow, sloping inwards towards the centre in such a manner as more or less to cover-in the original spire, which is thus only partially visible on its free surface, or may even be entirely concealed. The form of the segments is usually more or less ventricose; that of the entire shell will vary according to the degree of their oblique elongation, the centre being depressed when the spiral is merely surrounded by the cyclical growth, but being elevated when the spiral is covered by the inward extension of the cyclical.

359. Now the spiral plan of growth in which *Planorbulina* always commences, may continue without giving place to the cyclical; and thus are generated three forms, *Truncatulina*, *Anomalina*, and *Planulina*, which connect the typical *Planorbulinæ* with the ordinary *Rotalines*. The former of these, *Truncatulina*, has ordinarily a plano-convex shell, with a crenulated margin, and is attached to sea-weeds, zoophytes, shells, &c., by its flat side, on which the whole spire is apparent; whilst on its unattached surface, which is really the inferior, the earlier portion of the spire is more or less overgrown by the later (Fig. XXXII, D, E, p. 20). Its form, however, is liable to very great variation, in accordance with the place and nature of its attachment, the depth of water, the character of the sea-bottom, and other less definable influences; so that many plates of the great work of Soldani (CI) are devoted to the figures of the very protean *T. variabilis*, the ordinary Mediterranean example of this type. The shell is coarsely porous, and its surface in the older specimens is roughened by minute tubercles. The apertural fissure, instead of being restricted to the umbilical margin of that portion of the chamber-wall which forms the septal plane, is usually extended upon the inner margin of the inferior lateral surface, so as to become visible from beneath; this prolonged portion of the fissure is not included by the succeeding chamber, and thus it happens that some of the later chambers continue to retain a direct communication with the exterior; this, however, being closed by a subsequent deposit of shell-substance in all the earlier chambers. The shell of *Truncatulina* may assume the form of a high cone, as in *T. refulgens*, a northern form, of moderate depths, distinguished by its smoothness and polish; but the real apex of the spire is still on the flat surface, where the whole spire continues visible. On the other hand the shell may be extraordinarily flattened, so as to become scale-like and nearly symmetrical, with squared edges and elevated septal lines, as in the variety described by D'Orbigny as *Planulina Ariminensis* (Fig. XXXII, F); this presents so close a conformity to

the Operculine type as to be readily mistaken for a member of that series, its "truncatuline" character being only made evident by a comparison of the gradational forms by which it is connected with the type. The *Truncatulina* of northern seas is seldom observed to present any more considerable departure from the ordinary Rotaline plan of increase; but that of the Mediterranean continually takes on a "wild" growth, its later segments being added without any regularity, though usually in such a manner as to tend towards a cyclical arrangement; and specimens of this kind are very commonly found attached to the larger bivalves (such as *Pinna flabellum*) in company with *Planorbulina mediterranensis*, exceeding the latter in size, though not developing nearly as many chambers. In tropical seas the arrested "truncatuline" forms are rare; the exuberance of increase manifesting itself very early in the transition to the "planorbuline" type, on which a number of new chambers may be formed at once, instead of in the succession required by the spiral plan.

360. The type which has been distinguished by D'Orbigny as *Anomalina* may be described as a modified *Truncatulina* of which the two surfaces are nearly equal, so that the spire comes to have almost a nautiloid character, and presents a broad sunken umbilicus on either side. The apertural fissure does not show itself on either surface, being limited to the septal plane; but is nearer to the flatter side than to the other. This form may either become "planorbuline," or may graduate into the "truncatuline;" so that its differential characters are obviously of no more than varietal importance. One of the forms into which it passes has been distinguished as *P.* (*Anomalina*) *coronata*; a variety less common than *P.* (*Truncatulina*) *lobatula*, but abounding in certain localities (as on the coast of Norway and in parts of the Mediterranean) at depths of 100 fathoms, where it lives independently instead of parasitically, developing both its surfaces more or less freely. Both, in older specimens, are overlaid by an exogenous deposit of clear, non-perforated, shell-substance, which sometimes hides the septal lines; but in this there exist *lacunæ* for the exit of the pseudopodia, which seem especially to extend themselves from the periphery of the chambers; and these lacunæ seem to prefigure the canal-system which we shall find to constitute a remarkable feature in the exogenous skeleton of *Calcarina*.

361. It is in tropical regions that *Planorbulina* acquires its largest size and its most marked development, examples of the parasitic *P. vulgaris* not uncommonly attaining a diameter of 1-4th of an inch, and presenting such a resemblance to Polyzoa as to be easily mistaken for members of that group. This augmentation of size partly depends upon the greater multiplication of segments; but is partly due to the dimensions which the individual segments may attain. The early growth of this type (Plate XIII, fig. 13) closely corresponds with that of *P. mediterranensis*; but as its development proceeds we find a remarkable change in the condition of the apertures of communication between the chambers. These apertures, which in the *Planorbulinæ* of temperate seas are never more than faintly lipped, here become protrusive, each being furnished with a neck and an everted rim. As a general rule we find the pairs of these necks put forth from two adjacent marginal chambers converging towards each other, both being received into the new chamber which is formed in alternation with them (fig. 14, *a*, *a*); and the new segment in its turn puts forth two similar necks from near its peripheral margin, to be received into two separate chambers of the succeeding

growth. Sometimes the segments do not come into absolute contact with each other, being kept somewhat apart by the intervention of the apertural necks; and each chamber then has its own complete walls. This varietal modification, however, is much more remarkable in a parasitic form, which has received from Messrs. Parker and Rupert Jones the name of *P. retinaculata;* for the segments are here smaller, whilst the connecting tubuli are relatively larger and more numerous; so that the disk is composed of a sort of open network that spreads over the surface of the shell whereon it grows. Both in this and in the large varieties of *P. vulgaris*, the free surface is studded over with large tubercles which arise from it between the large and sparsely-set pores; these tubercles are sometimes formed of a remarkably white opaque kind of shell-substance, giving a very peculiar aspect to the organism (Plate XII, fig. 15). The *Acervulina* of Schultze (XCVII, p. 67) is nothing else than a *Planorbulina* which attaches itself to the stem of a Zoophyte or some other small rounded body, and of which the segments, instead of spreading discoidally over an expanded surface, cluster together in a mass, with more or less of regularity of arrangement. Sometimes the mass acquires considerable compactness from the mutual flattening of the segments against each other; and the "acervuline" *Planorbulina* may thus come to present so close a resemblance to *Tinoporus* and *Polytrema*, as to be almost undistinguishable from those types.

362. *Affinities.*—Besides its affinities to the ordinary Rotalines, and, as we have just seen to *Tinoporus* and *Polytrema*, this genus is related by some of its most symmetrical "anomaline" forms to the simpler nautiloid types of the family *Nummulinida;* whilst its arrested "truncatuline" forms are closely paralleled in general configuration by the "placopsiline" *Lituolæ* (¶ 213). In the cyclical arrangement of its segments of growth, which results from the mode of increase that may be considered typical of its advanced stage, *Planorbulina* seems to conduct us towards *Patellina;* in which we shall find the parallelism to *Orbitolites* most remarkably carried out.

363. *Geographical and Geological Distribution.*—The conditions which most favour the production of *Planorbulina* seem to be almost exactly the same as those under which *Discorbina* most abounds. The numerous specimens which come to us from arctic and temperate seas are of small size and arrested development; in both respects the Mediterranean forms of this genus show a decided advance; but it is in the tropical and Australian seas that it finds its congenial home amongst sea-weeds, corallines, and shell-beds, the specimens found at abyssal depths (1000 fathoms and more) being small and rare.—With respect to the apparent absence of this genus in the earlier stratified deposits, the remark already made in regard to *Discorbina* (¶ 356) equally holds good here; and it is interesting to observe that although *Planorbulina* makes its appearance in the Lias, it is represented there by very small forms, such as at present inhabit great depths; and that the like condition prevails for the most part in the Cretaceous formation. In the Tertiary series, however, especially in the Grignon deposits, it is often very large, although arrested in its development, its forms being identical with such as now present themselves at depths of from 30 to 100 fathoms.

Genus XV.—PULVINULINA (Plate XIII, figs. 4—6; and Williamson, Figs. 98—103).

364. *External Characters and Internal Structure.*—The group of Rotaline forms which are associated in this genus consists of those which accord more or less closely with its type,—the *Nautilus repandus* of Fichtel and Moll, the *Placentula pulvinata* of Lamarck, the *Rotalia* or *Rotalina repanda* of later systematists,—in the freedom of growth and in the fineness of the porosity of its shell; by both of which characters, but especially by the second, it is distinguished from *Discorbina*. The shells of this genus are usually composed of from seven to twenty-six segments of variable convexity, somewhat loosely aggregated in a depressed turbinoid spire, so as to have a biconvex form with the upper side thickest, and an angular or sub-carinate margin (Fig. XXXII, A, p. 201). On the under side there is a large umbilical space, which may either remain open (CX, Fig. 102), or may be partially or completely filled by exogenous deposit. The segments usually undergo a rapid elongation; and sometimes the later ones spread themselves out irregularly (CX, Figs. 95—100). An elongation takes place in the septal plane, in accordance with the extension of the chambers; and in such cases it tends to become flattened (CX, Fig. 95), and is very commonly punched with large "orbuline" foramina. The aperture is usually a large slit at the base of the umbilical margin of the septal plane; and is frequently still further enlarged by irregular deficiencies at its septal edge. In the typical *Pulvinulinæ* the exogenous deposit is chiefly confined to the septal bands, which it often raises into ridges so as to produce a strong "limbation;" but it may also roughen the general surface with minute granulations. Some of the most oblong varieties, as the *Rotalina oblonga* of Williamson (CX, p. 51) were included by D'Orbigny in his genus *Valvulina*.

365. The expanded form of this type may give place to one more contracted, in which the segments are more compactly arranged, so as to produce by their aggregation a thick conical shell, of which the external walls are "flush." In this variety the upper surface usually receives a considerable amount of exogenous deposit, which forms a strong "limbation" on the septal lines (CX, Figs. 101, 103), and covers the outer walls of the chambers with large closely-set granules; and the aperture passes into the condition of a notch. The limbation and granulation attain their maximum in the conus-shaped *P. caracolla* of the Oolite, Gault, and Chalk-marl, in which the limbation is stronger than in any other Rotalines, the faces of the chambers often lying deep between wall-like ridges both above and below. The variety known as *Rotalia Menardii* is a common deep-sea form of *Pulvinulina*, flattish, limbate, and granular; and this is sometimes accompanied by the *R. elegans* vel *Partschiana* (LXXIII), a large flush-chambered shell, with a prominent umbo formed by a mass of exogenous deposit, which variety ranges also into shallower water. In some other varieties allied to *R. Menardii* the limbation is wanting; the septal bands being flush with the surface, or being even furrowed. In the *R. Schreibersii* and allied varieties the limbation is but faint, or is altogether wanting, on the upper surface of the shell; whilst on the under surface there is a strong astral limbation proceeding from the exogenous deposit which occupies the umbilical vestibule.

366. The characteristic form of *Pulvinulina* is subject in the Laminarian zone of warmer latitudes to a modification so remarkable, that its Rotaline character would scarcely be recognisable if its affinity were not traceable through intermediate gradations. This form (Plate XIII, figs. 4—6) has been described by D'Orbigny under the designation *Planorbulina vermiculata*: but although to a certain extent analogous to *Planorbulina* in its plan of growth, it differs from it entirely in other characters, and can be readily shown to be essentially a *Pulvinulina* extremely flattened-out, of which the later chambers elongate themselves like the continuous tube of a *Spirillina*, with very few interposed septa, sometimes returning into themselves so as to form complete though irregular annuli, of which the earlier are surrounded by the later. The substance of the shell in this curious variety is very finely porous, the pores being grouped in little bundles (fig. 6), and sometimes looks almost horny in its transparency and hue; but on its attached surface (fig. 5) we notice that it is (as it were) punched-through with large irregularly scattered apertures. These expanded forms sometimes attain a diameter of 1-7th of an inch; on the other hand, the contracted deep-sea forms have no greater a diameter than 1-250th of an inch. The diameter of the ordinary trochoid forms of moderately deep water ranges from about 1-20th to 1-50th of an inch.

367. *Affinities.*—This genus holds among Rotalines, in regard to the fineness of the texture of its shell, and the freedom of its mode of growth, a rank analogous to that of *Bulimina* in the Textularine series. Its nearest affinity, however, out of its own sub-family, is to *Spirillina*, to which its lowest forms approximate closely in mode of growth; whilst the large pores that are met with in the chamber-walls, not only in these but in higher forms, mark the persistence of an Orbuline condition of the animal. In this genus, moreover, as in the two preceding, we find complanate nearly symmetrical varieties with raised edges, that bear a strong resemblance to *Operculinæ*.

368. *Geographical and Geological Distribution.*—The conditions under which this genus flourishes best are by no means the same as those which most favour the development of the two preceding types; for some of the largest examples of *Pulvinulina* come to us from within the Arctic Circle, and plenty of good-sized specimens may be obtained from extreme depths. The examples which occur in the Algal zone, on the other hand, are for the most part the feeblest. It is, perhaps, on account of its prevalence at greater depths, that this type has been distinctly recognised at an earlier geological period than any other of the Rotalines; the *P. elegans* having been found so abundantly in the Upper Triassic clay of Chellaston by Messrs. Rupert Jones and Parker (LV), as to constitute nearly one-half of the Foraminifera in which that deposit is rich. The genus continues to present itself in the Liassic and Oolitic series, its examples being generally small but strongly limbate; in the Gault their size increases, the limbation being still very strong; and they become still larger in the Chalk-marl. It is very probable that these diversities have reference only to the depths at which the clay-beds that have been hitherto examined in these formations were respectively deposited. The highest development of this genus seems to have been in the Tertiary series, and especially in the Crag-formation.

Genus XVI.—ROTALIA (Plate XIII, figs. 7—9; Williamson, Figs. 90—92, 106—108).

369. *External Characters.*—It is in the true *Rotaliæ*, of which *R. Beccarii* is the typical example, that we meet with the highest development of the Rotaline type, and the nearest approximation to the Nummuline. This approximation is shown in its shell-substance, which is of unusually fine texture, its pores being as minute and as closely set as they are in *Operculina* or *Nummulina* (Plate XIII, fig. 8). It is further marked in the general compactness of the shell, and in the mode in which it is strengthened and completed by an "intermediate skeleton." But it is especially manifested in this important feature,—that every chamber is completely surrounded by its own proper wall, no part of its boundary being borrowed from that which belongs to the penultimate segment. Hence every septum dividing adjacent segments is double instead of single; and its substance rather resembles that of the intermediate skeleton than that of the ordinary chamber-wall, being entirely destitute of the minute porosity which characterises the latter. In this respect, therefore, there is an important advance in that development which consists in progressive differentiation. In the ordinary British form of *P. Beccarii*, which is accurately described and figured by Prof. Williamson (CX, p. 49, Figs. 90—92), the shell has a rather depressed turbinoid form, with a rounded margin; and is composed of a considerable number of segments progressively increasing in size, disposed with great regularity, and having their apposed surfaces closely fitted to each other. The whole of the spire from its commencement is visible on the upper surface; whilst on the lower only the last convolution shows itself, the segments being arranged around a deep umbilical vestibule, which is filled up with a column of homogeneous semi-crystalline shell-substance. This column sometimes projects as an umbo from the surface, and is clustered over with granulations and incrustations of the like material; similar granulations extend along the umbilical margins of the segments, which are frequently a good deal separated from each other, the intermediate spaces being sometimes filled up with the semi-crystalline substance resembling that of the umbilical column. Owing to the somewhat ventricose form of the segments, their lines of junction along the whole spire would be deeply furrowed, were it not that the depressions are partly filled up by deposits of the like substance, which strongly mark the septal lines by the difference of their aspect from that of the intervening porous chamber-walls. The septal plane is distinguished by its translucency; and the aperture is usually a neat arched slit, which is much more nearly medial than in the Rotalines generally, being very little beneath the contiguous peripheral margin of the penultimate convolution. In some varieties, however, the aperture has a notch in the umbilical margin of the septal plane. The diameter of this shell, which is an inhabitant of moderately deep water, is usually from 1-25th to 1-30th of an inch.

370. A feeble shallow-water or littoral variety of this type has been described and figured by Prof. Williamson (CX, p. 54, Figs. 106—108) under the designation *R. nitida*: here the segments become quite "flush," so that the surface of the cone is smooth; the walls of the chambers are very thin and translucent, and there is but very little exogenous deposit either along the septal bands or in the umbilical vestibule. A like deficiency of exogenous deposit is observable in the large smooth *R. ammoniformis* (D'Orb.) of the Rimini shore, which has

the umbilicus open, as in the recent feeble forms. In the strongest tropical forms of moderately shallow water, on the other hand, of which the *R. Schroeteriana* (erroneously designated *Faujasina* by Prof. Williamson CIX) is a characteristic example, the form of the shell is completely changed, by the peculiar form and disposition of the segments, from that of a *Turbo* to that of a *Conus;* the upper surface being now flat or nearly so, whilst the lower surface becomes conical (Plate XIII, fig. 7). Notwithstanding this striking metamorphosis, the essential identity of the two types is proved by the existence of a complete series of gradational links between them, some of these intermediate forms being almost equally conical on the two sides, but showing the whole spire on one lateral face, whilst only the last convolution is seen on the other. In the typical *R. Schroeteriana,* which attains a diameter of 1-12th of an inch, the upper surface is rendered "limbate" by the prominence of the septal bands, which are ornamented with rows of hyaline tubercles; and these tubercles are continued along the septal bands down the side of the cone, until they join a large irregular mass of the same semicrystalline substance that occupies the apex of the cone, which is here the real umbilicus of the spire. Between these tubercles there may be distinguished, under a sufficient magnifying power, a single or double row of large pores along each septal band. The aperture has more or less of an oval form, and is usually situated about half-way between the upper flat surface and the umbilical prominence. In a remarkable variety of this type from the Fiji islands, the spire is more symmetrical, and the aperture is bridged over by transverse bars (as in *Calcarina*), so that the shell becomes almost isomorphic with *Polystomella craticulata;* to which type it further bears considerable resemblance in the disposition of the exogenous deposit, and in the mode in which the intraseptal passages open on the surface along the septal bands (§ 372.)

371. Various weaker modifications of the preceding forms present themselves at different depths in the tropical ocean and in marine deposits of different geological ages. Thus, from 100 fathoms and more we have recent examples of the *R. Soldanii* of the Vienna Tertiaries (LXXIII), which is identical with the *R. umbilicata* of the Chalk; a close thickset smooth form, without septal granulations, and having its umbilicus sometimes occupied by a single large rounded tubercle. Again the *R. orbicularis* (which ranks as *Gyroidina* in D'Orbigny's models) is almost hemispherical in form, its chambers being quite "flush," and its upper flat surface showing the entire series, which consists of about forty segments, whilst its lower spherical surface shows ten or twelve. A still more marked departure from the typical form is produced by the extension of three or four of the septal bands of the first convolution into long smooth radii, giving rise to the variety described by D'Orbigny as *Calcarina pulchella,* which is further remarkable as having each of its raised septal bands double. And finally, in a conus-shaped tropical variety, which has received from D'Orbigny the names *Asterigerina carinata* and *A. lobata,* the umbilical lobes of the chambers are separated from the principals by the intervention of a septum, so as to constitute a secondary series of chamberlets which interdigitate or dovetail themselves between the proper chambers, as do those of the lower surface of *Amphistegina vulgaris* and its varieties (Plate XIII, fig. 23), instead of lying in a lower plane like the subsidiary chambers formed by astral flaps in *Discorbina* (§ 352).

372. *Internal Structure.*—The internal structure of the most developed form of the genus

Rotalia has been very accurately described by Prof. Williamson (CIX), whose account of it is confirmed in every particular by my own inquiries. When a horizontal section is taken near the upper or flat surface of the shell, the whole spire is laid open, as shown in Plate XIII, fig. 8; the finely-tubular structure of the lateral walls of its chambers, and the absence of tubuli from the intervening septa, are apparent; while a marked peculiarity here presents itself in the septa being composed of two lamellæ, between which there is sometimes a considerable interspace. The intraseptal spaces are connected into a system of passages which extends in a radial direction from the centre towards the periphery; each passage first traversing one of the intraseptal spaces, and then usually bifurcating as it enters the spiral lamina, its two branches divaricating in such a manner as to pass to two septa in the next convolution. By comparing this, however, with such a vertical section as is shown in Plate XIII, fig. 9, it is made apparent that what seem to be *canals* between the septa are in reality the lower edges of intraseptal *fissures*, which intervene between the two lamellæ through nearly the whole area of each septal plane. From that edge of each fissure which is nearest the flat surface, passages are given off which run towards that surface to open between the tubercles on its septal bands; whilst from that edge of the intraseptal fissure which abuts on the oblique side of the cone, there is given forth a row of passages which open along the septal band that passes vertically towards the umbilicus. Before reaching the surface these passages usually divaricate, and the wedge-like space between each bifurcation (fig. 8, *a*) is occupied by non-tubular substance, which forms, in fact, the base of one of the tubercles that rises from the septal band. The exogenous deposit of which these tubercles are formed, extends over the whole surface of the shell, adding considerably to the original thickness of the walls of the chambers. It is shown by the vertical section (fig. 9) how the peculiar form of the shell is engendered by the remarkable elongation of the later chambers between the lateral surfaces, so that the upper side of each succeeding whorl is kept on a level with the preceding whorl *above*, whilst it is produced far beyond it *below*. This production of each whorl leaves a large umbilical fossa of irregular form, which is filled up with homogeneous shell-substance, so as to become a sort of columella.

373. *Affinities.*—The very marked participation in certain characters of the Nummuline series which is exhibited by this genus, would suffice, if taken by itself, to justify its claim to a place among them; the relationship of its most developed forms to those of *Polystomella* in particular being so intimate, that the two cannot be justly considered as far removed from each other. But, on the other hand, the general affinity of *Rotalia* to the other genera of the Rotaline series is so close, that it is quite impossible to detach it from them; and it must be regarded, therefore, as the link which establishes the transition between the ordinary Rotaline and the Nummuline series. It is impossible, moreover, not to be struck with the analogical relationship between *Rotalina* and *Carpenteria*, which hold the highest places in their respective series; for *Carpenteria* would in all essential particulars be an outspread *Rotalia* attached by its upper lateral surface, if its chambers communicated with one another, instead of opening separately into a common vestibule.

374. *Geographical and Geological Distribution.*—The true *Rotalia* may be considered as essentially a sub-tropical form; its characteristic features being well exhibited in specimens

from the Levant. It has not yet been found in the Arctic seas, and it is neither abundant nor of more than half its ordinary size on the British coasts; on the other hand, it is in tropical specimens that we find it most thickly clothed with exogenous deposit, and its canal system most developed. It does not flourish in deep waters, its size being reduced to less than one fourth at a depth of 100 fathoms; whilst its form is altogether changed, and it becomes very small and rare, at 1000 fathoms. On the other hand, it extends far up estuaries and into salt-bogs.—No true *Rotaliæ* are at present known to have existed earlier than the Chalk, in which formation there occur examples of *R. Beccarii* whose small size indicates that they lived at considerable depths, probably from 100 to 400 fathoms. It is in the Tertiary formations, however, that this sub-genus occurs in greatest abundance; some shallow water-beds of the Crag and of the Siennese deposits being almost entirely composed of *Rotaliæ*.

Genus XVII.—Cymbalopora (Plate XIII, figs. 10—12).

375. *External Characters and Internal Structure.*—This small genus, including only four specific forms hitherto described, was instituted in 1850 by Hagenow ("Die Bryozoen der Maastrichter Kreide-bildung") on the basis of a minute fossil which he supposed to be a Bryozoon, but which has been found by Messrs. Parker and Rupert Jones to agree in structure with the *Rosalina Poeyi* of D'Orbigny (xcii), a type distinguished by peculiarities of conformation quite sufficient to differentiate it from all other genera of the Rotaline sub-family. All the examples of this genus are of comparatively small size; the diameter of the largest of them (fossil from the Upper Chalk of Maestricht) being not more than 1-18th of an inch; whilst that of the ordinary specimens obtained from deep water at the present time does not exceed 1-120th of an inch. When seen from the superior lateral surface, or looked at edgeways (Plate XIII, fig. 10), a *Cymbalopora* does not present any marked feature that distinguishes it from a trochoid *Discorbina*, save that the spiral arrangement of its segments does not appear to be continued with regularity as the cone enlarges. But when its inferior surface is examined, a very extraordinary departure from that regularity displays itself; for we there find its segments arranged concentrically around a deep umbilical vestibule, which extends far up into the cone. Sometimes these segments are numerous and narrow, and being as it were wedged in between the segments of the preceding layer, they are separated from each other by considerable intervals (Plate XIII, fig. 11). But in other cases they are few in number (the whole annulus being made up of only four or five), broad, and flat; and the interval between them is reduced to a fissure (fig. 12). In either case each segment communicates with the umbilical vestibule by a prolonged tubular neck; and it also has two large lipped orifices on either side, apparently for the passage of sarcode-stolons to the adjacent segments. The shelly lamina which forms the basal walls of these segments is much more hyaline and less porous than that which bounds them externally; and we notice the homologue of the asterigerine flaps of *Discorbina* in the frequent extension of a lamella of shell over the umbilicus, closing-in its cavity, and connecting together the internal necks of the segments. It can scarcely be doubted that this umbilical cavity is occupied in the living condition by a portion of the sarcode body of the animal; and that from this are put forth by gemmation the seg-

ments that form each new annulus of chambers, since the chambers of one annulus have no direct communication with those of the annulus which preceded it. In this respect, therefore, we have a curious analogy to *Dactylopora*, in which, however, the independence of the segments is greater, no communication existing between even those of the same annulus (¶ 190).

376. The mode in which the spiral growth is exchanged for the concentric seems to be essentially the same with that in which it is accomplished in *Planorbulina* (¶ 358); the spire first becoming excentric by the development of new chambers on one side only (in such a manner that the primordial segment seldom lies at the apex of the cone, but a little on one side of it), and being then inclosed by an annulus formed by the gemmation of new segments. In *Planorbulina*, however, each successive annulus is formed around the margin of the preceding, from which every one of its segments derives stolon-processes; whilst in *Cymbalopora* each new annulus is formed beneath the preceding, and has apparently no direct derivation from it. The principal departure from the typical form is shown in the *C. bulloides* (*Rosalina bulloides*, D'Orbigny, XCII), in which the whole of the base is occupied by a single large chamber, the wall of which, instead of being furnished with its normal apertures, is perforated by numerous large 'orbuline' lipped pores.

377. *Affinities.*—In the character and disposition of its earlier segments, and in the asterigerine lamella at the base of its cone, *Cymbalopora* may be considered as most nearly related to *Discorbina*; but in the exchange of the spiral for the cyclical plan of growth, it accords with *Planorbulina*, differing from the last-named genus, however, far more than the "wildest" of those forms to which we have extended its designation.

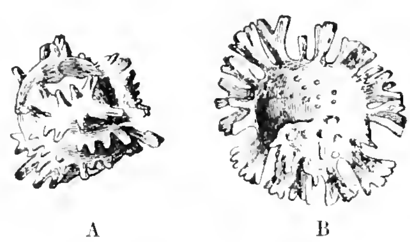
378. *Geographical and Geological Distribution.*—The little *Cymbalopora* is at present restricted to the warmest seas, not being found in the Mediterranean, but being common in the Red Sea, in the East and West Indian Seas, and on the shores of the Fiji and other Polynesian islands and of Australia. It frequents the Algal and Coralline zones and shell-beds; and becomes small and irregular when presenting itself (as it not rarely does) at depths of 500 fathoms. The only occurrence of this genus in a fossil form is in the Maestricht beds, in which it presents itself in association with *Calcarina* and *Discorbina*. Its absence in the Tertiary strata of Europe (so far as is yet known) taken in connection with the essentially tropical *habitat* of its recent representatives, is a fact of some significance.

Genus XVIII.—CALCARINA (Plate XIII, fig. 21; Plate XIV, figs. 1—10).

379. *External Characters.*—The name bestowed on this genus, of which the *C. Spengleri* (the *Nautilus Spengleri* of Linnæus) is the typical form, is derived from the resemblance which it presents in general aspect to the rowel of a spur (Plate XIV, figs. 1, 2), this resemblance being produced by the divergence from the central disk of a set of rays or spines, which vary

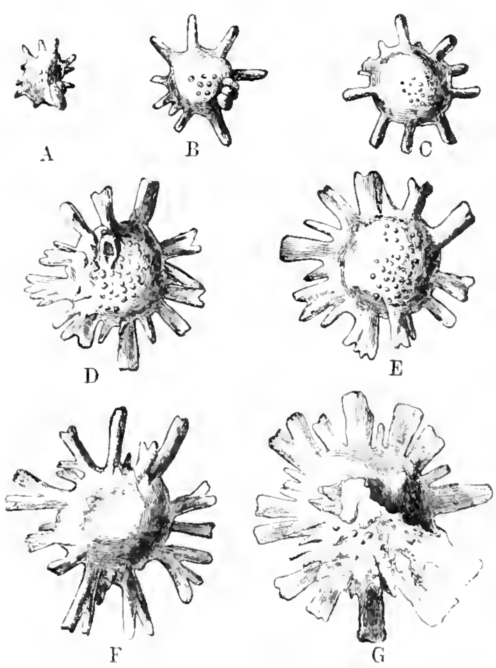
alike in number, length, and direction. These spines are usually few in young specimens, and become numerous with age; but this rule is by no means constant, since full-grown specimens are occasionally met with having no more than four or five very short spines (Fig. XXXV, H). The spines are usually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

Fig. XXXIII.



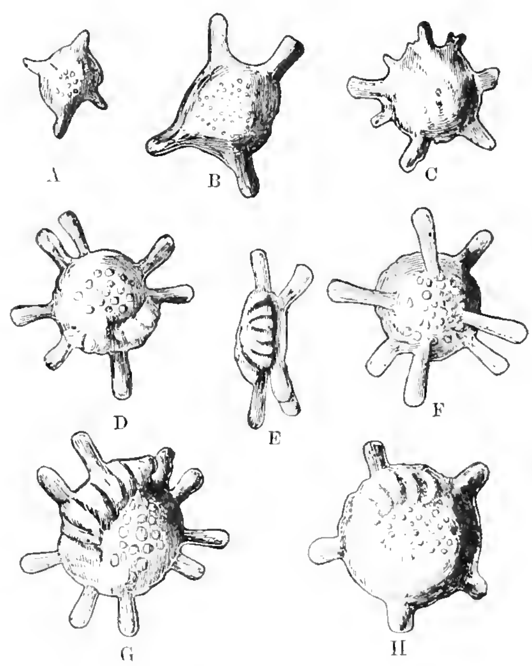
Two specimens of Philippine variety of *Calcarina*, distinguished by unusual exuberance of spinous outgrowths.

Fig. XXXIV.



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

Fig. XXXV.



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

that very little of that margin is left free. The length of their spines, moreover, at different ages, varies pretty constantly with the diameter of the disk, the average proportion being about two-thirds; though we occasionally meet with specimens in which the disk is unusually large and the length of the spines does not equal more than half its diameter, and others in which the disk is unusually small and the length of the spines is equal to its whole width. In the Mediterranean *Calcarinæ*, on the other hand, I have seldom met with more than nine spines; and any excess beyond that number is only presented by specimens in which the disk is very large, so that wide intervals present themselves along its margin between the bases of the spines. Their spines are nearly always simply clavate in form, any tendency to bifurcation or trifurcation at their extremities being rare; and they show but little disposition to increase in length with the enlargement of the central disk, being often not only relatively but even absolutely shorter in old specimens; as if the spines had entirely ceased to grow, and the disk had (as it were) included their basal portions within itself. In some instances, indeed, they scarcely show themselves enough to attract attention; being little more than tubercular projections from the margin of the disk (Fig. XXXV, H). Notwithstanding, however, this strongly marked difference in general physiognomy, it becomes obvious, on the comparison of a sufficient number of individuals, that no line of specific distinction can be fairly drawn on such a basis between the Philippine and the Mediterranean forms; since among the Philippine we meet with numerous specimens in which the spines are as few and simple as they are in the great bulk of the Mediterranean (Fig. XXXIV, B, C); while specimens not unfrequently present themselves among the Mediterranean, in which there is not merely an addition to the ordinary number of the spines, but a manifest disposition in many of them to subdivide near their extremities, thus showing an obvious approximation to the Philippine type. Although the spines usually radiate nearly in the equatorial plane, yet it becomes obvious, when their connexion with the central disk is examined, that they originate at different levels (Fig. XXXV, E, F); this will presently be found to depend on the turbinoid form of the spire (¶ 383). Besides the ordinary radiating spines, an extraordinary growth of short pointed spines is sometimes seen, either partially or completely covering one or both surfaces of the central disk (Fig. XXXIV, G); and examples occasionally present themselves (Fig. XXXIII, A), in which the development of these seems to have altogether superseded that of the ordinary radiating spines.

380. It is remarkable that among the very young specimens of this type, a yet greater variety shows itself than among those further advanced in life. At Fig. XXXIV, A, B, C, is shown what may be considered the ordinary or normal aspect of the young *Calcarina*: whilst in Plate XIV, figs. 6, 7, we have a representation (under higher magnifying powers) of an example of what may be termed the *hispid* condition, which so frequently presents itself in small *Calcarinæ* as to give rise to a question whether they should not be made to constitute a distinct species. I have satisfied myself, however, by the comparison of a large number of specimens, that so continuous a gradation presents itself between the smoothest and the most hispid specimens, as to render the attempt to separate them specifically altogether futile; and Mr. Parker, who has examined a yet larger number of specimens, fully confirms this conclusion. Moreover, the internal structure of these hispid specimens shows no departure whatever from the ordinary type.

381. Returning, now, to the external aspect of the fully-developed *Calcarina*, we have to notice that each surface of the disk is very commonly elevated, especially in its central portion, into rounded tubercles, more or less closely set together (Plate XIV, fig. 1). These are sometimes large and prominent, and present the semi-transparent appearance which is common among the like tubercles of *Operculina* (¶ 436) ; more commonly, however, they are less conspicuous either as to size, prominence, or distinctive aspect ; and sometimes they are almost or altogether wanting (fig. 2). Yet it is seldom, if ever, that they are absent from both surfaces of the disk ; and it is more common to find them deficient on the surface nearest to the apex of the spire, than on that on which its last-formed chambers are visible. And even when no prominent tubercles are present, a distinction may be generally made out by careful examination in the parts of the surface corresponding to their usual situation. For whilst the exterior of the disk is marked, more or less conspicuously, with minute punctations (fig. 8), these are not to be seen on its tuberculated prominences ; and the like deficiency is generally to be noted in circular spots of the surface, even when it is not raised into tubercles. Occasionally, though rarely, not even this mark of differentiation is seen, the punctations being uniformly distributed over the surface, which is in that case always the one nearest the apex of the spire. The surface of the spines is marked, more or less conspicuously, by a longitudinal furrowing (fig. 8), not unlike that of the "marginal cord" of *Operculina* (¶ 444). The furrows maintain a general parallelism, but there are frequent inosculations between them ; and punctations marking the orifices of deeper canals are often to be noticed at the bottom of the furrows. On one of the surfaces of the disk the indication of a *spire* is more or less distinctly observable (Plate XIV, fig. 1) ; also (Fig. XXXIV, B, Fig. XXXV, D, G, H). This indication is sometimes limited to two or three chambers ; but more commonly about half a turn may be distinguished, the spire becoming absorbed (as it were) into the solid mass of the disk, as we trace it backwards. The walls of the last-formed chambers, where entirely disengaged from the disk, are extremely thin (Plate XIV, fig. 8, *b*, *b*), so that it is rare to find them perfect ; and an opening formed by the fracture of the wall of the newest chamber has been mistaken by Fichtel and Moll, and apparently by D'Orbigny also, for the true aperture of the shell, which, as will presently appear, is of an entirely different character, and is not easily to be distinguished. The prominent surface of the walls of the conspicuous chambers of the newest whorl is covered with punctations resembling those of the general surface of the disk ; but they are more minute and more closely set together, and they are distributed with great uniformity, no unpunctated spaces being anywhere visible.

382. *Internal Structure.*—When the internal structure of this organism is examined by means of thin sections taken in different directions, the apparent anomalies of its conformation are found to be dependent simply upon the extraordinary development of its "supplemental skeleton ;" its general plan of structure being much simpler than the peculiarities of its aspect would seem to indicate. The spire, as laid open by vertical section (Plate XIV, fig. 3), is turbinoid ; consisting usually of about five whorls (a, a^1, a^2, a^3, a^4), that start as usual from a central cell, and progressively increase in size ; each whorl is applied merely to the surface of the preceding, and does not invest it in any degree, the chambers being altogether destitute of alar prolongations. The aspect of the spire as seen in equatorial section is

shown in fig. 4; this section, being taken in such a plane as to cut through the outer whorls a^4, a^3, a^2, passes entirely over the surface of the two inner whorls a^1 and a. The disposition of the chambers, as indicated by such sections, is ideally shown in fig. 8. The turns of the spire are separated from each other by the interposition of a thick layer of solid shell-substance; and this is quite distinct from the proper walls of the chambers, as is well seen in fig. 4, where the walls, *b*, of the newest chambers are shown to be entirely destitute of any such addition, whilst in the preceding part of the same whorl we observe them encrusted by a thin additional layer *d*, and as we trace this layer backwards to d^1 and d^2, we perceive that it progressively augments in thickness, until it acquires its maximum at d^3, just where it is covered by the subsequent whorl. This distinction between the proper walls of the chambers and the "supplemental skeleton" can be traced to the very centre of the spire. The septa are entirely formed by the infolding of the proper walls of the chambers, which at their planes of junction are destitute of the pores with which their substance is elsewhere minutely penetrated; sometimes the septum consists throughout of only a single lamella, as in *Discorbina;* but most commonly it is composed at its outer part of two lamellæ, which, though usually in contact, sometimes diverge to give passage to canals; whilst sometimes it is double throughout. There does not appear, however, to be any regular "interseptal system" as in *Operculina* and *Polystomella*. The communication between the adjacent chambers of the same whorl is effected, as in *Polystomella*, through a series of pores (fig. 3, *c*) disposed at pretty regular intervals along the inner margin of the septum; these may be considered as formed by the bridging over of an elongated fissure by delicate bars of shell-substance. The external aperture of course presents the same character (fig. 8, *c*).

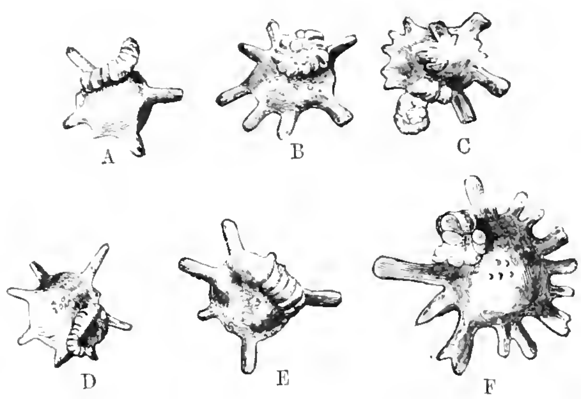
383. That the spines entirely originate from, and are strictly appendages of, the "supplemental skeleton" is well seen in fig. 4, which shows their connexion with its successive convolutions. Thus the spine *f* is one of the oldest, being traceable inwards to the earlier whorls; whilst those marked f^1, f^2, f^3, f^4, f^5 are obviously of progressively later production, their respective origins being further and further removed from the centre of the spire. It is, moreover, to be observed that each spine receives an augmentation in thickness as the convolution from which it sprang is encircled by others; this augmentation, however, is not marked (as in the spines of *Echini*) by lines of demarcation between the earlier and the later formations; and there is every reason to believe that the growth of the spines, both in length and in diameter, is continuous rather than interrupted. Although it might seem, from the examination of such sections only as are taken in the direction of the equatorial plane or in one parallel to it, as if the course of the spire must be seriously interrupted by the radiation of the spines (which sometimes appear to be so interposed between consecutive chambers as completely to separate them), yet the fact is that owing to the turbinoid form of the spire, a spine projecting from an earlier whorl is very little in the way of even the next convolution; for as this passes by the spine on a different level, its chambers are but slightly encroached-on, and this only upon the side which looks towards the apex of the spire,—as will be readily understood by examining the relation of the last half-convolution, visible in such a specimen as the one delineated in Plate XIV, fig. 1, to the pre-formed spines, or by an inspection of the ideal represented in fig. 8.

384. The canal-system of *Calcarina* presents a development so extraordinary in itself, and so obviously related to that of the "supplemental skeleton," as to throw great light upon its special functional destination. We do not here observe any such peculiar but limited distribution of systematically arranged passages, as that which constitutes so remarkable a feature in *Polystomella*; but every portion of the supplemental skeleton, with the exception of certain solid cones presently to be noticed, is traversed by canals which run very close together, with frequent inosculations, and which thus form a continuous network with long narrow meshes, that commences from the parietes of the chambers and extends itself to the very extremities of the spines (figs. 3, 4, 8). The proper walls of the chambers, as already stated, are uniformly perforated, like those of the chambers of *Discorbina*, by foramina of considerable size (averaging about 1-3000th of an inch in diameter); with these the canals of the supplemental skeleton do not seem to be directly continuous, for they are of about double the diameter and lie further apart from one another; but immediately round the proper walls of the chambers (as shown in fig. 3) there seem to be irregular lacunar spaces, into which their foramina open externally, and from which the passages of the canal-system originate. How numerous and closely-set these passages are, is shown in fig. 9, which is taken (under a much higher magnifying power than the rest of the figures) from a section that passes through the supplemental skeleton just outside the walls of one of the chambers, in such a direction as to cut through the passages transversely or obliquely. These passages run in different directions; some proceeding directly towards the external margin of the convolution, and being continued into the spines where these are given off from it; whilst others pass not less directly towards the two convex surfaces of the disk. In the earlier whorls of the spire, as shown at fig. 4, *a*, indications of spiral canals, commencing (as in *Polystomella*, ¶ 478) in a central lacunar system, are frequently traceable; and sometimes we may make out a general distribution of the canal-system of the earlier whorls, that strongly reminds us of that which prevails in *Polystomella* (¶ 477), the canals of the spines originating (as seen at *a*) in diverging branches which radiate outwards through spaces left between the two layers of the earlier septa. But this arrangement soon seems to be merged, as it were, in the much more copious distribution of passages that arise from the lacunæ round the proper walls of the chambers. The canals which pass towards the two lateral surfaces soon lose the general uniformity of arrangement which they elsewhere present; for they become crowded together in some situations and separated in others, so as to leave a number of columnar spaces untraversed, whilst the intercolumnar spaces are copiously penetrated by them,—as is seen at *e*, *e*, *e*, in figs. 3 and 10, the former showing the solid columns divided longitudinally, and the latter showing them as they are cut transversely. The varying appearances of the external surface, as described in ¶ 381, will now be understood. When, as commonly happens, the summits of the columns rise above the general level of the surface, they will show themselves as rounded tubercles. But when they are not thus elevated, they will merely be distinguished as circular spots surrounded by the punctations which are the orifices of the canals. In the spines, on the other hand, the canals form a longitudinally inosculating system (figs. 4, 8), of which the branches near the surface usually reach it so obliquely as to pass along it for some distance as open furrows, the punctations seen in which are the orifices of branches that strike the surface at a greater angle.

385. It is obvious from the foregoing description, that the nutrition of the spines must be provided for either through the investment of their surface by external prolongations of the sarcode-body, or through the penetration of its substance by prolongations of the sarcode-body conveyed into it by the canal-system, or through both methods jointly. That the sarcode-body is continued in the form of pseudopodial prolongations into the canal-system can scarcely be doubted, when it is borne in mind that such prolongations are known to pass through the pores which are scattered through the chamber-walls of *Rotalia*, and to extend themselves through the surrounding medium. After having made their way through the proper walls of the chambers of *Calcarina*, they will probably coalesce again in the lacunar cavities on the exterior of these, just as they coalesce to form a continuous layer of sarcode over the chamber-walls of *Rotaliæ* or *Polystomellæ*; and from the aggregation of sarcode in those cavities a new set of pseudopodial prolongations will take their departure through the canal-system of the "supplemental skeleton," just as a secondary set of pseudopodial filaments of sarcode are often seen to diverge from the little agglomerations formed by the reunion of some of those that primarily issue from the pores of the shell (¶ 33). The analogy of other Foraminifera, moreover, renders it very probable that the prolongations of the sarcode-body which reach the surface through the canal-system, will reunite upon it so as to form a continuous investment over the whole; and that this will be especially the case on the spines, appears to be indicated by the provision there is in the furrowing of the surface, for conveying the prolongations of the sarcode-body to every portion of their exterior.

386. One more fact remains to be noticed, which is of much interest as showing that the growth of the spire and that of the "supplemental skeleton" are to a certain extent independent of each other:—I refer to the departure from the regular form that frequently shows itself in the later turns of the spire, which (so to speak) often "run wild" in a variety of strange modes, examples of which are so well represented in Fig. XXXIII, A—F, that it is

Fig. XXXVI.



Abnormal specimens of *Calcarina*.

unnecessary to refer to them in other than these general terms. The extension of spines from the whole surface of the disk, in the mode represented in Fig. XXXIII, A, may in like manner be regarded as a sort of "running wild" of the supplemental skeleton.

387. *Varieties.*—The highly developed type which is now being described, is subject to considerable modification in feebler forms. One of these, the *C. calcar* of D'Orbigny (XCII), is remarkable for the radiating prolongations of the chambers themselves (Plate XIII, fig. 21), every one of which is ensheathed by a layer of exogenous substance that extends itself to form the points of the ray.

388. *Affinities.*—Although I consider the difference of aperture, with the extraordinary development of the supplemental skeleton and its canal-system, as sufficient, when taken together, to give to *Calcarina* a title to distinct generic rank, yet there can be no question of its extremely close relationship to *Rotalia*. The arrangement of the chambers is in all essential particulars the same as that which is characteristic of that genus; and the subdivision of the fissured aperture of the *Rotalinæ* into a row of pores is no greater a difference than that which we shall find to exist between the "nonionine" and the typical *Polystomellæ*, being moreover absent in some feeble *Calcarinæ*, whilst it presents itself in a variety of the true *Rotalia*. In certain forms of *Rotalia* we have had to notice a considerable development of the supplemental skeleton, which sometimes extends itself into radiating outgrowths; and where this exogenous deposit is formed in largest amount, we find the canal-system most complete and symmetrical. Thus the characters which differentiate *Calcarina* from *Rotalia* are altogether gradational.

389. *Geographical and Geological Distribution.*—The generic type we have now been considering appears to be pretty widely diffused through the tropical and warmer temperate seas, but to be limited to these; the Mediterranean and Adriatic being its extreme northern limit. Although bodies resembling *Calcarinæ* in outward form are occasionally, though rarely, found in the White Chalk, yet it is not certain whether they belong to this or to the succeeding genus. The Maestricht beds, however, are crowded with *Calcarinæ* (*Siderolinæ*, Lam.), which attain an extraordinary development, their size much surpassing that of the largest specimens now living in tropical seas. This type is common in the Grignon Tertiaries, also in the Miocene of North America, and in European Pliocene deposits; and I also have examples of it from deposits in Madagascar and Bourbon, the age of which is uncertain.

Genus XIX.—TINOPORUS (Plate XV).

390. *History.*—For reasons which will be presently explained, I think it well to revive a generic designation originally instituted by De Montfort in 1808, although, like a large proportion of his new designations, it has been rejected as uncalled-for by subsequent systematists. In his 'Conchyliologie Systematique' (tom. i, p. 147), he described and figured under the name of *Tinoporus baculatus* a small polythalamous body, which he seems to have distinguished from the other varieties of *Nautilus* (*Calcarina*) *Spengleri* figured by MM. Fichtel and Moll, partly by the fewness of its spines, and partly by the difference of its structure as displayed in vertical section. And although his figure and description are alike inaccurate (the former, as pointed out by Messrs. Parker and Rupert Jones, LXXVII, having been partly drawn from specimens of *Calcarina*), yet I can scarcely doubt that

he had before him a specimen of the type I am about to describe, since he distinctly notices, both in his description and in his rude figure, that cellulation "sur divers plans" which gives to its vertical section somewhat the appearance of that of a Nummulite. No such appearance is presented by vertical sections of *Calcarina;* whilst, as will presently appear, *Tinoporus* is made up of several layers of cells superimposed one upon another; and although its relation to *Nummulina* is really remote, yet the resemblance in aspect presented by vertical sections of the two may easily seem, to such as are unacquainted with the real meaning of their respective appearances, sufficiently close to justify the parallel. With the *T. baculatus* of Montfort it will be shown that we must associate, on account of its close structural relationship, a type which has been described (LXXIX) under the generic designation *Orbitolina,* since it may be comprehended in the very vague definition given of that genus by D'Orbigny (LXXIV); and this type is the representative of an extensive series of forms, both recent and fossil, to which the same definition applies, and to which the name *Orbitolina* has been assigned (loc. cit.) by Messrs. Parker and Rupert Jones. Now there is a very grave objection to such an employment of the term. According to the usage of many systematists, *Orbitolina* would be nothing else than the appropriate distinction of the *recent* forms of *Orbitolites;* and even to such as do not accept this usage, the close similarity of name would assuredly suggest the existence of a structural relationship. But it will presently become apparent that no such relationship exists, the essential structure of the so-called *Orbitolinæ* being altogether different from that of *Orbitolites,* and no real resemblance existing between them except as regards their plan of growth. Hence it seems very desirable to discard the name *Orbitolina* altogether; and since another form of the same type had previously been distinguished by De Montfort, his name *Tinoporus* may fairly claim to be substituted for that of D'Orbigny.

391. As the genus *Tinoporus* presents itself under a considerable variety of external forms, I think it desirable in the first instance to describe an example that presents what seem to me the essential features of its structure, and is at the same time free from those complications by which those features are elsewhere masked.. Such an example I find in the forms which have been described as varieties by Messrs. Parker and Rupert Jones (LXXIX) under the designations *Orbitolina vesicularis, O. congesta,* and *O. lævis:* these, as I do not hold their differences to be of any account, I reunite under the designation *Tinoporus vesicularis.**

392. TINOPORUS VESICULARIS: *External Characters.*—The largest examples I have seen of this type present the form of a short truncated cone, much resembling the lower half of a sugar-loaf (Plate XV, fig. 1), having its margins rounded off, and attaining at the base a diameter of about 1-10th of an inch. The base commonly exhibits a slight central depression. Sometimes the cone is more depressed, and spreads out more widely at the base; and in this case the basal concavity is usually wider and deeper. The examples I have seen from

* In my previous description of this type (XVI), I designated it *T. lævis;* but I think it better to substitute the specific designation *vesicularis,* under which one of its varieties has been described elsewhere, as better agreeing with the generic name;—"a smooth" "stick-bearer" being a contradiction in terms.

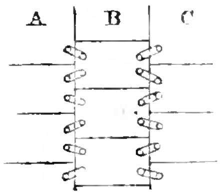
other localities have for the most part a spherical or spheroidal shape; but a careful examination will generally make it apparent that this shape is derived (so to speak) from that last mentioned, by the folding-inwards of its peripheral portion towards the centre of its lower surface, so as to leave a deep cavity at that part of the sphere,—the relation of the two forms being very much like that which exists between the expanded *pileus* of an Agaric, and the same *pileus* whilst still included within its *volva*. I cannot regard these diversities of form as possessing any specific value; since they depend entirely upon mode of growth, and are not connected with any differences of internal structure. In whatever form the *T. vesicularis* may present itself, it is recognised by the absence of projection or angularity, and by a regular areolation over its whole surface, which a good deal resembles that of the cuticles of many leaves, the areolæ preserving a tolerably constant average of size, but being very indefinite as regards form. The septal divisions are marked by a very definite limbation, sometimes formed of continuous ridges of shell-substance, and sometimes of rows of granules; and in the interspaces between these, under a sufficient magnifying power, minute punctations may be seen.

393. *Internal Structure.*—When the structure of this organism is examined by means of sections taken in different directions, it is found to be composed of an aggregation of minute chambers of nearly uniform size, which are piled one upon another in pretty uniform layers, each of these presenting an approach to a concentric disposition (Plate XV, figs. 2, 3). Although it is difficult to make out with certainty the arrangement of the first-formed chambers, yet it is clear that as in other Foraminifera the point of departure is a spheroidal cell (fig. 3, *a*), which soon comes to be surrounded by a cluster of secondary cells (*b*, *c*) derived from it by gemmation. In what manner these are given off from the first,—whether by a spiral or by a cyclical extension of the sarcode-body,—I have not been able to satisfy myself, on account of the difficulty of precisely carrying the plane of section through this group of chambers. In *T. baculatus* I have been fortunate enough to do this in several instances, and have found that the early growth is unquestionably spiral (fig. 12),—soon, however, giving place to the cyclical, as in those varieties of *Orbitolites* whose growth commences after the same fashion (¶ 180); and whether this be or be not the case in *T. vesicularis*, it is indubitable that before long the extension of the organism in diameter is effected by a budding-forth of new chambers from all parts of the circumference, not with such regularity, however, as to form distinct annuli like those of *Orbitolites*. Whilst this extension is taking place peripherally, additional layers of chambers are formed, as in *Orbiculina*, above and below the primordial cluster, meeting each other on the equatorial plane; and in this manner the increase of the organism in thickness is effected. The growth on the two sides of the equatorial plane, however, is seldom or never symmetrical; and that of the more convex portion seems continually tending to overpower that of the opposite surface, so that the equatorial plane becomes more or less deeply concavo-convex. I have reason to believe that this inequality is due to the attachment of the flat or subconcave base to the surface of sea-weeds or zoophytes; in virtue of which it will naturally happen that the free side will grow faster than the other. It is by an excess of this predominating growth that the spheroidal form is acquired, with its deep residual cavity, as just now described.

394. On more minutely examining the structure of the walls of the chambers and the

mode of communication between their cavities, we find that their *horizontal* partitions or floors are perforated by numerous large pores (Plate XV, figs. 2, 3, 4) which closely resemble those of the shell of a *Rotalia* or a *Planorbulina* in their size and arrangement; and these will allow of free communication, by pseudopodial threads of sarcode, between the segments that are lodged in the chambers piled vertically one over the other. The *vertical* partitions are much thicker, and are not thus minutely and regularly perforated; but they exhibit a small and variable number of large apertures (fig. 4, *a*, *a*), that lead into the adjacent cells which lie in or near the same horizontal plane. I say *in* or *near*, because it is seldom if ever the case that the horizontal partitions or floors of two adjacent vertical piles of cells are on the same level; and, in fact, the typical arrangement (though frequently departed from) seems to be, that there is an *alternation* in the levels of the floors of adjacent piles (as shown in the accompanying diagram, based on some parts of fig. 3), and that every chamber in any pile B normally communicates with two chambers in each of its adjacent piles A and C, by one passage above and the other below the floor that divides them. Neither the horizontal floors nor the vertical partitions consist of more than a single lamella.

FIG. XXXVI.



395. TINOPORUS BACULATUS.—The original type of the genus, namely, the *T. baculatus* of De Montfort, agrees closely with *T. vesicularis* in the fundamental characters of its organization, but differs in being furnished with a variable number of radiating appendages that give it a strong external resemblance to *Calcarina*. Of the specimens in my possession, the greater part present the aspect represented in Plate XV, figs. 6, 7, and on a larger scale in fig. 5; and these were collected from coral reefs in various parts of the Polynesian Archipelago,—my earliest acquisition of them, however, having been from the contents of the stomach of an *Echinus* taken on the coast of Borneo, which were kindly put into my hands by Dr. J. E. Gray. I am informed by Mr. Denis Macdonald that on certain coral islands which he has particularly examined, these organisms are so extraordinarily abundant, that they accumulate in the lagoons in regular strata, commonly alternating with strata of *Orbitolites*. The more massive and ruder forms represented in Plate XV, figs. 8, 9, occur in Mr. Cuming's Philippine collection.

396. *External Characters.*—The typical form of the central portion of *Tinoporus baculatus* may be considered as an oblate spheroid; sometimes, however, the organism is nearly spherical, and sometimes it is much flattened out, especially when the body extends itself into the radial prolongations. Its surface is divided into areolæ (fig. 5) very much as in *T. vesicularis*; but the angles of junction of the partitions between the areolæ are very commonly occupied by rounded projecting tubercles, strongly resembling those of *Calcarina*. The number and size of these tubercles vary greatly among different individuals, as will be seen on comparing figs. 6 and 7. They seem to be altogether wanting in the Philippine specimens, being apparently replaced by a multitude of small spines, which give to the surface a hispid aspect. From the marginal portion of the central disk there spring a variable number of conical prolongations having the furrowed surface of those of *Calcarina*; and these appear seated (so to speak) upon extensions of the central disk itself, which is sometimes so deeply

subdivided at its margin as to resemble the body of a Star-fish (figs. 7, 9), the areolar division being continued nearly to the extremity of each ray, and its point only being formed by the furrowed prolongation. These appendages are usually from four to six in number; I have occasionally seen only two, and in no case have I met with more than eight. They usually diverge in or near the equatorial plane; but they sometimes come off in very different directions (fig. 8).

397. *Internal Structure.*—The general organization of *T. baculatus*, brought into view by sections taken in different directions, does not differ in any essential respect from that of *T. vesicularis*; the origin of the whole aggregation of chambers in a central cell, their subsequent multiplication both horizontally and vertically, and their methods of communication in both directions, being all the same. As already mentioned, I have very distinct evidence, in sections of this species, of a *spiral* commencement (fig. 11 *a*), soon giving place to an *irregularly-cyclical* growth (*b, b*); and it is remarkable that the first-formed portion sometimes bears so close a resemblance to the innermost part of the spire of *Calcarina*, that in this earliest stage of their growth the two types could not be distinguished from each other. The essential difference between *T. baculatus* and *T. vesicularis* consists in the possession by the former of a "supplemental skeleton," which presents itself under two principal aspects. The piles of chambers extending vertically from the equatorial plane towards the two surfaces of the spheroid are partially separated by the interposition of pillars of solid shell; and it is by the projection of the summits of these pillars (as in *Calcarina*) that the tubercles of the surface (fig. 5) are formed. The spines also, which form the extremities of the radiating prolongations, belong to the same system; and they are shown, by sections that pass in a favorable direction (fig. 12), to be extended from a solid framework which begins to be formed even with the first convolution, and which adds greatly to the thickness of the partitions between the chambers, giving off a multitude of minute spines from their external surface. This framework is penetrated by a canal-system, which not only forms passages through the solid axis that is prolonged into the spines (fig. 10, *b, b*), but also extends itself into the partitions between the chambers (fig. 10, *a, a*). The canal-system of the solid axis, moreover, communicates freely with the cavities of the chambers that are adjacent to it, as is shown at fig. 10, *b, b*. These chambers are arranged around it with considerable regularity, as is seen in fig. 11, which is a transverse section of the base of one of the radiating prolongations, showing the solid axis with its radiating canals, surrounded by three rows of chambers. It would seem as if, in the Polynesian variety of *T. baculatus*, the material of the supplemental skeleton were appropriated rather to the formation of the solid pillars than to that of a solid axis for the radiating prolongations; the latter being much less conspicuous than it is in the Philippine specimens, and sometimes appearing to be deficient altogether at their extremities. On account of the variability of these differences, however, I cannot regard them as of any essential value.

398. If any further evidence had been required as to the essential relation between the "canal-system" and the "supplemental skeleton," I think that it must be satisfactorily furnished by the comparison of the two species of *Tinoporus* now described. For in *T. vesicularis* it is obvious that the system of communications which exists between its chambers is adequate for all the ordinary wants of an organism of this type, the structure of which is

uniform throughout. But when, as in *T. baculatus*, an additional framework of solid walls is interposed in the midst of the building, for the support of the extensions into which it is prolonged, a special system of passages, originating from the cavities of the adjacent chambers, and extending throughout the solid framework, is provided for its nutrition.

399. *Varieties.*—The foregoing constitute the only examples of the genus *Tinoporus* that are certainly known to exist at present; but a far larger extent of variation as regards size and shape presents itself in a group of fossil forms which are probably to be referred to the same type. Thus in the Chalk we meet with great numbers of globular bodies varying in size from small shot to bullets, having their surface so characteristically marked by a superficial meshwork of septal limbation, that we can scarcely hesitate in regarding them as examples of the smooth form of *Tinoporus*, although their internal structure has been so obscured by fossilization as not to show more than the general arrangement of the chambers.* These are accompanied by conoidal and hemispherical bodies having the like surface; and from such we pass to large outspread flattened forms, one of which, the *Orbitolina gigantea* of D'Orbigny, attains a diameter of nearly four inches. The synonymy of these fossils, which have been very commonly regarded as Sponges, and referred to the genera *Coscinopora* and *Tragos*, has been fully elucidated by Messrs. Parker and Rupert Jones (LXXIX).

400. *Affinities.*—The relation of this interesting type of structure to that of *Planorbulina* is extremely intimate. For, as in that genus, the first-formed portion of *Tinoporus* evidently consists of a flattened disk, consisting of numerous segments which are arranged spirally in the first instance, but subsequently on a more or less regular cyclical plan. We do not find in *Tinoporus*, however, those tubular and margined apertures which are so characteristic of the most developed forms of *Planorbulina*; whilst, on the other hand, we do not find in the most "acervuline" *Planorbulinæ* that regular piling-up of segments on both sides of the primitive spire which is characteristic of *Tinoporus*. The affinity of *Tinoporus baculatus* to *Calcarina*, again, is marked not merely by the very close correspondence of their adult forms in external shape, but by the precise correspondence between the early conditions of the two as regards their internal structure. Again, we shall find that the curious genus *Polytrema*, the place of which among the Rotaline Foraminifera was long since suspected by the sagacity of M. Dujardin (XXXVI, p. 259), is only a still more aberrant modification of the same plan of growth. Lastly, there will be found, when we come to describe the structure of *Orbitoides*, a considerable resemblance in plan of growth between that genus and *Tinoporus*; the chief difference being that in the former type the chambers of the median plane are more differentiated in character and in mode of communication from those which pile themselves on their lateral surfaces, than they are in the latter. But it seems pretty clear that in its most essential characters *Orbitoides* is more nearly related to the cyclical forms of the Nummuline than to those of the Rotaline series.

* Many of these fossil globular forms, like the recent (¶ 392), have an irregular tubular cavity on one side, extending to a greater or less distance into the interior; and such appear to have been used as beads (the perforation being carried through to the opposite pole) by the old "flint-folk" of the Valley of the Somme, being common in the gravel that yields the flint implements.

401. *Geographical Distribution.*—The recent examples alike of the simple and of the baculate types of *Tinoporus* are found in greatest size and abundance in the Australian and Polynesian seas, occurring chiefly in the shelly sands of rather shallow water; and *T. baculatus* does not appear to range far beyond those regions. I am informed by Mr. Denis Macdonald (late of H.M. surveying ship, "Herald"), that on some annular coral islets he has met with *Orbitolites* and *Tinoporus baculatus* in most extraordinary quantity, not only on the windward side of the external shore, but also in their internal lagoon, into which these bodies are washed by the surf, and in which they gradually accumulate to such an amount as to have an important share in filling it up. The small spherical forms of *T. vesicularis*, on the other hand, are for the most part inhabitants of deep waters, being brought up in dredgings from muddy bottoms and shell-sands; and they have also a wider geographical range, having been found not only in the Australian and Polynesian seas, but in the East and West Indies, at Mazatlan on the coast of California, in the neighbourhood of Teneriffe, in the Mediterranean, and even on the British coasts as far north as Arran.

402. *Geographical Distribution.*—The obliteration of the internal structure of the earlier fossil specimens which we believe ourselves justified in referring to this type, prevents us from stating with certainty in what strata its first remains occur. From the evidence of external form and surface-markings, however, it is pretty clear that some of those small spheroidal bodies in the Greensand, and a large number of those occurring in the various beds of the Cretaceous series, which have been regarded as Spongeous, are truly referable to the simple form of the genus *Tinoporus.* If so, they are not only by far the largest examples of this type, but are also amongst the largest of the Foraminiferous group. The Cretaceous period would seem to be that in which this type attained its *maximum* of development; for although examples of it occur in the Nummulitic limestone, and in the later Tertiaries of Palermo, Bordeaux, and San Domingo, these are not of larger dimensions than the recent specimens. The "baculate" form of this type cannot be distinguished with certainty in fossil specimens from *Calcarinæ*, by external characters alone; so that it is as yet uncertain whether any of the radiate and stellate bodies which occur in the Maestricht Chalk and in the Nummulitic Tertiaries, are or are not the ancestors of the similar organisms at present so abundant on the reefs and islands of the great Coral Sea.

Genus XX.—Patellina (Plate XIII, figs. 16, 17).

403. *History.*—Some of the large fossil forms which seem properly to belong to the genus now to be described, have been referred to the genus *Orbitolina* (D'Orbigny), whilst another has received from D'Orbigny the designation, *Cyclolina,* and another has been described by Mr. Carter (xxiii *a*) under the name *Conulites;* and its minute recent representatives also have been referred by Messrs. Parker and Rupert Jones (lxxix) to the genus *Orbitolina.* For the reason already stated (¶ 390), however, I think it undesirable to adopt the generic term *Orbitolina* for this type, any more than for the last; and as the definition given by D'Orbigny of his genus *Cyclolina* is so unsatisfactory as to leave the true character of its type in complete

uncertainty,* I have thought it just to Prof. Williamson, who has accurately described and figured (cx, p. 46, figs. 86—89) the recent form that best elucidates the structure of these fossils, to adopt the generic name *Patellina* which he has conferred upon this. I shall first give an account of the recent type *P. corrugata*, partly based on Prof. Williamson's observations, and partly on my own examination of more developed specimens obtained by Messrs. Parker and Rupert Jones from the coast of Australia; and shall then describe the fossil types on the basis of Mr. Carter's observations and my own.

404. Patellina corrugata: *External Characters and Internal Structure.*—This very beautiful but very minute shell has the form of a depressed cone, resembling that of a *Patella*, its diameter being twice or three times its height; the apex of the cone is occupied by the primordial segment; and its regularly chambered structure forms only a thin shelly wall, the interior of the cone being more or less completely filled up by an irregular growth of secondary chambers. In the British form of this type, the primordial segment is surrounded by two or more turns of an irregular spiral (cx, fig. 90 *a*,) reminding us of the outspread spiral of *Pulvinulina vermiculata* (¶ 366); and the subsequent growth of the cone is effected by the addition of semi-annuli which interdigitate with one another (cx, figs. 87, 88), so as to present a certain resemblance to *Textularia* in plan of increase. Each annulus or semi-annulus is described by Prof. Williamson as being divided into chamberlets by transverse secondary septa, which spring from the external margin and pass towards the internal, but which do not quite reach it; so that all the chamberlets thus formed communicate with each other by a continuous passage left along the internal side of the chamber (cx, Fig. 90). This partial subdivision is marked externally by a crenulation of the surface. The secondary septa in the British specimens are very commonly wanting, or are merely rudimentary, in the early vermiculate spiral portion of the cone. Prof. Williamson expresses himself as unable to determine in what mode the principal semi-annular chambers communicate with each other. The diameter of his specimens of this organism does not exceed 1-80th of an inch.—In the more highly developed Australian forms of this type, on the other hand, which sometimes attain a diameter of nearly 1-25th of an inch, the growth is cyclical from its commencement; the primordial segment being encircled by a circumambient segment, as in *Orbitolites* (¶ 157), which is often itself partially subdivided, and from which a complete annulus of segments is given off (Plate XIII, fig. 16); and I find no trace of any subsequent division into semi-annuli, resembling that described by Prof. Williamson. Moreover, I find that the partitions between the chamberlets are complete, not merely extending to the margin of the preceding annulus,

* D'Orbigny's definition of *Cyclolina* (lxxiii, p. 139) is so nearly applicable to *Orbitolites*, that Mr. Carter was formerly (xix) misled into characterising as a *Cyclolina* what I have shown to be a mere variety of *Orbitolites*, and was further misled into characterising the white limestone in which this occurs as Cretaceous instead of Eocene; so that, as he has truly remarked (xxiii *a*), "It would have been better if M. D'Orbigny had never written anything about *Cyclolina*, than just enough to mislead." There is, in fact, nothing either in his figures or descriptions of this fossil that enables us to identify it with any certainty; its geological position being the chief point which differentiates it from *Orbitolites*, and which renders it probable that it is to be associated with those subconical *Orbitolinæ* which seem properly to belong to the genus *Patellina*.

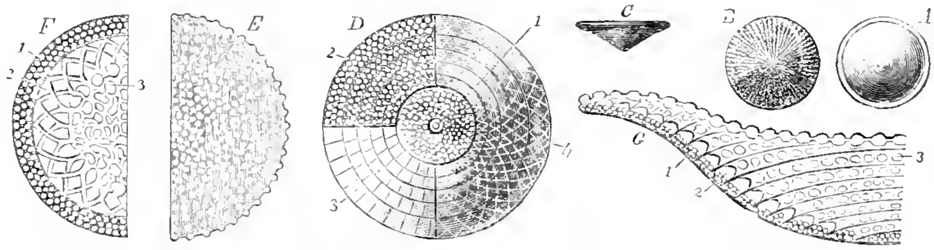
but being prolonged inwards beneath that margin (Plate XIII, fig. 17), until the peripheral chamberlets lose their distinctness by merging into the secondary growth which occupies the umbilical cavity. The chamberlets are prolonged in a radial direction so as to have a tubular form; but not unfrequently we find that as we trace them from without inwards two of them coalesce into one, as often happens in *Cymbalopora*. Owing to the conical arrangement of the successive annuli, only a small part of each (except the last) is seen where it crops out upon the surface, the remainder being concealed by those above and below it. The external walls of the chamberlets are perforated with a few minute pores; but those which separate the chamberlets and annuli from each other are altogether imperforate, so far as I have been able to distinguish. —The interior of the cone, in the British specimens of this type, is described by Prof. Williamson as partly occupied by an exogenous deposit of hyaline shell-substance, possessing no regular arrangement; and this seems evidently analogous to that which fills up the umbilical vestibule in the most developed forms of *Rotalia*, and which tends to form a secondary chamber-structure in the "asterigerine" *Discorbinæ*. This umbilical deposit seldom fills the cone so completely as to conceal the last annulus, which is consequently the one best seen from the under side, and frequently the only one there visible (CX, fig. 89). In the larger Australian forms it has a distinctly loculated structure; its chambers, however, are not arranged with any regularity, but constitute a system of intercommunicating *lacunæ* hollowed out in the midst of a mass of solid shell-substance; and in this system the chamberlets of the peripheral annuli appear to terminate at their central extremities, just as the chambers of *Cymbalopora* communicate with the umbilical vestibule. I find it impossible, however, to speak with the confidence I would desire upon this point; for notwithstanding the beautifully hyaline texture of this shell, its very small size as a whole, and the minute subdivision of its parts, render the examination of its internal structure very difficult. The still more minute forms described by Messrs. Parker and Rupert Jones (LXXIX) under the names *Orbitolina simplex* and *O. semiannularis*, are obviously young or imperfectly developed examples of the type that has now been described.

405. Patellina concava: *External Characters and Internal Structure.*—From the Nummulitic limestone of the Pyrenees I have fossil specimens which resemble the preceding in form and in superficial characters, but which are of comparatively gigantic dimensions, attaining a diameter of 1-4th of an inch; these appear to me to be identical in structure (so far as their metamorphic condition allows me to judge) with the fossil which has been recently described by Mr. Carter (XXIII *a*) under the name *Orbitolina lenticularis*, being regarded by him as identical with the species so named by Blumenbach, which had been first described and figured by Deluc ('Journal de Physique,' tom. lvi, p. 344). I believe them also to be identical with the *Orbitolina conica* of D'Archiac ('Mém. Soc. Géol. France,' tom. ii, p. 178), and the *O. conoidea* of Gras, ('Foss. de l'Isère,' p. 51, pl. i, figs. 4—6), from the Cretaceous beds of France, as also with the *O. discoidea* of Gras and the *O. plana* and *O. mamillata* of D'Archiac. As all these appear to be varieties of the *O. concava* of Lamarck, it seems convenient to adopt this last (as Messrs. Parker and Rupert Jones have done, LXXIX) as the specific designation of the type, since it expresses a form intermediate between its conical and its discoidal varieties.* The form of this fossil (Fig. XXXVII, A, B, C) seems to

* I must freely confess, however, that I am not as yet prepared to say with certainty what of

vary from that of a high to that of a depressed outspread cone; and the diameter of the Indian specimens ranges between 1-8th and 2-3rds of an inch, the smallest being relatively the highest. The general plan of structure of this fossil corresponds with that of the recent *Patellina;* the cone being formed externally of a succession of annular segments subdivided by transverse partitions into chamberlets (D, 3); whilst its interior is more or less completely filled up by a secondary umbilical growth. But there are two very important differences in detail. In the first place, each of the chamberlets of the annular series is again partially subdivided into four or more, by septa which project from their external wall, but which do not extend above half-way towards the interior (Fig. XXXVII, D,2,3, G,1,2); so that the surface of the cone

Fig. XXXVII.



Patellina lenticularis:—A, B, C, conical surface, basal surface, and edge view, one half larger than the natural size:—D, Diagram showing 1, arrangement of chambers at the centre or apex, which is at first more or less confused, and then cyclical; 2, external or reticulated chamber-layer; 3, subjacent or large chamber-layer; 4, engine-turned arrangement of chambers below the last-mentioned layer:—E, Magnified view of portion of patulous surface, to show the arrangement of the ends of the columnar chambers in the form of granulations:—F, Horizontal section, showing, 1, reticulated layer; 2, large chamber-layer; 3, columnar chamber-structure:—G, Vertical section of half the fossil, showing, 1, reticulated layer externally; 2, large chamber-layer; 3, columnar chamber-structure.—After Carter.

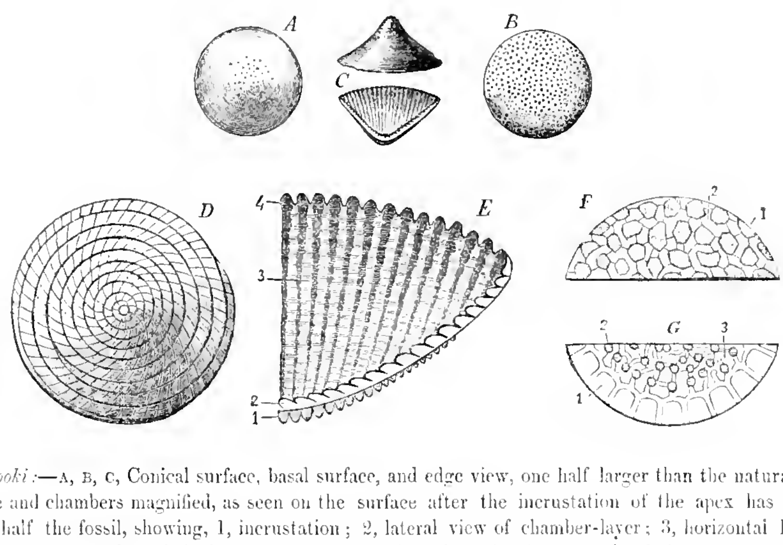
shows a very minute subdivision of its external layer, whilst the removal of this brings into view the larger chamberlets formed by the primary subdivision of the annulus. This arrangement is represented in the accompanying figures, which are copied from Mr. Carter's somewhat diagrammatic delineations. I feel certain, however, that in my own specimens the large chambers of the peripheral annuli are prolonged inwards in a radial manner much further than Mr. Carter represents them, and that they communicate freely with those which fill up the hollow of the cone, instead of being terminated on their inner side by transverse walls. The umbilical growth consists of an aggregation of compressed chambers, which are described and figured by Mr. Carter (D, 4) as having an engine-turned arrangement; and these rest one upon another in columnar piles, more or less completely filling the cone, and sometimes extending even beyond its base, so as to give this a convex surface. This surface is marked by tubercular granulations (E), which probably result (like those of *Tinoporus*, ¶ 392) from septal limbation. In my own specimens of this fossil, the

the *Orbitolinæ* of Lamarck and subsequent writers are to be referred to the genus *Tinoporus*, and what to the genus *Patellina*; since their forms are derivable from those characteristic of either type, and their internal structure is seldom sufficiently well preserved to afford the means of positive diagnosis. I am inclined to believe, however, that all those conoidal, lenticular, or discoidal forms which exhibit a more or less distinct *annulation* are true *Patellinæ*.

umbilical chambers have been so completely altered in fossilization, that I can give no account of their structure; and it is to be regretted that Mr. Carter, whose specimens appear to be in better condition, should have given so imperfect a description and so merely diagrammatic a representation of it. But I can scarcely hesitate in the belief that this columnar chambered structure must essentially correspond with that which we have seen in *Tinoporus* (¶ 394), and with which we shall meet again in *Orbitoides* (¶¶ 505, 506). It seems most likely that the discoid fossil which has been designated *Cyclolina cretacea* by D'Orbigny, is nothing else than a very outspread form of the *Orbitolina lenticularis* of Lamarck, which is probably to be regarded as the fully developed type of our genus *Patellina*, the recent forms being comparatively feeble. Such a form, agreeing in all essential particulars with the foregoing, has been recently described by Mr. Carter (XXIII *a*). On the other hand, Mr. Carter has met with the same type of structure in very high conical forms; and in some of these the reticulation of the surface is wanting, and the septa are indistinctly developed. It is not a little curious that in some of these there should be exactly the same disposition of semi-annular imperfectly subdivided chambers interdigitating with each other, as has been described in the recent *P. corrugata* (¶ 404).

405. Patellina Cooki: *External Characters and Internal Structure.*—The fossil described by Mr. Carter (XXIII *a*) under the new generic name *Conulites* does not appear to me to differ so essentially from the preceding in general plan of structure as to require being generically separated from it. Like *P. lenticularis*, it is a more or less depressed cone (Fig. XXXVIII, A, B, C), of which the exterior is formed of a series of chamberlets (G, 1) arranged in

Fig. XXXVIII.



Patellina Cooki:—A, B, C, Conical surface, basal surface, and edge view, one half larger than the natural size:—D, Central portion of the spire and chambers magnified, as seen on the surface after the incrustation of the apex has been removed:—E, Vertical section of half the fossil, showing, 1, incrustation; 2, lateral view of chamber-layer; 3, horizontal layers of chambers; 4, opaque, white columns of condensed shell-substance:—F, Basal surface, showing, 1, ends of the columns of white substance; 2, ends of the columns of chambers:—G, Horizontal section, showing, 1, part of the spiral chamber-layer; 2, truncated ends of opaque white columns; 3, ditto, of columns of chambers. (After Carter.)

regular succession, whilst the interior is filled by columnar aggregations of compressed chambers (G, 2). The arrangement of the chamberlets of the exterior, however, seems from

Mr. Carter's figure and description to follow a regular spiral plan throughout (D), the spire being continuous from the base to the apex of the cone; and the chamberlets are simple as in *P. corrugata*, not again subdivided as in *P. lenticularis*. The upper part of the cone is covered by an exogenous deposit of shell-substance (C, 1), which gradually subsides, about half way down the cone, into granulations that project in rows from the septal bands, forming a superficial limbation. On the other hand, the chambered structure of the interior of the cone is strengthened by solid columns of a somewhat conical form (E, 4), the apices of which are directed to the interior of the cortical layer, whilst their bases form large tubercles which project from the basal surface (F, 1). These columns are obviously analogous to those which we have seen to be formed in *Tinoporus baculatus* by the accumulation of solid shell-substance at the meeting angles of the septa which divide the piled-up chambers (¶ 397); and the whole description given by Mr. Carter justifies the belief that the chambered structure is essentially the same in the two cases. Now, from what we have already seen in *Tinoporus*, and from what we shall hereafter find to be the case in *Operculina*, *Nummulina*, and *Orbitoides*, it may be stated with certainty that the presence or absence of these solid columns is a character so extremely variable as not in itself to have even a specific value. And when the account already given of the recent *Patellina* is taken in connection with the facts formerly stated in regard to the varieties in plan of growth shown by *Orbitolites* and *Orbiculina*, it becomes obvious that the persistence of the early spiral succession through the whole period of increase is not in itself a character of sufficient importance to constitute a specific differentiation; more especially as we are informed by Mr. Carter that the spire is subject to irregularities, sometimes becoming double. The subdivision of the superficial portion of the chambers of *P. lenticularis*, however, if it should prove to be a constant character of that type, and to be altogether wanting in *P. Cooki*, would be held sufficient for the specific differentiation of the former from the latter.

406. *Affinities.*—So far as the minuteness of the recent examples of this genus, and the imperfect preservation of its larger fossil specimens, allow us to form an opinion of its affinities, these appear to connect it, on the one hand, with those aberrant forms of the Rotaline series in which the spiral tends to give place, at an earlier or later period, to the cyclical plan of growth; whilst, on the other, it seems related to the minutely sub-divided spiral and cyclical forms of the Nummuline series. There is something in its sharply defined trochoid cone which strongly reminds us of the typical *Pulvinulinæ*; and although it is only in the *P. Cooki* that the spiral plan of growth is maintained throughout, yet the vermiculate spiral in which *P. corrugata* often commences no less strikingly resembles that of the complanate forms of *Pulvinulina*. And it seems further to be allied to that genus, rather than to *Discorbina* or to *Planorbulina*, in the fineness of the porosity of its shell. To *Discorbina*, however, it is specially related in the occupation of its deep umbilical cavity by an aggregation of secondary chambers, which thus conceal its inferior lateral surface; and in its general plan of growth it may be considered as specially related to *Cymbalopora*. The relation of the large, highly-developed, fossil forms of *Patellina* to the conical, outspread examples of *Tinoporus* seems to be exceedingly intimate; the essential difference appearing to lie in the limitation of the secondary chamber-growth to one side, and in the distinctness of that growth from the layer in which the organism originates. At present it can scarcely be said with certainty what

fossil forms are to be referred to these two types respectively; and the diagnosis will probably rest essentially on this, that whilst the surface-markings of the upper and under side are alike in *Tinoporus*, though one side may be convex and the other concave, the convex side of *Patellina* always shows either a continuous spiral or a succession of annuli of chamberlets.

407. *Geographical and Geological Distribution.*—The little *Patellinæ* which constitute the existing representatives of this genus are very generally diffused, but do not seem to be anywhere very abundant. They have been found in Arctic, British, Mediterranean, Indian, and Australian seas, between the littoral zone and depths of five hundred fathoms.—If we are right in identifying with this type the *Orbitolina lenticularis* of Blumenbach and the *Cyclolina cretacea* of D'Orbigny, this genus was highly developed at the Cretaceous epoch; and the same fundamental type seems to have presented itself under great diversities of form, twelve or more different specific names having been given to its varieties. This genus is also represented, as we have seen, by examples of considerable size in the Eocene Tertiaries of India. Subsequently, however, it seems to have declined; the *Patellinæ* of the Grignon sands being neither so large nor so well developed as those at present existing in the Australian seas.

Genus XXI.—POLYTREMA (Plate XIII, figs. 18—20).

408. *History.*—The genus *Polytrema* was instituted by Blainville (VI, *a*), for the reception of the curious little bodies which had been previously described by Lamarck (LX), under the name of *Millepora rubra*. Neither of these systematists appears to have entertained any doubt of its Zoophytic character; but its probable relationship to the Foraminifera was suggested by Dujardin (XXXVI, p. 259), who, after speaking of the probably Rhizopodal nature of *Rotalia*, *Planorbulina*, &c., continues:—" J'ai bien constaté que toutes les loges sont occupées à la fois par la substance glutineuse; mais je n'ai point vu les expansions filiformes, non plus que dans le *Polytrema rubra*, que je conjecture appartenir à cette même famille d'après la nature de la partie vivante." A similar view was afterwards taken by Dr. J. E. Gray ('Proceedings of the Zoological Society,' April 27th, 1858), who further suggested that *Polytrema* might be specially related to *Carpenteria*, an idea which is not confirmed by examination of the internal structure of these types.

409. *External Characters.*—Of all Foraminifera there is none so decidedly Zoophytic in its form and habit as *Polytrema*; for although it sometimes spreads itself as a scaly incrustation on the surfaces of shells, corals, &c., it not unfrequently rises from those surfaces in an arborescent form; whilst sometimes its stalk, instead of branching, swells into a globular protuberance, which bears a strong resemblance in size and general aspect to the globular form of *Tinoporus* (Plate XIII, fig. 18). The surface is always areolated, but the character of the areolation is not uniform, even on different parts of the same specimen; for sometimes the boundaries of the areolæ are elevated as in *Tinoporus*, sometimes a little depressed as in *Carpenteria*, while sometimes they are on the same level with the spaces they enclose, and are only distinguishable by their difference of texture, the areolæ being porous, whilst their boun-

daries are formed by solid shell-substance (fig. 19, *a*). In the arborescent forms of *Polytrema* it is generally to be noticed that the extremities of the branches are rugged, instead of being smoothly rounded off; and when these are looked at with a sufficient magnifying power, they are seen to present several openings of considerable size (fig. 19, *b*). Similar openings are sometimes observable in the solid spheroidal forms. Occasionally, moreover, solid tubercles resembling those of *Tinoporus baculatus* are seen on the surface of the spheroidal forms. It is a fact not undeserving of notice that specimens of *Polytrema* which have been kindly placed in my hands by Mr. Denis Macdonald (late of H.M.S. "Herald"), were completely coated over with a membranaceous Sponge, the spicules of which seemed to radiate from the extremities of the branches. Of the parasitic characters of this sponge, I can entertain no doubt whatever; and it is a fact of some importance with regard to the presumed spongeous characters of the body of *Carpenteria* (¶ 313), that although (as will be presently seen) the openings at the extremities of the branches of *Polytrema* communicate very freely with the chambered interior, I have not been able to find the least trace of the penetration of the spongy parasite into its substance.

410. *Internal Structure.*—When the interior of *Polytrema* is laid open by section (Plate XIII, fig. 20), its structure is found to be essentially the same with that of *Tinoporus*, but less regular, and with freer communications between the chambers. In the arborescent forms it is generally to be observed that in the centre of each branch there is a cluster of longitudinal canals (*a*, *a*), each of which seems to have been formed by the coalescence of several segments, or rather to result from a want of segmental division; and it is by the termination of these canals at the extremities of the branches, that the openings are formed which are commonly seen there. The canals communicate with each other and with the surrounding chambers by large, circular orifices; and similar orifices of communication, though of smaller size, are observed between the chambers elsewhere; but sometimes there are spaces of considerable size which present scarcely a trace of subdivision, so as to bear a considerable resemblance to the chambers of *Carpenteria*. Thus the whole shelly texture has ordinarily a less solid character than that of *Tinoporus*, although formed on a plan essentially the same; but we occasionally find an aggregation of calcareous substance in solid pillars (*b*, *b*) exactly resembling those which we have seen in *T. baculatus* and in *Patellina Cooki*. The presence of these appears simply due to an exuberance of calcifying material; and it is obvious, from their extreme variability of distribution, that no reliance can be placed upon them as furnishing differential characters. I have not been able to ascertain with certainty the mode in which the growth of *Polytrema* commences; but from the indications presented by the youngest specimens in my possession, I have little doubt that its original development is essentially "planorbuline;" that is, that its early segments are arranged in an outspread spire, attached by its flat side; and that when its growth becomes "acervuline," the newly added segments tend to go on piling themselves upon its upper surface, instead of extending the disk horizontally.

411. *Affinities.*—No lesson can be more instructive to the systematist who aims to arrange the Foraminifera upon truly natural principles, than to trace out the affinities of this singular genus. At the first statement of the proposition that the zoophytoid *Polytrema* is

nothing but a modified Rotaline, any person unacquainted with the essential characters of this group might be excused for incredulity. But I cannot question that any candid inquirer, who, having first mastered my general principles, may have followed me through the preceding details, will be disposed to acquiesce even in this remarkable result. If it be true that the character of the individual segments, as marked by the texture of the shell and the mode of communication of the chambers, is a character of more importance than the form which these segments may develope by their aggregation, then it cannot be questioned that the serial assemblages of "globigerine" chambers (¶ 270) which form the turbinoid spire of *Discorbina*, the outspread disk of *Planorbulina*, the conoidal or spheroidal mass of *Tinoporus*, and the arborescent ramifications of *Polytrema*, are all most intimately related one to the other. In the general plan of its chambered structure, *Polytrema* is obviously most nearly allied to *Tinoporus*; but if I am correct in the idea I have formed of its early mode of growth, its fundamental affinity is rather to *Planorbulina*, since its subsequent increase takes place, as in that genus, upon only one side of the original spire, instead of upon both sides as in *Tinoporus*. It is not a little curious that there should be a strong external resemblance between *Polytrema* and some of the less regular forms of *Carpenteria*; a resemblance which is increased by the presence of free openings at the extremities of the branches in the former, and by the precise conformity which its areolation often presents to that of *Carpenteria*. The relation is one, however, of mere isomorphism, as we have seen the internal structure of the two organisms to be essentially different.

412. *Geographical Distribution.*—All the specimens of this genus hitherto collected have been obtained from the surfaces of shells, zoophytes, stones, &c., brought from tropical or sub-tropical regions; the large foliated bivalves of the Indian and Polynesian seas being its favorite *habitat*.—We have not as yet any certain knowledge of the occurrence of this type of structure in a fossil state; but it is very probable that a considerable number of the arborescent fabrics which have been detached by D'Orbigny from the genus *Ceriopora* and thrown into *Polytrema* will prove on examination to be referable to it, and will have to be removed from the Bryozoa, with which they are at present associated.

CHAPTER X.

FAMILY NUMMULINIDA.

413. The Nummulites and their allies, as they are the most gigantic, are also the most highly developed representatives of the Foraminiferous group: their structure presenting in every particular an advance upon that of the types already described. It is in this family that the shell attains its greatest density, that of some genera being of an almost ivory-like toughness; and this character seems in some way related to the exceeding fineness of its tubularity, being most pronounced in those cases in which the tubuli are most minutely and most regularly disposed. It is here, too, that we find it to be a rule without exception, that the septal plane is completely differentiated from the rest of the shell, the ordinary tubular structure being deficient, and no other passages than the principal aperture existing in the septum, except a few large "orbuline" pores. Again, it is here a rule *almost* without exception that the wall of each chamber is complete in itself, instead of being a mere "tent;" hence each septum consists of two laminæ, one belonging to each of the chambers which it divides; and between these laminæ is interposed a set of radiating canals, which communicate with a system that passes along the successive turns of the spiral or the annuli of the cyclical disk—according to the plan of growth. The development of this canal-system is related to that of the "intermediate" or "supplemental skeleton," which is here in almost every instance superadded to the proper walls of the chambers, consolidating into one compact fabric what would otherwise be a series of slightly connected segments.

414. The typical plan of growth in this family is a symmetrical spiral, with progressive increase in the breadth of its convolutions, giving to the shell more or less of the character of that of a *Nautilus* or an *Ammonite*. And, as a general rule, each convolution invests the whole of the preceding on both sides; the spiral lamina of shell being continued to the umbilicus, even where it so closely adheres to that which it overlies as to leave no space whatever for the extension of the soft body between the two. In the typical *Nummulinæ*, however, each segment of the body gives off a pair of alar lobes (¶ 71), which prolong themselves to the umbilicus in alar extensions of the chamber which it occupies. These alar lobes, moreover, in certain *Nummulinida*, are detached by intervening septa from the segments to which they seem properly to belong, and may even be broken up into small sub-segments, so as to form on either side of the spire an overgrowth of secondary chamberlets which bears a strong analogy to that of *Tinoporus*. Even in those genera, however, in which the complete invest-

ment of the earlier whorls by the later is the typical plan, we not unfrequently find that the last convolution tends to detach itself from the spire, being adherent to its margin only, and flattening itself out into so remarkable an extension as often completely to alter the original contour of the shell. The aperture, in the typical nautiloid forms of this family, is a narrow fissure that is left between the outer margin of the penultimate convolution and the inner margin of the septum; and alike in its form, and in its position with regard to the two lateral surfaces of the shell, it is consequently quite symmetrical. The fissure may, however, be bridged over by processes of shell, so as to be converted into a row of discrete pores.

415. The NUMMULINIDA which conform to this general plan of symmetrical spiral growth, may, therefore, in some respects, be considered as more nearly related to the higher LAGENIDA than they are to the *Rotalinæ;* for in respect to the nautiloid form of its shell, and the fineness of its texture, there is an obvious resemblance between *Cristellaria* and *Operculina*. But we shall find that this resemblance is superficial only; the latter possessing a complex internal structure which is wholly wanting in the former, but to which we have found a very decided approach in the most elevated forms of the genus *Rotalia*. Now, it is not a little remarkable that whilst *Rotalia* thus forereaches on the NUMMULINIDA, we should find among NUMMULINIDA a most distinct reversion to the Rotaline type; the genus *Amphistegina* having not only a unsymmetrical spire that sometimes approaches the turbinoid form, but having its aperture also on the under side of the spiral plane, and being also destitute alike of the double septal laminæ and of all trace of canal-system. In these last respects, therefore, it is decidedly inferior to the highest forms of *Rotalia;* yet in the arrangement of its alar lobes and in its general morphology it conforms so closely to the Nummuline type, that there can be no more question of its title to a place in this family, than there can be as to the retention of the true *Rotalia* among the Rotaline GLOBIGERINIDA.

416. In the genus *Polystomella*, again, some of the characteristic features of the Nummuline type are almost entirely absent; the texture of the shell being far less elaborate, the alar extensions in the later whorls being often deficient, and the spire being frequently in some degree unsymmetrical. But we have, on the other hand, in this type, the highest development of the canal-system that we anywhere meet with; and even in those simple "nonionine" forms which are among the most degraded examples of the Nummuline series, we find this canal-system presenting a definiteness and symmetry much greater than that which it exhibits in the most developed *Rotalia*.

417. Passing onwards now from the typical *Nummulinæ* to a higher plan of growth, instead of reverting to a lower, we find that by a process of subdivision exactly analogous to that by which a *Peneroplis* becomes an *Orbiculina*, the undivided chambers of *Operculina* are converted into the rows of chamberlets, whose regular spiral increase is the essential character of the genus *Heterostegina*. If, however, this increase should take place on the cyclical plan, as in *Orbitolites*, instead of on the spiral, we have a *Cycloclypeus*, a type in which the plan of structure of the individual segments is so completely conformable to that which prevails in *Heterostegina*, that marginal fragments of the two could no more be distinguished from each other than could marginal fragments of *Orbitolites* and *Orbiculina*. And, finally,

in *Orbitoides* we have the discoidal plane of cyclically arranged chamberlets, overgrown on either side with piles of flattened secondary chamberlets, which on the one hand bear a strong resemblance to those of *Tinoporus*, and on the other are analogous to those formed by the subdivision of the alar lobes in certain *Nummulinæ*. In regard to complexity of structure, *Nummulina* and *Orbitoides* may be considered as holding a corresponding rank; and it is very interesting to remark that these two types attained their highest development at the same geological periods, and that they represented each other in different localities. Owing to the metamorphic condition of the shell of *Fusulina*, a type which is only known as occurring in the Palæozoic series, it is not certain whether it is to be rightly referred to this family, or should be placed in the porcellanous group in close proximity to *Alveolina*, which it resembles in its plan of growth; and the only reason I can advance for regarding it as an early and somewhat rude representative of the Nummuline type, is afforded by faint indications of a tubular structure in its shell, and by an appearance of duplication in its septal lamellæ.

418. According to the system of M. D'Orbigny, the genera which we group together in this family would be distributed under three of his orders, as follows:

Order II.—CYCLOSTÈGUES. Cycloclypeus, Orbitoides.

Order IV.—HÉLICOSTÈGUES. Fusulina, Nummulina, Operculina, Polystomella (including Nonionina).

Order V.—ENTOMOSTÈGUES. Amphistegina, Heterostegina.

In our view their affinities may be represented somewhat as follows:

FAMILY NUMMULINIDA.

	Amphistegina.		
Polystomella	*Nummulina*		
Nonionina	Operculina .		
Fusulina ?	*Heterostegina* .	*Cycloclypeus* .	*Orbitoides.*

Alike by *Amphistegina* and by *Polystomella* this family is connected with the genus *Rotalia*; whilst by some of its most degraded Nonionine forms *Polystomella* is related to *Pulvinulina*. The relation of *Heterostegina* to *Orbiculina*, and of *Cycloclypeus* and *Orbitoides* to *Orbitolites*, is one of analogy only, arising from the similarity of their respective modes of growth, and is no more indicative of any real affinity than is that which arises out of the superficial resemblance between *Peneroplis* and *Operculina*, two types which are separated from each other in every character of real importance as widely as any two polythalamous Foraminifera can be.

419. It is a point of no slight interest in regard to the Geographical Distribution of this family, that it is scarcely at all represented at the present time in the seas of temperate or arctic zones, being almost exclusively confined to tropical or sub-tropical regions. The few examples that occur nearer to the poles than to the equator are the least developed of their respective genera, in regard both to size and to complexity of structure; whilst the larger and more developed forms of those genera, like the great *Heterostegina* and the gigantic *Cycloclypeus*, are only to be met with between or near the tropics. This fact is one of considerable interest and importance in relation to the question of the climate that prevailed in Europe during the earlier portion of the Tertiary Epoch.

Genus I.—AMPHISTEGINA, (Plate XIII, figs. 22—29.)

420. *History.*—This genus was first constituted by M. D'Orbigny in 1825 (LXIX) for the reception of a type of Foraminiferous shells which does not seem to have been previously distinguished by systematists who have given their attention to this group, in consequence, it may be, of its limitation to the seas of warm latitudes. Notwithstanding the very close relationship which it will be presently shown to bear to *Nummulinida* in general plan of structure, it was considered by M. D'Orbigny to depart from them in a character which he regarded as of such fundamental importance as to serve for the basis of a distinct order, that of *Entomostègues*, of which the following is his most recent definition (LXXIV): "Animal composé de segmens alternes, formant une spirale. Coquille composée de loges empilées ou superposées sur deux axes alternant entre elles, et s'enroulant en spirale." The mode of increase in these shells, he elsewhere says (LXXIII, p. 199), presents a singular mixture of that of the *Enallostègues* with alternating chambers, and of the spiral involution of the *Helicostègues*. I have already pointed out that such a combination does actually exist in *Cassidulina* (¶ 338), which, so far as I know, is the only type that exhibits it; but the alternation of chambers supposed by M. D'Orbigny to characterise *Amphistegina* will be found not to have a real existence. His account of it, however, has been taken upon trust by all those Naturalists who have adopted his system; the only investigator, so far as I am aware, who has questioned his views being Prof. W. C. Williamson, who, in his extremely valuable memoir "On the Minute Structure of the Calcareous Shells of some Recent Species of Foraminifera" (CVIII), gave an account of the *Amphistegina gibbosa* of the West Indian seas, which, as far as it goes, is extremely accurate. He rightly apprehended the fact of its close conformity to the Nummuline type, save in the fact of the want of symmetry which is occasioned by the turbinoid declination of its spire; but he failed to detect that peculiar "asterigerine" arrangement of the alar prolongations on the under side, the misinterpretation of which seems to have been the source of M. D'Orbigny's erroneous conception of the essential characters of this type. The elucidation of the real nature of these is due to Messrs. Parker and Rupert Jones, who have kindly furnished me with the materials on which the following account of it is based.*

* In the third series of my "Researches on the Foraminifera" ('Phil. Trans.,' 1859), I described under the name of *Amphistegina Cumingii* what I am now convinced to be a *Nummulina*, since it is not only perfectly symmetrical, but is destitute of the "astral lobes" which characterise all true *Amphistegina*.

421. *External Characters.*—The shell of *Amphistegina* closely corresponds in external form with that of *Nummulina*; but it is only for some of the smaller Nummulines that *Amphistegina* could be mistaken, since its diameter seldom exceeds 1-8th of an inch, which is not uncommon among the larger Rotalines. When viewed from either side (Plate XIII, figs. 22, 23), it presents an almost exact circular outline, its spiral growth not much affecting the regularity of the curvature of its margin; this is partly due to the fact that its chambers are very numerous, and the increase of their size gradual, and partly to the peculiar direction of its septa (fig. 25). In certain varieties, however, the later chambers thin-out and extend themselves rather suddenly, so that the primordial segment loses its central position, and the entire shell becomes ear-shaped. When viewed edgeways, the shell presents a form somewhat resembling that of the crystalline lens in the unequal curvature of its two surfaces, but having a more acute margin, as is well seen in vertical section (fig. 26). The under side, that is, the one on which the aperture presents itself, is normally the most prominent; but frequently there is very little difference between the curvature of the two faces; and sometimes even it happens that the general convexity is greatest on the upper side, whilst the surface of the shell so sinks in around the umbilical "boss" on the lower side, as to render it "circumvallate." On the other hand, the upper surface may be nearly flat, whilst the umbilical portion of the lower surface becomes very prominent; so that the general form of the shell, like that of *Rotalia Schroeteriana*, comes to resemble that of a *Conus*. Occasionally, though rarely, the shell is more or less curled or twisted, and may even become saddle-shaped, like certain individuals among *Nummulinæ* and *Orbitoides*. As, in conformity with the general plan of construction of the *Nummulinida* (¶ 414), each convolution normally invests the whole of the preceding, only the last convolution for the most part is visible on the surface of the shell. On looking at its upper side (fig. 22), we see the subjacent septa marked out by lines of a different texture from the rest of the shell, which proceed in a nearly radial direction (though slightly curving forwards) until within a short distance of the margin, and then suddenly bend backwards. On the under side, however, the lines which radiate from the centre are interrupted at a short distance from the margin (fig. 23), returning as it were upon themselves, whilst the marginal backward-curving lines in like manner seem to return upon *them*selves, thus apparently marking out two sets of chambers which slightly interdigitate with one another. The centre of each surface is occupied by a large "boss" of non-tubular shell-substance, which is so pellucid as to allow the subjacent structure to be distinctly seen through it. The contour of this boss is commonly "flush" with the general curvature on the upper side (fig. 26, *b*), whilst on the lower side (b^1) it is more prominent. When a vertical section of the shell is examined, each boss is seen to have its origin from the surface of the primordial chamber, and to increase in diameter with every new overgrowth which this receives, so that it comes to acquire a pretty regular conical shape. Hence, as the central terminations of the chambers of each whorl usually stop short of those of the preceding whorl, the latter can be seen to project beneath the former, so that the whole series of these central terminations may be traced inwards from those of the latest to those of the earliest convolution. This is more constantly to be seen on the upper surface than on the lower; as it is on the former that the alar prolongations of the later whorls stop short at the greatest distance from the centre. Sometimes, however, the alar lobes of the later segments extend nearer to the centre than do those of the

earlier, so as partially or even entirely to conceal the central boss; and there is occasionally an apparent interdigitation between the alar lobes of successive whorls, arising out of differences in the extent of their central prolongation. This appearance is sometimes seen also on the under surface; but as the alar lobes of that side much less frequently stop short of the centre than they do on the upper side, those of each whorl usually conceal those of the preceding.—The position of the aperture and the direction of the septal plane in *Amphistegina* constitute very marked features of differentiation from the ordinary Nummuline type, and of approximation to the Rotaline. For whilst in *Nummulina* and its immediate allies, the septal plane is at right angles to the median plane of the spiral, and the aperture is a narrow fissure between its inner margin and the edge of the penultimate convolution, the septal plane of *Amphistegina* is very oblique, making a very obtuse angle with the under surface of the shell nd an acute angle with the upper, and it adheres closely to the penultimate convolution from its margin to its upper umbo, separating from it on the lower side at about one-third of the distance between the margin and the lower umbo, so as to form a much wider and freer opening than exists in the typical Nummulines. Thus, whilst the proper Nummuline aperture belongs equally to both sides, the Amphistegine aperture belongs exclusively to the lower side, as in the Rotaline group. The septal plane is differentiated in texture from the ordinary chamber-wall, being destitute (except near its margin) of the fine tubularity by which the latter is characterised; but it is usually perforated by a few large "orbuline" pores.

422. The ornamentation of the proper surface of the shell by exogenous deposit constitutes a very peculiar feature of this type. The septal bands are often rendered "limbate" by rows of tubercles composed of non-tubular shell-substance; and a smooth deposit of the like substance along the margin often forms a sort of projecting keel. The general surface frequently receives an investment of the like character, which may be composed of very minute, closely-set granules, or of larger and more separated tubercles; this may cover the whole of each lateral surface, but if restricted to one portion, it is found rather upon the older than upon the newer segments; and such an investment is so constant upon that portion of the under side which lies nearest to the aperture, that its presence there is one of the ordinary characters of this type, the surface being crowded with granulations which are generally arranged in rows, and sometimes melt into ridges, whose direction is transverse to that of the septal bands. The outer surface of the septal plane is itself very commonly ornamented (as in many *Discorbinæ*) by tubercles, tears, or ridges, of clear substance, which are arranged in lines that pass from the apex to the base of the plane, and which often so project over the low-arched aperture as almost to divide it into a line of pores (fig. 24). In some of the conus shaped fossil *Amphisteginæ* from St. Domingo, the upper (flat) surface presents several large tubercular masses, each about equal to an ordinary upper "boss."

423. *Internal Structure.*—Although most of the principal features of the organization of *Amphistegina* may be made out by transparent sections of the shell taken in different directions, yet there are others which such sections altogether fail to elucidate; and it is fortunate for the true comprehension of these, that we have the additional means of information afforded by "casts" of the interior of the chambers (see p. 10). Turning our attention in the first instance to the vertical section which is represented in Plate XIII, fig. 26, we observe a very marked diffe-

rence in the convexity of the upper and the under surfaces, and in the position of the primordial chamber in respect to each; and this difference is due in part to the gradual declination of the spire along the plane traversed by the line *g*, *h*, and in part to the excess in the growth of all the parts below that line as compared with that of the parts above it, this being apparent not merely in the size of the cavities, but also in the thickness of the layers of shell by which they are separated. It will be observed, moreover, that whilst the alar lobes (*a*, *a*) of the upper sides thin-out rapidly as they approach the centre of each convolution, those of the lower side (*a*, a^1) thin-out much more slowly, and are often continued as far as its centre. The shell is finely-tubular, like that of *Rotalia*, *Operculina*, and *Nummulina*; and is composed of several lamellæ superposed one on the other, the tubuli being continuous throughout. At the umbonal portion (*b*, b^1,) of each surface, however, the tubuli are deficient, the shell-substance being there quite pellucid; and the same condition usually presents itself at the margin (*c*, c^1, c^2, c^3) of each convolution. A very considerable difference presents itself between the thickness of the chamber-walls of the last convolution (*e*, e^1) and that of the preceding (*d*, d^1); and this will presently be found to depend, as in *Calcarina*, upon an exogenous shell-growth superimposed upon the proper chamber-walls; such increase, however, being made by the successive addition of laminæ exactly corresponding in structure to the original one, and so perfectly continuous with it and with each other that the pseudopodial tubuli may be traced without the least interruption through their entire thickness. This section further shows the position of the aperture (*f*, f^1) entirely below the marginal plane of each convolution; and it exhibits also the projection of the tubercles formed by exogenous deposit upon the older parts of the surface, into the cavities of the chambers by which that surface subsequently comes to be invested. At *i* is shown an apparent subdivision of the outer wall of the convolution, so as to form a small additional chamber outside the principal one; but it will be found, when the vertical section is compared with the horizontal (fig. 25), that this apparent subdivision is due to the remarkable backward curvature of the septa, which often causes sections that are taken in a radial direction to traverse the inner portion of one chamber, and the outer portion of another chamber of the same convolution.

424. Owing to the turbinoid form of the spire, a section through any horizontal plane cannot traverse more than one convolution in its median plane, and must pass either above or below the median plane of the rest. The horizontal section shown in fig. 25, passes through the median plane of the outer convolution; consequently it lays open the penultimate convolution along its under side; and it passes altogether beneath the interior convolutions. The remarkable backward curvature of the septa, by which every septum glides (so to speak) into the periphery of the convolution, along which it is continued, is a very distinctive feature in this type; the continuity of the shelly lamina formed at each increase over the whole of the surface previously exposed, being made evident by the regularly progressive increase in the thickness of the peripheral layer from the newest chamber to the earliest of the same convolution. It is a very peculiar feature of this type, that its septal lamellæ are not double, as in the proper Nummulines, but single, as in the lower Rotalines; so that each chamber is a "tent" set upon the exterior of the preceding. At the inner margin of certain septa, we see that they stop short of the wall of the previous convolution; this being where the plane of the section has happened to pass through the aperture. The anterior surfaces of the

septa, like the margins of the enclosed whorls, are seen to be studded with large tubercles, which project into the cavities of the chambers. In the central portion of the section are seen the indications of the converging prolongations of the septa, which are interposed between the alar lobes of the under surface. In those portions of the inferior chamber-wall which have not been removed by the section, we see the general surface minutely studded with the orifices of the pseudopodial tubuli, which are considerably larger on the inner surface than they are on the exterior; these, however, are wanting in those parts that underlie the tubercles of the surface, which are always composed of non-tubular substance (fig. 25, A).

425. Nothing is shown either in vertical or in horizontal sections to explain that peculiar disposition of the septal lines which has been already stated to present itself upon the under surface of the shell; and this might have remained without adequate elucidation, but for the fortunate accident which has placed in the possession of Messrs. Parker and Rupert Jones the means of obtaining internal casts of the cavities of this shell in silicate of iron. These casts so perfectly represent the form of the sarcodal segments which occupied the interior of the chambers, that their surfaces are rendered hispid by the minute projections which passed into the entrances of the tubuli of the chamber-walls. On looking at the *upper* side of one of these casts (fig. 27), we see, as we should expect, the "alar lobes" prolonged inwards from the anterior portions of the peripheral lobes or "bodies" of the successive segments, and gradually narrowing towards the centre, which they do not quite reach. But on looking at the *under* side (fig. 28), we observe that the peripheral bodies of the segments only fold over that surface for a short distance, and then suddenly round themselves off; whilst the place of their alar prolongations is occupied by a set of "astral lobes," which interdigitate in a very peculiar manner with the bodies of the segments, and send extensions peripherally to the very margin of the spire. Although, at first sight, these astral lobes appear to be altogether disconnected from the bodies of the principal segments, yet, on a careful scrutiny of the most perfect casts, we find that the peripheral extension of each astral lobe is continuous with the retral extension of the body of the segment that lies in front of it, as shown at *a, a*; this continuity being sometimes established by a thick neck, and sometimes by a very slender peduncle. Hence it is obvious that these "astral lobes" are nothing else than the alar prolongations of the chambers on the under side, each being pinched off (so to speak) from its principal segment by the intervention of a septum, and being also somewhat displaced backwards.

426. We have seen that the surface of the shell in the neighbourhood of the aperture so commonly becomes studded with tubercles of exogenous deposit, that their presence may almost be regarded as among the characteristics of this genus; and since, as each new chamber is formed, the tuberculated surface is received into it, and a new exogenous deposit takes place beyond, every chamber will thus exhibit a projection of these tubercles into its interior. Now it commonly happens that this deposit extends from the margin towards the centre of the shell, so that the floors of the alar prolongations of the chambers become studded with tubercles; these are sometimes small and closely set without any particular arrangement, whilst in other instances they are fewer and more prominent, in which last case they are very commonly arranged in radial lines. These varieties are very beautifully marked in the "casts" of the alar and astral lobes. In some instances the inner surface of these lobes is

honeycombed with minute depressions, which do not extend, however, very far into their thickness; whilst in other cases each lobe is divided for a great part of its length into two, three, or even four, narrow bands, connected with each other at intervals, so that the whole lobe has the character of a network, the meshes of which are occupied by the tubercles or elevated lines of shell-substance (Plate XIII, fig. 29). These tubercles or lines, rising through the whole thickness of the alar lobes, join themselves on, like the septa between the lobes themselves, to the spiral lamina; and, as they consist of non-tubular shell-substance, there are no tubuli to pass on into the portion of the spiral lamina which overlies them; and thus their position is marked on its surface by clear lines, usually more or less interrupted, which intervene between those that mark the position of the subjacent septa (fig. 22). The alar lobes often communicate with those adjacent to them by connecting bands of their own; and it sometimes happens, especially in specimens in which these lobes are most broken up, that these communications are almost as numerous as those uniting the different bands of the same lobe; so that the portion of the sarcode body covering the lateral surface of the shell forms one continuous network, in which the division into alar lobes is scarcely distinguishable. This varietal modification is of peculiar interest, as representing in this type the still more remarkable modification of the alar prolongations which we shall find to be characteristic of certain forms of *Nummulina* (¶ 462).

427. The various forms of *Amphistegina* which have been ranked as distinct species differ from each other only in characters which our extended study of this group has led us to regard as non-essential;—such as the degree of convexity of the shell in proportion to its diameter; the amount of inequality between its two lateral halves; the amount and kind of exogenous deposit on its surface; the number of chambers in each whorl, and the proportional distance between their septa; the degree of backward curvature of the septa of the marginal portion of the convolution; and the mode in which the astral lobes of the under side are intercalated between the marginal segments. The differences in all these particulars which may be presented by individual specimens, are found, when large numbers are examined, to be so gradational, that no definite lines of division can be drawn between them. In point of size, there would seem at first sight to be a marked distinction between the recent and the fossil examples of this genus; for whilst the diameter of the former does not ordinarily exceed 1-14th of an inch, and is often not more than 1-20th, that of the latter sometimes attains 1-7th of an inch. This difference, however, no more constitutes a valid specific distinction, than do any of the preceding; for I have recent specimens from the Philippine seas, which attain a diameter of 1-10th of an inch, and which are yet unquestionably of the same type with the ordinary examples of not half their diameter.

428. *Affinities.*—From a comparison of the preceding description with the account of the Rotaline type given in the preceding chapters, it will be evident in what particulars *Amphistegina* presents the characteristic features of that type. The turbinoid spire, the consequent inequality of the upper and under sides, the limitation of the aperture to the under side, and the obliquity of the septal plane, are all Rotaline peculiarities; the singleness of the septal lamellæ is a most important additional link of affinity to that group, and so also is the distinctness of the "astral lobes," which specially links *Amphistegina* to *Rotalia* (¶ 371). All these

peculiarities, whilst they indicate the relationship of *Amphistegina* to the Rotalines, differentiate it in the like degree from the Nummulines. To the latter group, however, it presents so close a conformity in the texture of its shell, in the complete investment of each convolution by that which succeeds it, in the presence of alar lobes upon its upper as well as on its under surface, and in its general tendency to bi-lateral symmetry, that we cannot hesitate in considering it as most nearly related to the Nummulines; its special affinities being to *Nummulina* its general plan, and to the simple "nonionine" *Polystomellæ* in the exogenous deposit which forms its umbilical "bosses." It may thus be considered in the light of a Nummuline degraded to the Rotaline level; just as the true *Rotalia* is a Rotaline elevated to the Nummuline level, so as to stand, in grade of development, considerably higher than *Amphistegina*.

429. *Geographical and Geological Distribution.*—The range of this type through tropical and sub-tropical regions appears to be very general, as it has been found in various parts of the Indian Ocean, the great Polynesian area, and the West Indian seas; the furthest limits to which it is known to extend northwards are the Red Sea and the neighbourhood of the Canary Islands; while southwards it has not been traced further than New Zealand. It occurs in greatest size and abundance at depths of from 15 to 50 fathoms; but small specimens have been brought up from abyssal soundings in the Red Sea. No true *Amphistegina* has yet been discovered earlier than the Tertiary epoch; and this genus does not seem to have become abundant until after the period when the proper Nummuline type attained such an extraordinary development, presenting itself especially in the Miocene and Pliocene deposits of Bordeaux, Vienna, San Domingo, the Sub-Apennine group, Virginia, South Carolina, Alabama, and New Zealand.

Genus II.—Operculina (Plate XVII).

430. *History.*—The genus *Operculina* was first created by D'Orbigny (LXIX) for the reception of a type of Foraminiferous structure allied to *Nummulites*, but definitely (as he considered) differentiated from it; examples of this type, however, had been previously described by Gronovius (L) and Schroter (XCV) under the generic designation *Nautilus*, and by Basterot and Defrance (XXIX) under that of *Lenticulites*, a name which has been applied to such a great variety of dissimilar organisms that it cannot with any propriety be retained. According to D'Orbigny (LXXIII), *Operculina* is distinguished from *Nummulina* by the extreme compression of its discoidal shell, by the smaller number and more rapid increase of its whorls, by the non-investment of the earlier whorls by the later, so that the former remain apparent on both sides through the whole of life, and by the form of the aperture, which is a transverse slit in *Nummulina* but triangular in *Operculina*. The genus, as characterised by D'Orbigny, has been adopted by many subsequent systematists, as Bronn and Pictet; and it is also admitted by D'Archiac and Haime (I), who, however, seem to have clearly perceived the fallacy of D'Orbigny's description of the convolutions as non-embracing, and of the aperture as triangular, since they consider it to be distinguished from *Nummulina* only by the depression of its form, the small number of its convolutions, and the rapid increase in breadth of the last whorl, which (according to them) constantly remains open, whilst that of *Nummulina* always

tends to close in. As I shall show hereafter, I cannot admit the validity of the last distinction; and the difference between *Operculina* and *Nummulina* comes to rest only on the general form of the spire and the conspicuousness of its convolutions,—characters which seem by no means sufficient for the separation of the former as a genus distinct from the latter. As, however, they mark a difference in the respective physiognomies of these types which enables them to be at once distinguished by their external conformation, it seems for the present desirable to retain *Operculina* as a generic type; more especially as it is very generally diffused at the present epoch, whilst *Nummulina* proper is almost extinct.

431. The minute structure of this type had been investigated by two excellent observers previously to the appearance of my own description of it (XV). Under the designation of "an undescribed species of *Nonionina*," Prof. Williamson gave an account (CVIII) of the structure of a shell abounding in the Manilla sand, which, not merely from his figures and descriptions, but from a comparison of the specimens which he has kindly enabled me to make, I know to be one of the smaller forms of the Philippine *Operculina*. Mr. H. J. Carter (XVIII) still more minutely described the organization of an *Operculina* which he obtained in great abundance on the south-east coast of Arabia, the shells coming up attached to the grease of the sounding lead from sandy bottoms of between ten and twenty fathoms depth; and of the identity of this with a larger form of Philippine *Operculina* I am enabled to speak, from an examination of specimens which Mr. Carter has obligingly transmitted to me. The rich store of material placed at my disposal by Mr. Cuming from his Philippine collection, not only enabled me to prosecute my inquiries into the minute structure of this organism upon specimens of unparalleled size and degree of development, but also enabled me to bring together a great body of data for comparison as to the extent of variation which it may undergo, alike in external conformation and in internal organization. And as the information hence obtained has a most important bearing upon the study of the closely-allied genus *Nummulina*, I consider it desirable to go into more minute detail on this point than would be otherwise accordant with the general character of the present treatise.

432. *External Characters.*—The shell of a fully developed *Operculina* of the ordinary type (Plate XVII, fig. 1)* is a compressed spiral of about ·25 inch in diameter, and about ·015 inch in thickness, consisting of between three and four convolutions gradually increasing in breadth; these are in general nearly flat, but are sometimes a little arched between their inner and outer margins, and are sometimes depressed so as to present a slight concavity, especially near the outer margin of the last whorl. The chambers are about seventy-five in number, commencing from a primordial spheroidal cell, and progressively increasing in dimensions with the widening of the spire; their septa have for the most part a radial direction, but they bend backwards near the outer margin of each whorl; and they are marked externally by bands which are distinguished by their semi-transparent aspect from the dull brownish hue of the general surface. These septal bands are commonly on the same plane with the intervening portions of the shell; but sometimes the walls of the chambers are a little arched between

* For the better display of the internal structure, the ideal figure has been constructed on the model, not of the ordinary compressed *Operculina*, but of a variety with a more turgid spire.

the septa that bound them, so that the septal bands are slightly furrowed; whilst the walls of the chambers are sometimes a little depressed, so that the septal bands are prominent; and such varieties may present themselves in different parts of one and the same shell. Not unfrequently the whole surface is seen to be marked by very minute punctations; but more commonly they are larger and fewer in number, and are often arranged in pretty regular lines parallel to the septal bands,—one, two, or three rows of such punctations being seen on the wall of each chamber: these punctations, which often present themselves abundantly on some parts of the surface, whilst they are entirely absent from others, are found, when sufficiently magnified, to be spots of semi-transparent shell-substance resembling that of the septal bands; and, as in the case of these, their surface is sometimes on the same plane with that of the general surface of the shell, sometimes a little elevated so as to form papillæ, and sometimes a little depressed into minute fossæ. Sometimes, instead of a limited number of comparatively large and regularly arranged punctations, we find a vast number of very minute papillæ, scattered without order over the entire surface of the chambers; these, again, may be absent from some parts of a shell over other portions of which they are abundantly distributed. There is commonly a large semitransparent tubercle at the umbilicus, and smaller tubercles are often seen along the septal bands, especially of the earlier whorls: not unfrequently, however, the umbilicus is depressed instead of being elevated into a tubercle, and the moniliform tubercles along the septal bands are wanting.

434. The departures from this typical form, however, are very wide. A glance at any considerable collection of specimens reveals to us an extraordinary variety not merely in size but also in proportion; and our attention is first attracted by a series which are not only distinguished by a size greatly above the average—their long diameter reaching nearly 4-10ths of an inch,—but also by the extraordinary flattening of the later convolutions, and the rapidity with which the spire opens out. The approximation between the two lateral walls of the chambers is here so close, that not only are the septal bands rendered very prominent by the depression of the lateral surfaces between them, but even the outer marginal band stands up as a ridge from which the walls of the chambers slope down. In fact, an examination of this form leaves the observer impressed with surprise that any room can be left for the animal, the segments of which must be extraordinarily attenuated, losing in thickness what they gain in area. Now a careful comparison of this form with the ordinary type, not only makes it obvious that the former differs from the latter in no other particular than this attenuation, which (as already pointed out in the case of *Peneroplis*) is a common feature of the later growths in Foraminifera, but also that the attenuation takes place in such different degrees in different individuals, that any attempt to use it as a differential character is completely baffled by the continuous gradation of forms which is presented between the one assumed as the typical and such as most widely depart from it in this particular. Among the smaller Philippine specimens, on the other hand, a very different configuration is presented. In those whose diameter does not exceed 1-10th of an inch, the spire, instead of being flat, or even somewhat hollowed, is often so highly arched between its inner and its outer margins that the breadth of the septal plane is equal to its length or nearly so; and a like turgidity, to the degree represented in Plate XVII, fig. 1, sometimes shows itself in specimens of nearly twice that dimension. This variety of conformation, however, being limited to shells whose

earlier period of growth is evinced by their smaller number of convolutions and of chambers, and being often seen, moreover, in the earlier whorls of those which afterwards present the greatest flattening, may safely, I think, be regarded as partly a character of age. It will be recollected that the young of the flattened *Peneroplis* often resembles *Dendritina* in the comparative turgidity of the spire (¶ 130); but I do not find that *Operculina* ever continues long to increase upon such a plan; for the compression of the spire always shows itself in the third whorl, if it has not previously done so, and is accompanied with a corresponding augmentatian of its breadth, so that the septal plane becomes narrowed in Fig. XL. Such a section makes it obvious that no basis for specific distinction can be afforded by the most marked differences in the form of the spire, as shown in the proportions of the septal plane; since differences equal to those presented by the most compressed and the most turgid forms of the spire are there exhibited by the successive convolutions of one and the same individual.

435. Another marked feature of difference to be noted among individual *Operculinæ* is the depression or elevation of the central region relatively to the peripheral. In what I have assumed as the typical form, the central region presents the same general level with the rest, though the umbilicus itself is often marked by a prominent tubercle. In young specimens with a turgid spire, however, the umbilical region is rather depressed than elevated; and this depression is often observed in older specimens whose early growth has taken place on this type. But a form is not uncommon, in which the whole central region is so exceedingly prominent as to form a cone whose apex is marked either by one large tubercle or by a cluster of smaller ones; and this conformation gives so peculiar a physiognomy to the shells which present it, that few systematists would hesitate in placing them apart as specifically different from the rest. On a careful comparison of a large number of individuals, however, it becomes apparent that this difference, like the preceding, is gradational; every degree of prominence being traceable from the individuals which have the umbilicus marked only by a tubercle, through those in which the region generally is slightly elevated, to those in which it presents the most marked prominence. We shall presently find (¶ 441) that this difference depends mainly on the degree in which the investing layer, prolonged from the later convolutions over the surface of the earlier, is separated from that surface by the extension of the alar prolongations of the chambers of the investing whorls; as to which point there is a most remarkable diversity, not only among different individuals, but between the several convolutions of the same individual.

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

sented also in no less a degree by those whose umbilicus is flat or even depressed. The most remarkable departure from the ordinary type is seen in a small group of specimens in which the tubercles are not only extremely large and prominent, but are distinguished by their opaque whiteness, which contrasts strongly with the semi-transparence ordinarily characterising these prominences. But even this character has no diagnostic value; for a specimen which has the tubercles opaque in one part may have them semi-transparent in another; and as to the size of the tubercles, their degree of prominence, and the proportion of the entire spire over the septa of which they occur, there is every degree of variety. In one of my largest and flattest specimens, the central region is strongly tuberculated, but the tubercles almost suddenly cease when the spire begins to open out, and the septal bands are thenceforth as smooth as in the ordinary type.

437. A less obvious but still very decided feature of individual difference, consists in the presence or absence of papillary elevations *between* the septal bands. I have already spoken (¶ 433) of the frequent existence of symmetrically arranged spots, sometimes slightly depressed, but more commonly elevated, that are distinguished from the rest by the semi-transparence of their shell; these spots are sometimes considerably enlarged, and their elevation increased, so that they become prominent papillæ, closely resembling the tubercles upon the septal bands. Their size and disposition vary considerably. Sometimes they are small, numerous, and scattered without any definite arrangement over the entire surface of the wall of the chamber; whilst in other cases they are considerably larger, and form single, double, or even triple rows between the septal bands. Another remarkable variety of external aspect is produced by the elevation of the general surface into rounded eminences closely abutting on one another (like the pustules of the skin in a case of confluent small-pox), and distinguished from the preceding by the absence of any peculiarity in the texture of the shell. That these and other analogous variations of surface-marking have no value as differential characters is at once demonstrated, not merely by their gradational approximation in different individuals, but by the fact that they are presented in very different degrees on different parts of the surface of the very same shell; the chambers of one part of the spire being strongly marked by certain of these peculiarities, whilst those of another may only present indications of them, and those of a third may be perfectly smooth.

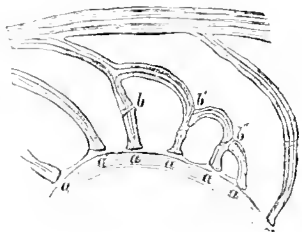
438. The collection of Mr. Cuming, however, furnished me with a group of forms which are at once distinguished from the rest by their general physiognomy, and which, when their characters are examined in detail, appear to be separated from them by well-marked differences. Their aspect is much more lustrous, and their hue much whiter, varied, however, by a tinge of green diffused in irregular patches; the spire does not in the largest specimens make above three turns, and it begins to open out sooner than in the type already described; the septa are usually considerably more convex anteriorly, and are also rather more distant from each other, so that the interval between them is greater in proportion to the breadth of the spire, the shape of the chambers being thus modified, and the number of chambers in each whorl being diminished; the septal bands, not merely of the earlier whorls, but even of the last-formed portion of the shell, are raised into prominent tubercles; and multiple rows of large tubercles are seen between the septal bands. It is to this multiplication of smooth

tubercles, composed of a variety of shell-substance which reflects light much more strongly than the rest, that the more glistening aspect of this type is chiefly due; and I have not met in it with any instances of that general brownish coloration of the surface which is the ordinary characteristic of the other. The most constant and remarkable distinctive feature of this type, however, is the presence of a large hemispherical cluster of semi-transparent tubercles in the centre of the spire.—Having had no difficulty in setting apart a large number of specimens agreeing very closely with each other, and differing from the rest, in all the foregoing characters, I should have arrived at the unhesitating conclusion that this type deserves to take rank as a species of *Operculina* distinct from the preceding, were it not for the circumstance that every here and there I met with an example in which the differential characters were less strongly marked than usual. Thus in some individuals which preserve the general proportions of the spire, the green coloration is wanting, the large central cluster of tubercles is replaced by a single tubercle of extraordinary size, the septal bands of the neighbourhood are not more tuberculated than in many examples of the ordinary type, and the rows of tubercles over the chambers are either wanting altogether, or are not more prominent than in many individuals of the preceding type. This evidence of the negative value to be attached to the number or prominence of the tubercles as a specific character, is confirmed by a curious fact of an opposite nature; namely, that in certain individuals we find them developed to an extraordinary and obviously abnormal degree.—From the difficulty of deciding to which type particular specimens are to be referred, I had been almost led to adopt the conclusion of the specific identity of this with the ordinary form; when Dr. Gould, of Boston (U. S.), kindly placed in my hands some *Operculinæ* which had been collected on the coast of Japan by the recent American expedition to that country. These specimens combined in so remarkable a manner the most distinctive features of the two types,—namely, the general form and proportions of the one, with the umbilical hemispheric cluster of tubercles and the general abundance of tubercular elevations characteristic of the other,—as to remove all doubt from my mind with regard to their specific identity. Similar variations present themselves among the dwarfed examples of this type which are found on the shores of temperate seas (¶ 450), and also among the fossil forms of it which abound in the Eocene and other Tertiary deposits. The minute form most common in northern seas has been described and figured by Prof. Williamson (CX,) under the designation of *Nonionina elegans;* but I fully agree with Messrs. Parker and Rupert Jones (LXXX *b,* LXXXI), in identifying this as a varietal form of *Operculina complanata.*

439. *Internal Structure.*—The study of the internal organization of *Operculina* may be prosecuted in two modes;—by the examination, under sufficient magnifying powers, of thin transparent sections taken in different directions;—and by viewing under a low power, as opaque objects, fragments obtained by breaking the shell, especially (as Mr. Carter was the first to suggest) after these have been allowed to absorb carmine or indigo by being placed upon water in which either of these colours has been rubbed up. By the former method alone can certain minutiæ of structure be detected; but the latter is extremely serviceable in enabling the observer to trace out the relations of various parts, which sections exhibit to him disconnected from one another. Owing to the circumstance that large specimens of *Operculina* are rarely if ever quite flat, it is next to impossible to make a section through the median

plane that shall traverse all the whorls to the central cell; by choosing a sufficiently flat specimen, however, a sufficiently near approach to this may be made to bring into view the general disposition of the chambers. This is much less regular than would be supposed from a superficial examination of the exterior. For while there is a certain general average in the proportion which their long diameter (that is, the breadth of the whorl) bears to the short (or the distance between the septa) which may be stated as about $4\frac{1}{2}$ to 1, this is by no means constantly maintained, the long diameter being sometimes as much as 7 times, and sometimes no more than $2\frac{1}{2}$ times, the short. The ordinary course of the septa, too, is often strangely departed from. There are few individuals which do not present—besides abnormal sinuosities, greater or less in degree—very marked irregularities in the conformation of the chambers, analogous to those which occur in *Nummulites*. Frequently a septum, instead of passing continuously from the inner to the outer margin of the whorl, stops short without reaching the latter, and bends backwards to join the last-formed septum; and sometimes a second septum unites itself to the first in the same manner. The abortion is often still more marked; thus in Fig. XXXIX we see three septa thus interrupted, of which two do not traverse half the distance, and the third not a quarter, thus dividing the space between two complete septa into three small chambers along the inner margin, and one large irregular chamber extending to the outer.

Fig. XXXIX.



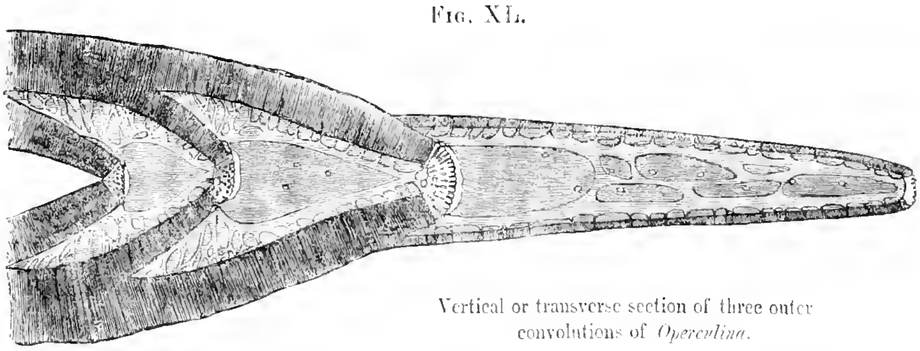
Irregular disposition of septa in *Operculina:*—*a, a, a*, normal apertures at inner margin of spire; *b, b', b''*, apertures of communication between abnormally divided chambers.

Generally speaking, the more nearly we approach the centre of the spire, the more regularly do we find the septa disposed, until we come into close proximity with the central chamber. In Plate XVII, fig. 6, we have an illustration of what may be considered the normal mode of commencement of the spire; from which it will be seen that it originates, as in Foraminifera generally, in a spheroidal cell, from which others are successively developed around it, the earlier chambers having no very definite shape, but those which succeed them gradually coming to assume the characteristic form and proportions.

440. Each chamber communicates with the neighbouring chamber on either side, by a long narrow crescentic fissure left by the non-adhesion of the septum to the outer margin of the preceding whorl (Plate XVII, figs. 1, 2, *e, e, e*). This fissure is best brought into view either by making thin transverse sections (as Fig. XL), or by breaking a specimen transversely and examining its fractured edges, by which such views will be obtained as are presented in

Fig. XLIII (p. 258), A, B, C, D. Besides this principal aperture, we observe in the septa, especially of the larger chambers, a variable number of "orbuline" or secondary pores (Plate XVII,

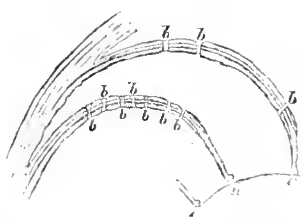
FIG. XL.



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

figs. 1, 2, *f, f*), generally circular, and of comparatively small size; these are disposed without any regularity, as is shown in Figs. XL, XLIII. They may or may not be brought into view in a horizontal section, according as its plane does or does not happen to pass through them; but when they are thus traversed (Fig. XLI, *b, b, b*), it is seen that these secondary pores, like the principal aperture, *a, a*, establish a direct communication between adjacent chambers. In the

FIG. XLI.



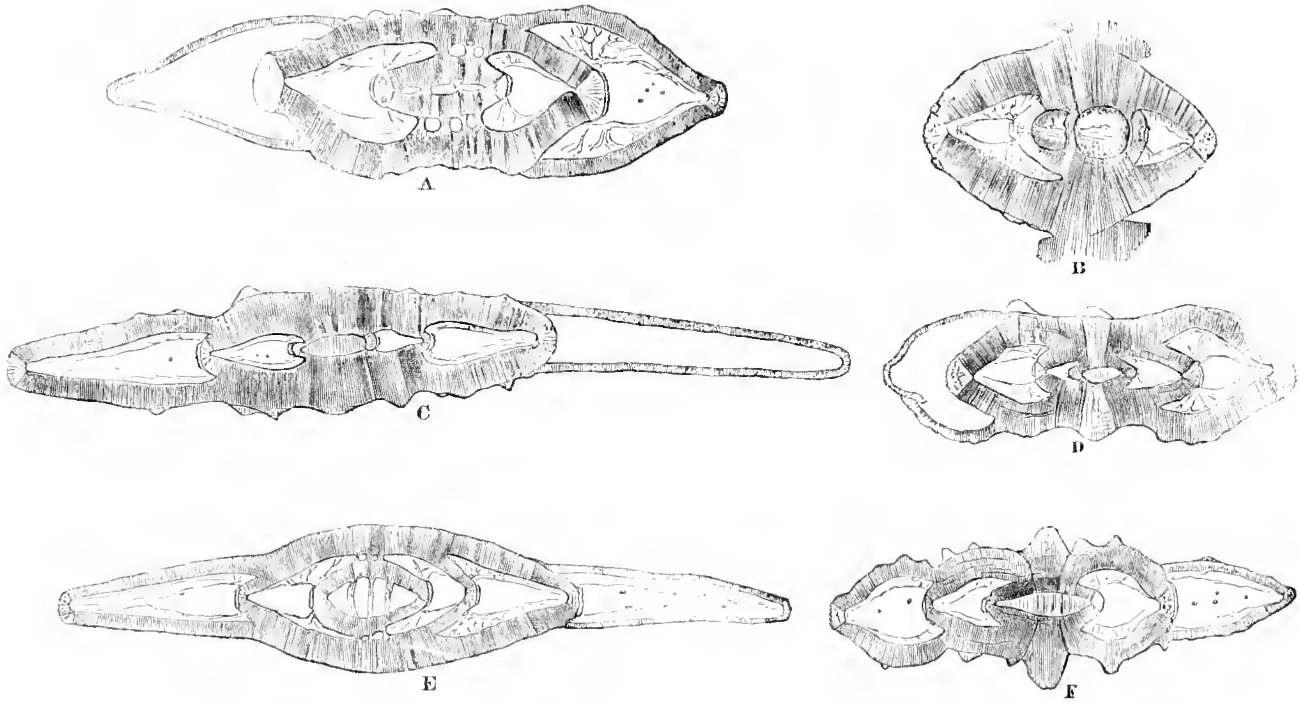
Section of the two septa of *Operculina* through the median plane, showing the secondary pores, *b, b, b*, in addition to the principal apertures, *a, a*, at the inner margin of the spire.

irregular formation represented in Fig. XXXIX, these secondary pores (*b, b′, b″*) present a disposition which would seem to indicate that they are scarcely less important for the maintenance of the communication between the chambers, than is the principal aperture itself; and it is curious to observe how exactly they repeat at *b′* and *b″* that mode of communication between *two* segments on the inner side and *one* on the outer, which is so characteristic of *Orbitolites* and *Orbiculina*. These secondary pores may be considered as representing, in the more elevated type with which we are at present concerned, the multiple pores which constitute the sole communication between the chambers in *Peneroplis* (¶ 124). Every septum is composed of two laminæ (Plate XVII, fig. 1, *d, d*), each being the proper wall of one of the chambers which it separates; these laminæ are commonly in close apposition with each other; but they separate at certain spots, to give passage to the very curious system of interseptal canals to be presently described.

441. A comparison of numerous vertical sections brings into view a most remarkable variety in the form and disposition of the chambers, not merely in different individuals, but

in different parts of the same individual. Commencing with one of the flattest variety, Fig. XLII, C, we observe that the breadth of the septal plane is very small in comparison with its length; and that although the spiral lamina of each whorl except the last obviously extends itself over the preceding whorls, the cavity of the chambers is not so extended, those of each

Fig. XLII.



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

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

442. The spiral lamina, in typical specimens, is much thicker in the inner than in the outer convolutions, that of the last whorl being always comparatively thin (Fig. XL); and a careful examination of transparent vertical sections makes it apparent, that the greater thickness of the spiral lamina of the earlier whorls is partly due to the prolongation of that of the later whorls over them, and to its coalescence with them. I have not been able to satisfy myself that the spiral lamina of the last whorl is thus extended over the preceding whorls; and it has rather appeared to me to be merely applied to the margin of that which it surrounds. The difficulty of certainly determining this point chiefly arises from the circumstance that the spiral lamina of the last whorl is reduced in thickness in proportion to its extension, as if in consequence of a limitation of the amount of calcareous matter employed in its formation. The spiral lamina is made up of a variable number of lamellæ of minutely-tubular substance (¶ 58); and its tubuli may be traced continuously through all its lamellæ, as shown in Plate XIX, fig. 3. In examining extremely thin transverse sections of this tubular shell-substance with a sufficiently high magnifying power, I have been able to perceive that the orifices of the tubuli are separated by a very delicate areolation (Plate XVII, fig. 9), as if the whole substance were composed of an aggregation of prisms with a tubulus in the centre of each, as is shown under a still higher magnifying power at fig. 8, A; and this accords well with the idea that each prism is really a hollow spicule (like that of *Acanthometra*, ¶ 18), formed around one of the pseudopodia. The diameter of the tubuli is greater at and near the inner surface of the walls of the chambers than it is at a little distance from them, as will be seen by comparing fig. 13 of Plate XVII with fig. 12; so that when a thin lamina from the innermost part of the wall is examined under a high magnifying power, the tubes are seen almost to fill the areolæ, as is shown in fig. 8, B, which is drawn on the same scale as A.

443. The shell-substance over the septa is not penetrated by tubuli, and is consequently far more transparent than the rest; and it is in consequence of this difference in texture, that the septal bands are so strongly marked on the external surface, as well as in sections parallel to it (Plate XVII, figs. 12, 13, *aa*, *a'a'*). The same is true, also, of the substance of the tubercles, whether occurring as elevations of the septal bands, or upon intermediate parts of the spiral lamina. In the latter case, the tubercles are seated upon inverted cones of the like substance, which do not usually reach down to the inner lamina, so that the internal surface presents the orifices of the tubuli regularly disposed over the interior of the chambers (as seen in fig. 13), even where sections passing at a little distance from these show rounded or

elongated spots of transparent substance (fig. 12, *b*, *b*), around which the tubuli are crowded together, as if they had been displaced by its interposition. Such spots occasionally present themselves in the ordinary type of *Operculina*; but it is of course in sections of the strongly tuberculated variety that we find them most marked, and this especially in the investing layers of the central region, where, from the size and approximation of the tubercles, the spaces between them are rendered almost opaque by the crowding together of the tubuli. The tubuli are generally seen, moreover, to be somewhat more crowded in the neighbourhood of the septal bands. The greatest local development of the non-tubular substance is seen in those varieties which have a large elevated tubercle in the centre; a section of such a variety has been shown in Fig. XLII, D, where it is seen that this tubercle springs from the spiral lamina of the innermost convolution, but that it increases in diameter as it is built-upon (so to speak) by each of the whorls by which this is subsequently invested.

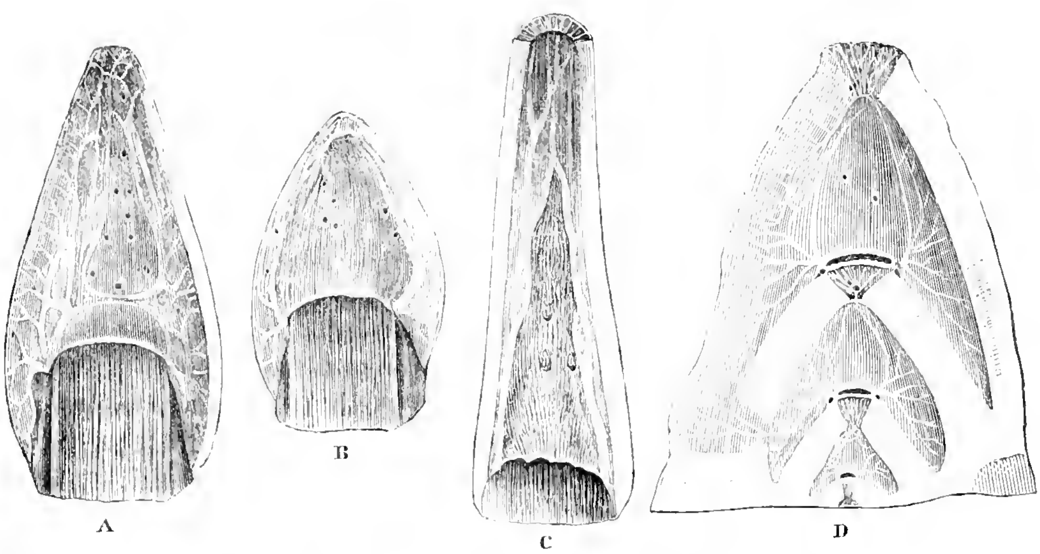
444. The texture of the shell-substance which bounds the chambers at the outer margin of each whorl (Plate XVII, fig. 1, *a*, *a*), however, presents a marked departure from that of the spiral lamina; a difference analogous to that which was first indicated by me in *Nummulites* (XII), and which has been found by MM. D'Archiac and Haime (I) to present itself so constantly in that genus, that they give to this marginal portion the special designation "bourrelet." The speciality in the structure of this part of the shell of *Operculina* was recognised by Mr. Carter (XVII), who described it as made up of an aggregation of fusiform spicules, and hence designated it as "the spicular cord."* Now I am very familiar with the appearance which has led him to take this view of its nature, since it is one which is commonly presented by thin sections that pass either through the median plane or parallel to it, as shown in Plate XVII, fig. 3, *a‴ a‴*; but this is only one out of many aspects which are presented by sections taken in various directions; and a comparison of the whole seems to me to lead to quite a different conclusion,—namely, that the supposed spicular composition of this "marginal cord" (as it may be appropriately termed) is due to the peculiar manner in which the homogeneous substance of which it is composed is traversed by the set of canals that are correctly described by Mr. Carter as forming the "marginal plexus." For if the section should happen to traverse a portion of this plexus in which the canals form a tolerably regular network of elongated meshes in one plane, the appearance delineated in fig. 3 is presented; but just as often a less complete layer of the network is traversed by the section.

* Mr. Carter has recently (XXIII *a*) criticised my account of the structure of the "marginal cord," and has re-stated his reasons for persisting in his original account of its "spicular" structure. So far from finding in this latter statement any reason for modifying my own views, I draw from it additional reason for believing that Mr. Carter has been misled by the results of the method of examination on which he seems to place most reliance; since by "cutting off tangentially portions of this cord with a small sharp scalpel," he must have almost necessarily found his sections frittered into the semblance of an aggregation of spicules. The true structure of the cord is much more certainly shown by sections made in various directions, and carefully reduced by rubbing down whilst attached to glass; of such sections I have numbers in my possession. It may be well for me to add that MM. D'Archiac and Haime have been equally unable with myself to admit the correctness of Mr. Carter's interpretation of the appearances he has witnessed.

and the form of the meshes is very inconstant, so that the appearance presented is rather that shown in fig. 4. Moreover the appearances exhibited by transverse sections of this marginal cord, highly magnified (fig. 5, *a' a'*), do not at all confirm the idea of a spicular arrangement, but are altogether conformable to the view I have expressed; the most complete confirmation to which is afforded by tangential sections, of which a very successful example, —giving a beautiful view, not only of the canal-system of the "marginal cord," but also of its communications with that of the septa, and of its relations with the two principal spiral canals to be presently described,—is represented in fig. 7, *a'*, *a'*. In this it is clearly seen how irregular is the disposition of the inosculating passages, whilst there is not a trace of the spicular structure, which ought, if it existed, to be as well brought into view in a section taken in this direction, as it is in the one shown in fig. 3, which is taken in a plane at right angles to it. The "marginal cord" is traversed on its external surface by longitudinal furrows, which are sometimes very shallow (fig. 5), but sometimes dip down deeply like those between the convolutions of the brain. These furrows usually form a kind of network with fusiform interstices, whilst in other cases they run parallel to each other and inosculate rarely. From the correspondence between their arrangement and that of the passages in the interior, I am inclined to think that they belong to the same system with these, being, in fact, canals not covered in by shell-substance, that communicate with the plexus within by inosculating branches, whose apertures may sometimes be detected in the bottom of the furrows.

445. The "marginal plexus" of canals communicates freely with the system of "interseptal canals" (Plate XVII, fig. 1, *g*, *g*), which are disposed between the two layers of the septa. The distribution of these is well seen, not only in vertical sections which have happened to traverse the septa as in Figs. XL, XLII, and in Plate XVII, fig. 7, but also in specimens laid open by fracture in the same direction, especially after the canals have been more distinctly marked out by the imbibition of a colouring liquid (Fig. XLIII, and

Fig. XLIII.



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

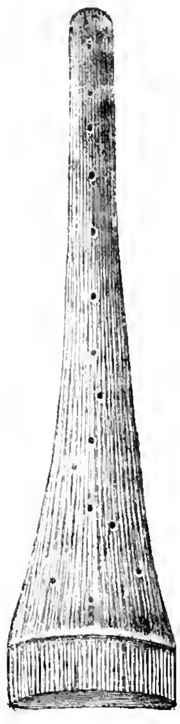
Plate XVII, fig. 2). It will be seen from these delineations, all of which are faithfully copied from specimens in my possession, that the distribution of the interseptal canals, whilst presenting a certain general uniformity of plan, is by no means constant in detail. In Figs. XLII, A, and XLIII, D, we see two principal trunks passing from the two angles of the fissure at the interior edge of each septum to join the marginal plexus at its exterior (as shown in Plate XVII, fig. 4), and sending out branches which ramify over the part of the septum that joins the spiral lamina (Fig. XLIII, D), leaving the intervening portion untraversed. But in Fig. XLII, A (as in Plate XVII, fig. 2), we observe two or more such trunks proceeding from each angle of the fissure, those of the same side frequently inosculating with each other; in Fig. XLIII, C the two principal trunks on the opposite sides inosculate as they approach one another in their course towards the outer margin of the septum; and in Fig. XL this inosculation is seen to take place much nearer the inner margin of the septum of the last whorl, so that the greater part of the septal plane is occupied by the plexus formed by their interlacement. The interseptal canals of one septum are occasionally, if not invariably, connected with those of another, by loops formed between the ramifications of those canals which extend along the alar prolongations of the septa towards the centre of the shell. Moreover, branches of the same system are generally found to penetrate the non-tubular shell-substance whenever it accumulates in any quantity; these branches are at once distinguished from the ordinary tubuli (as in fig. 12, Plate XVII), by their much larger size, their diameter being commonly about 1-5000th of an inch. Those which proceed towards the spiral lamina sometimes pass towards the surface in the non-tubular shell-substance that constitutes the septal bands, as is shown in Fig. XLIII, D, and in Plate XVII, fig. 1; they are also frequently seen to diverge from the septa over the walls of the chambers,—still, however being usually invested by a layer of transparent shell-substance, as is shown in Plate XVII, fig. 4. This last figure represents an appearance of areolation I have several times met with in the walls of the chambers,—though usually less conspicuously than in this instance,—which has made me suspect that the ramifications of the interseptal canals sometimes (if not as a regular rule) form a network in the spiral lamina over the entire surface of the chambers.

446. The interseptal system of each whorl is connected with the marginal plexus of the preceding by a very remarkable arrangement. At each junction of the marginal cord with the tubular substance of the spiral lamina, the orifice of a large canal (Plate XVII, fig. 2, *h'*, *h'*) may be seen in a vertical section which divides this canal transversely; and either of these canals (fig. 1, *h*, *h*,) may be clearly traced in sections parallel to the surface that have happened to pass through its plane, as at *h*, *h*, fig. 6, in which, by a fortunate accident, one of the spiral canals has been laid open in its entire course through the inner whorls, and can be traced nearly to the central chamber. In the tangential section, fig. 10, the two canals *a*, *a'*, can be seen running on the outside of what may be called the *nucleus*, consisting of the central chamber and the chambers immediately surrounding it. The branching-off of the successive interseptal passages from these two spiral canals, is shown in fig. 6; and the relations of the different parts of the system are brought extremely well into view in fig. 7, which represents a tangential section of a young shell, the rapid curve of whose spire causes the planes of even the contiguous septa to vary greatly in their direction. The spiral canals *h*, *h*, though only running along the angles of the marginal cord, as shown in transverse section at fig. 5, *h'*, *h'*.

pretty obviously communicate with the plexus of passages which it contains; and thus the interseptal system of one whorl is brought into direct connexion with that of the preceding. It is to be remembered, however, that independently of such connexion, the spiral mode of growth of itself brings about a continuity of the canal-system throughout, by means of the marginal plexus; the consecutive whorls not being added one to another like the successive annuli of *Cycloclypeus*, each of which is (so to speak) *closed* or complete in itself; but being formed by the prolongation of the spiral lamina and of the marginal cord, which may be considered as always *open* to indefinite extension.

447. Reverting, now, to the generic differentiation between *Operculina* and *Nummulina* that has been based by MM. D'Archiac and Haime on the closing-in of the spire, which they affirm to be a constant character of the latter, whilst in the former the spire seems ordinarily to open out so long as it continues to increase,—I have to remark that this is by no means an invariable difference; for I have met with several specimens of *Operculina* in which the spire closes-in by a somewhat abrupt inflexion of the marginal cord, so as to produce a rapid diminution in the size of the last four or five chambers, ending (as it would appear) in a complete cessation of growth. The closing septum of one of these specimens is shown in fig. XLIV. Looking, however, to the circumstance that these specimens bear but a very small proportion to those which exhibit no such tendency, and also to the fact that some of the specimens in which this closing-in is seen are very far from having attained their full growth, I am disposed to regard it as an abnormal, or at least as only an occasional occurrence in *Operculina*: and I must confess that, notwithstanding the positive assertion of MM. D'Archiac and Haime, I still entertain doubts as to whether it is to be accounted a uniform characteristic of *Nummulina* (¶ 456). At any rate, the occasional occurrence of this condition in *Operculina* deprives the character of that constancy which is requisite to make it good for generic differentiation; and if *Operculina* and *Nummulina* are to be retained as separate genera, I cannot perceive by what features they are to be distinguished, save by the marked compression in form, the limited number of convolutions, and the external display of the whole spire, which are the most obvious though not very important characteristics of the former.

Fig. XLIV.



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

448. It only now remains to speak of certain appearances indicative of *reparation after injuries*, which throw some light upon the physiology of this type of organization. Specimens are not unfrequently met with, exhibiting marked irregularities that may fairly be regarded as having been produced by fracture. A portion of the outer part of the spire being broken off, the wound heals by the formation of new shell at the margin: but in its further progress the spire often shows the effect of the injury, in a narrowing of that part of the convolution which succeeds it, the new chambers being formed (as it were) on the contracted basis to which their predecessors have been reduced. A very remarkable feature in all these reparations is *the*

continuation of the marginal cord along the fractured edge. It might have been supposed that the wound would have been healed with some rude exudation, which would have given rise to an amorphous shell-structure; but instead of this, we find the reparation chiefly effected by a new production (probably by extension from the old) of that portion which gives the most evidence in its canalicular structure of being intimately connected with the vital changes taking place in the organism. In one specimen in my possession, a reversal seems to have taken place in the direction of growth after the fracture, the spire having been broken across, almost through its centre, after the first two convolutions had been formed; and the extension of the marginal cord which has closed-in the fractured portion having proceeded not from the later but from the earlier of the two fractured extremities of the second convolution, its *backward* growth produces a reversal in the direction of the spire. A somewhat similar retrograde increase has been already noticed among the modes in which *Orbitolites* is occasionally repaired (¶ 175); and it obviously shows that every portion of the organism is equally capable of extending itself when left free to do so. It is worthy of remark that the growth of this specimen subsequently to the injury has taken place more after the plan of *Nummulina* than on the ordinary plan of *Operculina*, the convolutions being more numerous than usual and their rate of increase slow: there is evidence, however, in the presence of a small fragment of the final whorl, that it underwent the thinning-out which is characteristic of its type.—Notwithstanding the great number of specimens which I have examined, I have not met with one that presented any such departure from the normal type of growth as would deserve to be termed a *monstrosity;* so that it would seem as if such aberrations were more frequent in the *cyclical* than in the *helical* forms of Foraminifera.

449. *Affinities.*—Since in this genus we have a complete development of all the characters that essentially distinguish the Nummuline type, it is obvious that it can bear no direct relationship to any true Rotaline; and although several approximations to the form of *Operculina* are presented in the Rotaline series (¶¶ 353, 359, 367), yet as these are deficient in all its other distinctive features, its relationship to them is one of analogy only, not of true affinity. To *Amphistegina* it is obviously related much more closely, but it is differentiated from that type not only by its perfect symmetry and by the suppression of the alar and astral lobes, but also by the development of the additional septal lamella, of the marginal cord, and of the canal system. With *Nummulina* the relationship of *Operculina* is so intimate, that, as we have seen, it is difficult to find a valid generic distinction between them; that suppression of the alar lobes which constitutes the most obvious differentiation between the typical *Operculinæ* and the typical *Nummulinæ,* being a character which (as we shall presently see, ¶ 462) presents itself in the "assiline" group of true Nummulites. Although there is no very intimate relationship between the typical *Operculina* and the typical *Polystomella*, yet the approximation between some of the least developed examples of the former and the "nonionine" forms of the latter is so close that it is difficult to distinguish them; and the essential distinction will probably be found to lie in the distribution of the canal-system respectively characteristic of these two types. To *Heterostegina* the relationship of *Operculina* is extremely intimate; nothing more being required than the subdivision of its chambers into chamberlets, to convert the latter into the former. Such a subdivision we have seen to occur in numerous other

instances (¶¶ 64, 119, 143), without any essential departure from the characters of the respective types in which it occurs.

450. *Geographical and Geological Distribution.*—The statements already made regarding the geographical diffusion of Amphistegina apply equally well to *Operculina*, except that the dwarfed forms of the latter have a much wider geographical range, being found in European seas, and even within the Arctic circle. It is only between or near the tropics, however, that this type attains its characteristic development.—The earliest recognised appearance of *Operculina* in geological time is in the Cretaceous series; it seems to have become abundant at the commencement of the Eocene period, numerous forms having been described from the early Tertiaries of England, Continental Europe, and Asia: and it is traceable throughout the whole series of Tertiary formations, specimens of no inconsiderable dimensions being found in the Crag of Suffolk.

Genus III.—Nummulina (Plate XVIII).

451. *History.*—Among all the diversified types presented by Foraminifera, there is none which has either so long or so generally attracted the attention of Naturalists as that which is now familiarly known under the designation *Nummulite.* And this is easily accounted for, on the one hand by the comparatively gigantic size which it usually attains, on the other by the enormous aggregations of individuals which constitute, with some intermixture of other types of animal life, a stratum of limestone not unfrequently attaining a thickness of 1500 feet, which extends in an east and west direction through Southern Europe, Lybia and Egypt, and Asia Minor, and is continued through the Himalayan range of Southern Asia into various parts of the great Indian Peninsula, where it acquires a very extensive development. It is of this limestone that the Pyramids are partly built; and it is in relation to those structures that we find the first-recorded mention of Nummulites. Putting aside the question whether they are the bodies referred to by Herodotus and Pliny, it seems indubitable that they attracted the notice of Strabo, who adverted to the local traditions that they were the petrified remains of the lentils employed by the workmen as food, and remarked that this was improbable, since in his own locality (Amasia, of Pontus in Asia Minor) there existed a hill prolonged into the middle of a plain, the stone of which is filled with similar lentil-like bodies, —a statement which has been recently confirmed by M. de Tchihatcheff, who has brought from that locality a beautiful series of Nummulites. The first examples of this type noticed in Europe seem to have been those of the neighbourhood of Paris, which were described by Agricola and Conrad Gesner, the latter of whom regarded them as a kind of Cornu Ammonis. Aldrovandus adverted to them as "freaks of nature;" Kircher, who seems to have formed his notion of them from the vertical sections often produced by fracture, compared them to willow-leaves; while Clusius, who designates them "numismales lapides Transylvaniæ," refers to the popular belief of the Transylvanians that they were pieces of money turned into stone by King Ladislaus, in order to prevent his soldiers from stopping to collect them just when they were putting the Tartars to flight!

452. The commencement of a more exact knowledge of this type may be considered to date from Scheuchzer; who, at the beginning of the last century, gave a description of the examples of it occurring in Switzerland, which, as far as it goes, is very exact,* regarding them as a new type of Cornu Ammonis. Among succeeding naturalists, however, a great variety of notions prevailed as to their essential character; all which will be found elaborately set forth in the admirable monograph of MM. D'Archiac and Haime (I). It will be sufficient here to state that Lancisi (1719), who described them under the name of *nummi lapidei*, supposed them to be the madreporiform plates of marine Echinites; whilst Buckmann, who wrote specially on the *lapis numismalis* of Transylvania (1727), considered them to be bivalve Mollusks; and Bourguet in his Treatise on Petrifactions (1729), maintained that they were the opercula of Ammonites. Notwithstanding that Guettard, in a special memoir devoted to them (1770), pointed out that they have neither the large open mouth nor the siphon of those chambered shells, they were ranked by Plancus (LXXXIII), Gualtieri (LI), Soldani (C), and most writers of the latter half of the eighteenth century (sometimes under the name of *Helicites* and *Camerina*, the latter given by Bruguière), among Nautili or Ammonites. This erroneous view was adopted even by Cuvier, who in his first systematic classification ('Tableau Élémentaire,' 1798), ranged this type under the name of *Camerina* after *Orthoceratites*, at the end of his series of Cephalopod Mollusks; and also by Lamarck, by whom the genus *Nummulites* was first created (LVII). The first good descriptions of specific forms were those of Bruguière ('Encyclopédie Méthodique,' 1792), who distinguished four species of his genus *Camerina*, amongst them the *C. lævigata;* and his descriptions of these were followed by Lamarck.

453. The greatest confusion prevailed at the commencement of the nineteenth century, in regard to the objects ranked together under the several designations applied to Nummulites; and this confusion is especially apparent in the memoir of Fortis ('Mem. pour servir à l'Hist. Nat. de l'Italie,' 1802), who introduced the new name *Discolithus* for the bodies previously known under the names of "pierres lenticulaires, numismales, frumentaires, helicites, et dernièrement camérines;" and ranged under it the very different types which are now distinguished as *Nummulina*, *Orbitolites*, *Fabularia*, *Alveolina*, *Orbitoides*, and *Calcarina*. Towards clearing up this confusion an important step was made by the separation effected by Lamarck (LVIII, 1804, 1806), between the Nummuline and the Orbitoline types; the genera *Nummulites* and *Lenticulites* (the latter founded on differences which have since proved not to be of generic value) being retained among the chambered Cephalopods, whilst *Orbitolites* (under which designation were ranked some of the forms now distinguished as *Orbitoides*) was referred to the group of Zoophytes. As an illustration of the vagueness of the opinions yet prevalent on the nature of these bodies, it is worth while to mention that Deluc (1802) and De Roissy (1805) considered them to be altogether internal shells, analogous to the so-called "bone" of the cuttle-fish; whilst Duméril in his 'Zoologie Analytique' (1806) likened them to the disks of *Porpita*, and ranged them among the Medusæ. De Montfort (LXVII), according to his wont, erected certain species of Nummulites into the new genera *Lycophris*, *Rotalites*, and *Egeon;* names which are now entirely discarded. Subsequently (LX) Lamarck came to

* 'Specimen lithographiæ Helveticæ curiosæ,' &c., Tiguri, 1702.

perceive the strongly marked differences that exist between Nummulites and the ordinary siphoniferous Cephalopods; and he regarded them as internal shells, completely enclosed (like *Spirula*) within the animal, instead of giving lodgment to its body in its own chambers. In this view he was followed by Deshayes and Defrance (XXIX).

454. It was in 1825 that the Nummulites were detached by D'Orbigny (LXIX) from the siphoniferous chambered shells, and ranged with the minuter shells then first distinguished by the term *Foraminifera*; still, however, being considered to belong to the class of Cephalopoda. The Lamarckian designation *Nummulites* was altered by D'Orbigny to *Nummulina*, on the ground that the genus had existing representatives; the genus *Lenticulites* was not adopted, having been previously shown to be untenable; but a new genus *Assilina* was created for the reception of those forms in which the investment of the earlier whorls by the later is incomplete, so that the turns of the spire are partially apparent,—a distinction which we shall presently find to be of no essential importance. His description of the Nummulitic type was extremely inexact: and the first approach to a more precise account of it was given by Sowerby in his 'Mineral Conchology' (1829), who accurately described and figured the true aperture of communication between the chambers (which does not seem to have been at that time recognised by M. D'Orbigny), and traced the alar prolongations of the septa from the peripheral margin towards the centre on either side. Numerous dissimilar forms of Nummulites were subsequently brought to light by the researches of geologists in various localities; but for some time no essential advance was made in the knowledge of their structure; and the discovery of M. Dujardin in regard to the Rhizopod character of the animal of Foraminifera generally does not seem to have been applied to this particular type, until MM. Joly and Leymerie applied themselves to the investigation of its conformation. Their Memoir (LIII), published in 1848, brought together most of the results attained by previous inquiries, which were confirmed by their own researches; but they did not discover any new points of importance,—the chief novelty which they announced having been previously put forth by M. de Keyserling,* though probably without their knowledge. According to these observers, the spiral lamina of Nummulites is perforated with large apertures, the continuity of which through successive layers forms canals reaching from the median plane to the surface on either side: these canals are filled up in the process of fossilization by calcareous infiltration; and the projection of the ends of the columns thus formed, from the surface of specimens that have been subjected to attrition, gives rise to the granulations often observable thereon. The inquiries into the minute structure of Nummulites on which I was myself at that time engaged led me to the same view, without any knowledge that it had been previously arrived at; and having found myself fortified by the concurrence of MM. Joly and Leymerie (with whose researches I became acquainted before the publication of my own), I expressed it without hesitation (XII, p. 26) in the Memoir which contained the results of my earliest researches into the microscopic structure of Foraminifera. It was from the first opposed, however, by Prof. Williamson and Mr. T. Rupert Jones, who maintained that the supposed passages filled up by infiltration were really solid non-tubular portions of the original

* 'Remarques sur quelques points de la structure des Nummulites,' in "Verhandl. der Russisch Kaiser. miner. Gesellsch. zu St. Petersburg," 1847, p. 17.

shell, resembling those which occur in many recent types of Foraminifera; and a more extended acquaintance with the latter, and particularly the study of *Cycloclypeus* (XIV), satisfied me of the correctness of their interpretation of the appearances by which M. de Keyserling, MM. Joly and Leymerie, and I myself had been originally misled. The error has been endorsed, however, by the high authority of MM. D'Archiac and Haime (I); and, though I shall have to revert to this subject more fully hereafter (¶ 463), I may here remark that the contrast between the transparent semi-crystalline aspect of the non-tubular portions of the shell, and the brown semi-opacity of the tubular portions, is so striking in many Nummulites, whilst the limits between the two are often so sharply defined, that the misinterpretation of these appearances by such as have not familiarised themselves with analogous appearances among recent Foraminifera is almost inevitable.

455. In my own Memoir, which was for the most part restricted to an account of the structure of a single species, *N. lævigata*, attention was for the first time drawn to the doubleness of the septa that divide the chambers, and to the existence of a set of interspaces between their laminæ, communicating with passages excavated in the walls of the chambers; to the minute tubularity of the shell forming the spiral lamina, and to the coarser tubularity of that which forms the marginal cord; as well as to the various structural features which indicate the conformity of *Nummulites* to the general type of Nautiloid Foraminifera, as elucidated by Prof. Williamson's observations on *Polystomella crispa*: and I further drew attention to the varieties in the mode in which the alar prolongations of the septa are disposed on the surface of the previous convolutions, as likely to afford characters of value in the differentiation of species.—Not long afterwards (XVIII) Mr. Carter published the results of his inquiries into the structure of the allied sub-genus *Operculina*, which led him both to confirm and to extend my discovery of the canal-system in Nummulite; and having examined specimens of Nummulite with the additional light thus obtained, he saw enough to satisfy him of the essential similarity of the distribution of the canal-system in the two types. The elaborate monograph (I) of MM. D'Archiac and Haime, which appeared a few years later, brought together every discoverable notice of this type from the earliest times, giving a connected history of the progress of knowledge respecting it, of which I have freely availed myself in the preceding outline. They embodied also the most important parts of the descriptions of its structure which had been given by those who had investigated it; and to these they added some new facts of importance, by following out the modifications which the fundamental type undergoes, especially in regard to the course of the alar prolongations of the septa,—an inquiry which I was myself only prevented from pursuing by the want of the requisite materials. We shall hereafter see (¶ 462) that these modifications (to the importance of which as differential characters I had specially directed attention) furnish the basis of their division of the genus into subordinate groups. All the reputed species and their synonyms were most carefully investigated by them; and they succeeded in reducing a chaotic assemblage of about a hundred and fifty* to an orderly arrangement of fifty-five. According to the ideas of classification then prevalent, they were fully justified in the differentiation of the greater part of

* According to the Authors above referred to, *twenty-two* of the best known species of Nummulite figured in catalogues as *ninety-eight*; of these, 5 had been placed in *two* genera, 1 in

these, if not of all; but the knowledge since acquired of the range of variation among Foraminifera generally, and in the allied genus *Operculina* in particular, justifies a doubt whether the differences between them are really more than varietal, and whether, if a sufficient number of individuals were compared, they would not be found as gradational as are those we have met with elsewhere (see ¶¶ 434—438). The latest contribution to our knowledge of the structure of Nummulites is contained in a recent paper by Mr. Carter (XXIII *a*), which contains the results of his further study of the subject, especially in regard to the distribution of the canal-system. I feel it due to myself to state that the account of that system which I shall presently give is entirely based on my own previous re-investigation of it, with the light which I have derived from my examination of *Operculina*; and that the illustrations in Plate XVIII had all been not only drawn but printed before the appearance of Mr. Carter's paper, in which as to most points it will be found that I fully concur. In regard to the question of specific distinctions in this genus, I have been led by my own independent observations to an entire concurrence with the views recently put forth by Messrs. Parker and Rupert Jones (LXXX *b*), whose very careful and thorough investigation of the subject entitles their views to the respectful consideration of such as have formed their notions of the differentiation of species on the ordinary descriptions based on the examination of small numbers of specimens.

456. *External Characters.*—What may be considered the typical or characteristic form of the Nummulite, is a double-convex lens of moderate thickness; but the convexity gives place in certain cases to a flattening which approaches that of the flattest varieties of *Operculina*, whilst in other instances it is so greatly augmented that the lenticular form is converted into the spheroidal. A wide range of variation exists in this respect among individuals of what must be accounted (according to the views of the best systematists) one and the same species. Thus, in a Nummulite very common in Scinde (which was formerly considered by Mr. Carter to be the *N. obtusa* of Sowerby, but which he now regards as the *N. perforata* of D'Orbigny), the thickness of the lenticular specimens is a little less than half the diameter, the former being $4\frac{3}{4}$ lines while the latter is $10\frac{1}{2}$; but the proportion of the thickness to the diameter may increase until it reaches nearly three-fourths, the former being 9 lines whilst the latter is $12\frac{1}{4}$, so that the body becomes globose; whilst, on the other hand, the thickness may diminish until it is scarcely more than one-third of the diameter, the former being $2\frac{1}{2}$ lines and the latter 7. And what is even more remarkable, in a recent form which I have described (XV) under the name *Amphistegina Cumingii*, but which I am now satisfied, for reasons already given (¶ 420, *note*), to regard as a true *Nummulina*, although the form of the shell up to nearly its full growth is that of a rather thick bi-convex lens, yet the last whorl spreads out in a manner which alters its contour to even a more remarkable degree than we ever see in *Operculina*. The two lateral surfaces have usually a nearly equal curvature; and any want of symmetry is usually due rather to a departure of the median spiral from the plane on which it normally revolves, than to any excess in the growth of one side beyond that of the other—though such an excess unquestionably does occasionally present itself. The diameter of Nummulites usually ranges between 1-16th inch

three, 2 in *four*, 3 in *five*, 1 in *six*, 1 in *seven*, and 1 in *eight* different genera; and of specific names, 4 species had received *three*, 1 *four*, 3 *five*, 2 *six*, 1 *seven*, 1 *nine*, 2 *ten*, and 1 *eleven*.

and $4\frac{1}{2}$ inches; a considerable proportion of the reputed species ranging between half an inch and an inch. This type is consequently the most gigantic in its dimensions of all Foraminifera; its largest forms being only approached by *Tinoporus*, *Cycloclypeus*, and *Alveolina*, whilst its ordinary size is equalled by that of none save *Patellina*, *Orbitoides*, and *Orbitolites*. The fossilized specimens which afford us the most abundant means of studying this type, very seldom present what was probably their original surface quite unaltered, having nearly all been subjected to more or less of abrasion or decomposition; but in those which seem to have been least affected by such agencies, the surface may be either entirely smooth, without any indication whatever of the spiral convolution concealed within, or it may exhibit various inequalities which are related to the peculiarities of internal structure to be presently described. In the typical Nummulites, the last turn of the spire not only completely embraces but entirely conceals all those which preceded it; but in the group which has been formed by some into the separate genus *Assilina*, ranked by others as a sub-genus of Nummulites, and merely distinguished by MM. D'Archiac and Haime as the *explanate* form, the earlier whorls remain more or less visible, in consequence of either not being invested at all by the later, or being so invested that (as in *Operculina*) their spiral and septal partitions are not concealed. This feature, however, is by no means peculiar to the explanate group; since it presents itself occasionally in specimens which are referred by other characters to a different position; and this kind of variation will not be surprising to such as have learned to appreciate at their true value the corresponding variations of *Operculina* (¶ 441). In the type of this genus which has come down to the present epoch, the *N. planulata*, of which the *N. radiata* of Fichtel and Moll is a varietal form, we find the centre of each lateral surface occupied by a "boss" of transparent shell-substance, exactly resembling that which has been described as occurring in *Amphistegina* (¶ 421), and formed like it, by the filling-up with exogenous deposit of the umbilical hollow left by the stopping-short of the alar prolongations, which, in the later whorls, do not by any means extend to the centre.

457. The lateral surfaces, again, are often marked by punctations, which are sometimes depressed, but are more commonly elevated into rounded tubercles. The presence of these in unusual abundance and prominence has been held by MM. D'Archiac and Haime to characterise their group of *punctulatæ*: but as I am now fully satisfied that these punctations (whether elevations or depressions) only mark, as in *Operculina*, the spots in which the ordinary canaliculated shell-substance is replaced by the solid or non-tubular, and that they are not (as supposed by those and other observers) the indications of canals filled-up during fossilization, I cannot attach any essential importance to their larger or smaller size, or to their greater or less abundance, feeling confident that this character must be subject to the same kind of variation in Nummulite that we have seen it to present in *Operculina*.* When the surface has been worn by abrasion, moreover, the non-tubular portions of the shell being

* On this point, I find myself supported by the careful observations of Mr. Carter, who remarks (XXIII *a*, p. 371):—"The presence of the puncta, again, or their absence, their attachment to the septal lines, or their separation from them, or the existence of both in the same specimen, or, indeed, the absence of septal lines altogether, and the presence of an abundance of puncta, may exist, respectively, in the different forms of the globose Nummulite, *N. perforata*, which abounds in the valley

harder than the rest, stand out in greater relief; and thus it happens that the septal bands and tubercles, which may be scarcely distinguishable on some specimens, become very conspicuous on others, although the structure of the shell may be precisely the same in the two cases. Not only are the septal bands of the regular spire thus brought into view where this remains unconcealed by subsequent overgrowth, but those alar continuations of them may be rendered visible superficially, which, in the typical Nummulites, extend themselves from the last turn of the spire over the whole of each lateral surface; and thus those surfaces may come to be marked by striæ, which sometimes directly converge from the margin towards the centre, sometimes follow a course more or less sinuous, sometimes remain distinct from each other through their whole length, and sometimes divaricate and inosculate more or less freely so as to form an irregular reticulation.—From what has been stated of the diversities of form among Nummulites, it will be readily apprehended that their margin will sometimes be rounded or obtuse, sometimes thinned away to an acute edge. In adult specimens it seems to be always smooth, not being marked by those furrows which we shall find (as in *Operculina*) to traverse the surface of the "marginal cord" of the inner whorls; and it is affirmed by MM. D'Archiac and Haime that this type is distinguished by the entire closure of the last chamber, since, even in the best preserved specimens, they have not been able to distinguish that fissure between the inner margin of the septum and the outer edge of the preceding whorl which elsewhere constitutes the passage of communication between adjacent chambers. To this point I shall presently more particularly advert (¶ 466).

458. *Internal Structure.*—For the satisfactory investigation of the internal structure of Nummulites, it is requisite to make thin sections in various directions, capable of being viewed under the microscope by transmitted light, and also to break the shell in various modes, so as to obtain fragments which may be examined by reflected light.* Valuable information is also furnished, especially in regard to the distribution of the canal-system, by the siliceous casts of their internal cavities which have been occasionally preserved to us whilst the shells underwent disintegration.—The indications afforded by these methods are such as to leave no doubt that *Nummulina* very closely accords with *Operculina* in the most essential features of its internal structure; and it will therefore be unnecessary to do much more than indicate the differential characters by which the former type is specially distinguished.

459. When we examine the spire of a Nummulite as laid open by a section through the

of Kelat and Scinde; showing that much dependence must not be placed on the puncta or septal lines for specific distinction." (See also Parker and Rupert Jones, LXXVIII and LXXX *b*).

* Nummulites are generally most disposed to split through the median plane, so as to lay open the cavity of the spire. This property, which has been noticed in all ages, is due partly to the larger proportion of cavitary spaces which occupy that plane (as seen in Plate XVIII, fig. 9), and partly to the inferior density of that portion of the shell—the marginal cord—which bounds the edge of the spire. If a Nummulite be heated in a flame, or over the fire, it will often split into two halves through the median plane, if it be thrown into cold water or be struck lightly on its edge with a hammer: and this it will be more disposed to do, in proportion as it has been but little changed by fossilization, and has its cavities free from mineral infiltration.

median plane (Plate XVIII, fig. 5), we see that the number of whorls is usually much greater than in *Operculina*, and that their increase in breadth is by no means so rapid, especially between later convolutions. The progressive increase is tolerably regular in the earlier whorls; but it afterwards not unfrequently happens that the spire enlarges rather suddenly, whilst sometimes it contracts again to a breadth inferior to that of the convolution it embraces. The division into chambers, also, is far from being regular, the distance of the septa from each other being subject to great variation even in the same whorl; and chambers much smaller than the rest, and apparently *abortive* (resembling those shown in Fig. XXXIX, p. 253), being not unfrequently seen. It is worthy of remark that when the septa thus fail to divide the whole breadth of the convolution, it is invariably on its *outer* side (so far as my observation extends) that they are defective; thus indicating that their development does not commence from the marginal cord (as supposed by Mr. Carter, XXIII *a*), but from the internal edge of the spire,—as might naturally be inferred from the position of the aperture through which the mass of sarcode projects itself, whereon the new chamber is moulded. It is occasionally observed that a convolution subdivides into two, sometimes of equal, sometimes of unequal breadth; this abnormality is chiefly observable in such large and somewhat contorted forms as *N. gyzehensis* and *N. distans*. When the subdivision is equal, each portion soon acquires the dimensions of the original convolution, and continues to maintain a distinct course, sometimes undergoing further subdivisions. But it often happens that the supplemental convolution is so much smaller as to be a mere appendage to the principal, into which it returns after having retained its distinctness through a course of greater or less extent. I am not acquainted with any other helicoid type of Foraminifera in which such subdivisions occur; and I am disposed to connect it with the peculiar distribution of the canal-system to which I shall presently direct attention (¶ 464) as tending to favour growth in a *radial* direction corresponding to that of *Cycloclypeus*, in which type a multiplication of incomplete annuli is so common as to be the rule rather than the exception. In specimens whose chambers are occupied by transparent calcareous infiltration, it not unfrequently happens that the central portion of each crystalline aggregation (as shown in the upper part of fig. 5) is deeply tinged with dark brown matter, which has every appearance of being the carbonaceous residue of the original sarcode-body.

460. The form and position of the apertural fissure which establishes the communication between successive chambers, are precisely the same as in *Operculina* (¶ 440); and in this type also we meet with "secondary pores"* scattered irregularly over the surface of the septum, as shown in figs. 7, 8, 10. Each septum, in all well-preserved specimens, can be distinctly seen to be composed of two lamellæ, between which the canal-system is interposed, as shown in fig. 4; and it generally happens that the lamella which forms the anterior face of one septum can be traced along the inner edge of the "marginal cord" (as shown in fig. 4),

* These "secondary pores" were first observed by me in *N. lævigata* (XII, p. 21): I then believed, however, that they do not pass through both layers of the septa, but only establish a communication between the chambers and the interseptal passages—a notion which was supported by Mr. Carter (XVIII), but of the fallacy of which I afterwards became convinced by my own study of the allied recent types *Operculina* and *Cycloclypeus*.

a considerable interval being sometimes left between them, so as to become continuous with that which forms the posterior face of the next septum, as is well shown in many of MM. D'Archiac and Haime's beautiful figures. Hence it appears that each segment had its own proper and complete investment, and that the marginal cord is really to be considered as representing the "intermediate" or "supplemental" skeleton of *Calcarina* (¶ 382). Where, on the other hand, the septal lamellæ abut against the "spiral lamina," they become absolutely continuous with its innermost lamella, the structure of which is precisely the same as that of the numerous minutely-tubular lamellæ, of which (as in *Operculina*, ¶ 442) its whole thickness is made up.

461. This minutely-tubular structure is as distinctly seen in thin sections of Nummulites whose texture has not been altered by fossilization, as it is in *Operculina*; but sometimes the texture of the shell is so altered by fossilization that the tubular structure is replaced by a minute prismatic arrangement. The explanation of this is, I believe, to be found in the mode in which the shell is originally formed, which is doubtless the same as in *Operculina* (¶ 442).—The shell-substance over the septa (as shown at *b*, *b*, fig. 6) is not traversed by tubuli, and is thus more transparent than the rest; and it is of this dense hyaline substance that the septal bands are composed, which are visible over the whole surface of the "assiline" or "explanate" Nummulites. These bands are often broken up externally (as in *Operculina*, ¶ 436) into rows of tubercles; and such tubercles form the bases of columns of non-tubular substance, which are traceable into the superjacent investments formed by the later convolutions of the spiral lamina, so that they may even be continued through several of these to the external surface, as shown at *e*, *e*, *e*, fig. 8. I have not met in the portion of the spiral lamina that bounds the median portion of the chambers of any Nummulite, with those intermediate spots of non-tubular substance which are very common among *Operculinæ* (¶ 437); and though such intermediate spots frequently occur in the portion of the spiral lamina which invests the preceding convolutions, they are really formed on the basis of the septal tubercles of the included whorls.—The "marginal cord" which is shown in horizontal section at *a*, *a*, figs. 1, 3, 4, 6, 9, and in vertical section at *a'*, *a'*, figs. 2, 7, and of which the furrowed surface is seen at *a''*, fig. 7, bears a close general resemblance to that of *Operculina* (¶ 444); but differs from it, as will be presently shown, in the disposition of the canal-system (¶ 464).

462. When a typical Nummulite is divided by a section passing through its centre perpendicularly to the median plane, it presents an aspect (as shown in fig. 10) which remarkably differs from that of a typical *Operculina*. For although the spiral lamina in the latter, as well as in the former, is usually continued to the centre of the spire, yet in *Operculina* it is generally applied so closely to the lateral surfaces of the included whorls, that the cavities of the chambers are but little or not at all extended inwards by alar prolongations; and if, as sometimes happens (Fig. XLII, A, E, p. 255), such prolongations should exist, they converge uniformly towards the centre of the spire in which the alar prolongations of their septa all meet (see Plate XVII, fig. 1). In *Nummulina*, on the other hand, it is the rule (the exceptions being chiefly found in the 'assiline' or 'explanate' group) for the investing portion of each convolution of the spiral lamina to be separated from the lateral surfaces of the convolution it includes, by the alar extensions of the chambers of its own marginal portion, which extensions are

divided by prolongations of the marginal septa. These prolongations, in several of the smaller Nummulites (for the most part belonging to the group of *Plicatæ vel striatæ* of MM. D'Archiac and Haime), converge *radially* towards the centre, sometimes with a slight sinuosity. In a considerable proportion, however, of the middle-sized and larger Nummulites (including the whole of the *Læves and sublæves*, and several of the *Punctulatæ*, of MM. D'Archiac and Haime), the septal prolongations, though commencing radially at the margin, as shown in Plate XVIII, fig. 1, *b*,' *b*', soon become more or less sinuous, and meander without any definite direction over the whole surface of the disk, occasionally bifurcating near their origin, as shown at *b*'', *b*''. Another variety in the disposition of these alar prolongations of the septa consists in the formation of inosculations between those which adjoin one another, so that the extensions of the chambers over the lateral surfaces are divided-up into numerous isolated portions, as shown in fig. 9; and it is this arrangement which gives rise to those numerous interruptions in the interspaces between the successive whorls, which mark such vertical sections as the one represented in fig. 10. Further, these inosculations may be so frequent as to convert the whole system of septal prolongations into a *reticulation* covering the invested whorl, as shown at *b*', *b*', fig. 3; in which reticulation the continuity of those prolongations is altogether lost. The Nummulites in which this plan prevails are distinguished by MM. D'Archiac and Haime as *Reticulatæ* and *Subreticulatæ*. Thus, as has been pointed out by Messrs. Parker and Rupert Jones (LXXX *b*), there are three typical plans on which these alar prolongations are arranged, namely, the *radiate*, the *sinuate*, and the *reticulate*; but the first of these graduates imperceptibly into the second, and the second, with the like absence of any definite boundary, into the third. Among the reputed species of *Nummulina*, there are some (*N. striata* and *N. Biaritzensis*, for example) of which some individuals have radiate and others sinuo-radiate septal prolongations; whilst there are several (especially among the medium-sized "granulate" forms) which are radiate in their young state and sinuate when older. The passage from the sinuate to the reticulate plan, moreover, is marked by varieties of *N. complanata*, wherein inosculations of the septal prolongations occur which assimilate their arrangement to that presented by varieties of some of the sub-reticulate forms, as *N. lævigata*, which depart but little from the sinuate type.

463. In all the larger forms of typical Nummulites we find columns of non-tubular substance based upon the septal bands of the interior convolutions, and receiving additions to their height from successive investments of the spiral lamina, the substance of which is tubular where it overlies a surface whose tubularity allows the exit of pseudopodia, whilst it is non-tubular when the subjacent surface is of the like description. In *N. lævigata* and several other Nummulites, we see these columns (the form of which is very irregular) to be included between the two lamellæ of the alar prolongations of the septa, which diverge to give them passage, as shown at *e*,' *e*', *e*', fig. 9. In other instances, however, these columns pass up through the intermediate portions of the chambers, as is the case in *N. Garansensis* (fig. 3), but still more remarkably in *N. Verneuili* (see I, plate vii, fig. 1 *d*) and *N. Leymeriei* (I, plate xi, fig. 10 *e*). It is certainly the exception rather than the rule to be able to trace these columns from the inner convolutions to the surface with the continuity shown in

Plate XVIII, fig. 8; but such exceptions undoubtedly do occur,* although it is more common to find the columns stopping short after they have been traced through several floors, or to find that, without an absolute loss of continuity, their axes are shifted a little to one side or the other—of both of which conditions examples are seen in fig. 9. Extensions of the non-tubular substance from the septal bands of the spiral lamina over its intermediate substance are not uncommon; and it is stated by Mr. Carter (XXIII *a*, p. 321) that in *N. perforata* these extensions inosculate so as to form a minute reticulation all over the cameral spaces.

464. The interseptal portion of the "canal-system" of *Nummulina* bears a very close general resemblance to that of *Operculina*. In every septum (Plate XVIII, fig. 7, *f*) there seem to be at least two principal branches (seen in horizontal section at *f*, *f*, fig. 4, and in vertical section at *f′*, *f′*, fig. 8) which originate from the marginal cord of the previous convolution, and which converge as they pass outwards, and inosculate so as to form a network (fig. 7), some branches from which enter the marginal cord of their own convolution as shown in fig. 6. The marginal cord, however, somewhat differs in structure from that of *Operculina*. Although such a minute reticulation as that shown in the siliceous cast of *N. striata*,† represented in Plate XXII, fig. 6, may undoubtedly exist, yet the evidence of sections all tends to show that the marginal cord is usually penetrated by canals of a larger size, of which some run across it either radially or obliquely, whilst others traverse it in a longitudinal direction, the two sets occasionally inosculating, but not forming anything like a network. The radiating canals are well seen in vertical sections which divide the cord transversely (Plate XVIII, fig. 2, *a′*, *a′*); and their existence was pointed out by me in my former memoir, although I was not then aware of their import. Such sections also show the orifices of the large longitudinal canals which they divide transversely. The disposition of these canals is somewhat irregular; but generally there are found two passing in close proximity to each other along the inner edge of the cord, of which one is often brought into view in sections traversing the

* I cannot but feel surprised at the protest entered by MM. D'Archiac and Haime (p. 18), against the accuracy of the figure in my former memoir on *Nummulites* of which fig. 8, Plate XVIII, is a copy. Not only are those figures exact representations of a specimen in my possession, drawn by an artist (Mr. George West), whose accuracy in the delineation of subjects of this class cannot (I venture to say) be surpassed, but they are precisely paralleled as to this particular by several of the admirable figures in MM. D'Archiac and Haime's own Monograph; which show an equal continuity in the non-tubular columns (see especially plate iii, fig. 7, *c*, and plate iv, fig. 9, *d*). The theoretical objection drawn from the spiral plan of construction seems to me altogether without weight, when it is borne in mind how entirely destitute of any definite direction are the alar prolongations of the septa in Nummulites of the sinuate and reticulate types. I am strongly inclined to believe, from considerations based on the probable mode of formation of the tubular shells (§§ 59, 412), that the disposition of the alar prolongations of the septa will be governed in no small degree by that of the tubular and solid portions of the surface of the spiral lamina of the previous convolution, over which they extend themselves.

† It is worthy of note that this species belongs to the *radiate* group, which is most nearly allied to *Operculina*.

median plane (figs. 4, 6); and two more nearer to its outer edge, at a wider interval from each other. These last, which seem to be the representatives of the spiral canals in *Operculina,* sometimes lie close to the surface of the marginal cord, from which their outer walls form a projection, as shown in fig. 7; whilst in other instances they seem to be merely furrows in its surface of unusual depth, not covered-in externally, as has been noticed by MM. D'Archiac and Haime in *N. planulata* (I, p. 63, pl. ix, fig. 7), and by Mr. Carter in *N. Raimondi* (XXIII, *a*, p. 311, pl. xvii, fig. 15). All the longitudinal furrows with which the surface of the marginal cord is always strongly marked, are probably to be regarded (as in *Operculina,* ¶ 444) in the light of canals not completed into tubes by shell-substance; they seldom present that inosculation by transverse or oblique furrows which is often to be seen in *Operculina;* but the orifices of the radiating canals are very plainly to be distinguished in them in well-preserved specimens, especially when the surface of the marginal cord has been cleaned by dilute acid. It is evident both from vertical and from horizontal sections (figs. 2 and 4), that the radial canals which cross the marginal cord, and which establish a direct continuity between the interseptal system of each whorl and that of the succeeding whorl, constitute the most important feature of the canal-system; this communication being quite independent of the spiral canals, with which the radial canals here only incidentally inosculate. Thus the canal-system of *Nummulina* comes to bear a stronger resemblance to that of *Cycloclypeus* than to that of *Operculina;* the manner in which the interseptal systems of successive convolutions are brought into direct continuity with each other by the canals that cross the marginal cord, being almost identical in the two former cases (compare Plate XVIII, fig. 4, with Plate XIX, figs. 6, 7), whilst in the latter there is no such continuity, the "marginal plexus" of the cord itself affording all the means of communication that exists in addition to the spiral canals. Hence it seems fair to surmise that whilst in *Operculina* the growth is continuously spiral, the increase being effected by successive gemmations from the stolon that issues from the apertural fissure, the extension of large pseudopodial prolongations through the radial canals of the marginal cord may take a considerable share in the process in *Nummulina,* so that its growth may be partly radial, as in *Cycloclypeus:* especially since this indication harmonises in a remarkable degree with that which we have seen to be furnished by the occasional bifurcation of the spire (¶ 459).—Besides the radial and spiral canals, we find branches from the interseptal system proceeding towards the two lateral surfaces, usually either in the substance of the non-tubular columns (as shown at *c, c,* fig. 7) or in close contiguity to them. These branches, however, do not seem to attain the number and importance which they possess in some other instances. Other branches, again, occasionally extend themselves from the interseptal system over the intermediate portions of the spiral lamina, here again being surrounded by non-tubular substance; this, however, seems rather an abnormal than an ordinary distribution.—The interseptal system of canals is continued through the alar prolongations of the septa; and where these inosculate into a network, these canals form a complete reticulation surrounding the subdivisions of the chambers, as shown in fig. 3.

465. *Varieties.*—It will doubtless seem strange to such Palæontologists as have made a special study of Nummulites, and have not familiarised themselves with the wide range of variation that characterises the group to which they belong, for me to affirm that among all the reputed *species* of this type, I cannot satisfy myself that there are any which are entitled to a

higher rank than that of *varieties*. Taking the admirable monograph of MM. D'Archiac and Haime as a guide, and testing the value of their specific differentiations by the knowledge I have gained from the study of other types, and especially from that of *Operculina,* I find that these are nearly all based upon characters which I have found to be so inconstant as to be altogether fallacious. It is quite true that it would be a matter of no difficulty to pick out a series of well-marked types presenting respectively the *radiate,* the *sinuate,* and the *reticulate* arrangement of the septal prolongations, and characterised by great differences in figure and proportion; and under these types a large number of individuals might be unhesitatingly arranged. But each series of individuals thus grouped together under one designation will be sure to exhibit very considerable diversities; and with every increase in the number compared, especially when fresh specimens are brought from different localities, the range of these diversities will be found to increase, and doubts will hence arise as to the place of particular individuals, which mark the fallacy of any attempt to establish definite boundary lines between the groups in question. Referring to my detailed comparison of different varieties of *Operculina* (XV) as affording the chief basis of my conclusions on this point, I might here limit myself to the general statement that neither external form and proportions, the relative size of the primordial chamber, the number and breadth of the convolutions, the number of chambers in a convolution, the size and proportion of the chambers, the closeness with which the lateral surfaces of the earlier convolutions are embraced by those which succeed them, the degree to which the alar prolongations of the chambers extend themselves over the lateral surfaces, nor the amount of non-tubular shell-substance which forms columns and plates within, and shows itself on the surface in the granular tubercles or ridges with which it is occasionally marked,—form any sufficient justification, either separately or collectively, for specific differentiation. Nor, for the reasons already stated (¶ 462), can I attach any higher value to the course taken by the septal prolongations: since, although they serve to mark three primary types under which the numerous varieties may be distributed, they do not furnish characters of sufficient definiteness and constancy for that absolute differentiation which is required to satisfy the ordinary notion of a zoological species.—On this point I am happy to find myself in full accordance with Messrs. Parker and Rupert Jones, by whom the relations of the different forms of Nummulites have been studied far more systematically than they have been by myself (LXXVIII, LXXX *b*); their general conclusion being that "although it is expedient to have binomial terms at hand wherewith to name the more important varieties of *Nummulinæ,* recent and fossil, yet for the purposes of philosophical zoology, *Nummulina* may be recognised as a genus with but a single species, which, for our part, we should consider to be typified by *N. perforata.*" And it is obvious from Mr. Carter's recent investigations (XXIII *a*) that he, too, has been led to feel the impossibility of clearly defining the species of Nummulites.

466. *Affinities.*—It cannot be requisite again to point out in detail the very intimate nature of the affinity which exists between *Nummulina* and *Operculina;* indeed the difficulty lies in drawing a definite line of demarcation between them. For whilst in undoubted *Operculinæ* we occasionally find in the earlier whorls that the alar prolongations of the chambers extend themselves over the lateral surfaces of the included spire even to its centre, we often find in undoubted *Nummulinæ,* especially those of the radiate group, that the alar

prolongations of the chambers of the later whorls do not extend over the central portion of the earlier, but leave its spire exposed. This is the case with some of the largest existing *Nummulinæ*,—those of the Australian coast; between which and the *Operculinæ* of the same seas, there is a continuous gradation. And the closing-in of the last whorl in the adult, which is affirmed by MM. D'Archiac and Haime to be the characteristic distinction of *Nummulina*, can no longer be so regarded, when we find that not only does the same closure occasionally occur in *Operculina* (¶ 447), but that, in an indubitable *Nummulina*, the last whorl opens out as rapidly as that of the most widely spreading *Operculina* (¶ 456). The large "boss" of solid shell-substance which occupies the umbilical region on either side in many forms of the recent *N. planulata* (¶ 456), filling up the space which would otherwise be left by the non-advance of the alar lobes to the centre, exactly resembles that which we have seen in *Amphistegina*. Although the "reticulated" *Nummulinæ* differ widely from *Orbitoides* in their plan of growth, yet they present a marked approximation to that type in one character which is of considerable importance, namely,—the interposition of multiple flattened and isolated chamberlets between the successive lamellæ which intervene between the camerated median plane and the lateral surfaces. If Plate XVIII, fig. 10, be compared with Plate XX, fig. 1, it will be seen how strong a resemblance is thus imparted to the vertical sections of the two organisms; and if the condition of the segments of sarcode that occupy the reticulations into which the spaces between the spiral lamellæ are divided in *N. Garansensis* (Plate XVIII, fig. 3), be compared with that of the segments occupying the flattened polygonal chambers which are superposed one upon another in *Orbitoides Mantelli* (Plate XX, fig. 4), it will be seen that there is a strong similarity in the two cases. In fact it is difficult to conceive how these reticular spaces can be formed in *Nummulina* in any other way than the superficial flattened chambers of *Orbitoides*,—namely, by the extension of the sarcode from the tubes of the surface immediately subjacent, since their cavities are no less completely cut off from the chambers of the median plane in the former case than they are in the latter.

467. *Geographical Distribution*.—Notwithstanding the extraordinary development of the Nummulitic type within a comparatively recent geological period, it is now represented only by a small number of forms, all of them referable to the type *N. planulata*, occurring in arctic, temperate, and tropical seas, and for the most part of very humble dimensions. The biconvex variety found on our own coasts, *N. variolaria*, was first described as an existing Nummulite by Prof. Williamson (cx, p. 37); its diameter usually ranges between 1-12th and 1-16th of an inch. The tropical variety, *N. radiata* (the *Nautilus radiatus* of Fichtel and Moll, who obtained it from the Red Sea), attains on the Australian shores a diameter of 1-5th of an inch; while the diameter of its Philippine specimens,* of which the younger examples seem exactly conformable to the preceding, is increased in one direction by the spreading-out of their last whorl to more than 1-4th of an inch. This form belongs to the group with radiating septal lines, which presents

* This remarkable recent form of *Nummulina*, fully described by me (xv) under the erroneous designation *Amphistegina Cumingii*, whilst agreeing with the typical *Nummulinæ* in every essential particular, differs from them only in possessing a central boss of non-tubular substance like that of *Amphistegina*, and in the opening-out of its last whorl like that of *Operculina*.

the closest approximation to *Operculina;* and its relationship to that type is still more remarkably evidenced by the spreading-out of its last convolution.

468. *Geological Distribution.*—There is no fact in Palæontology more striking than the sudden and enormous development of the Nummulitic type in the early part of the Tertiary period, and its almost equally sudden diminution, bordering on complete extinction. The precise position of the immense beds of "Nummulitic limestone," the vast geographical extent of which has been already sketched (¶ 451), has been a subject of much discussion; but the researches of M. D'Archiac, Sir R. Murchison, Sir Charles Lyell, and others, leave no further doubt that these beds belong to the early part of the Tertiary period, and that they correspond in position with the "Calcaire Grossier" of the Paris basin, and with the "Bracklesham" and "Bagshot" beds of the London and Hampshire basins, in which deposits alone are Nummulites found in the British islands. Although Nummulites have been described as existing at periods anterior to this, it seems probable that such descriptions have been founded on the occurrence of other helicoid Foraminifera bearing an incomplete resemblance to them. What could have been the conditions which so specially favoured their production at the period in question,—which forced them (so to speak) to the attainment of a size so uncommon among Foraminifera,—which occasioned the development of such a multitude of varietal differences (some of these being limited to particular localities, whilst others present themselves in nearly all the regions in which Nummulites abound),—and which promoted and sustained the multiplication of individuals through a sufficiently long succession of ages to cause a vast thickness of solid rock to be formed of little else than their remains,* and what change in those conditions put a sudden and almost complete stop to these operations, constitute most interesting subjects for physiological and geological inquiry. Comparatively insignificant forms referable to *N. planulata* are the only examples of this type which can be traced into the later Tertiary strata; and these have continued to maintain themselves to the present time through changes which have proved fatal to their gigantic congeners.

Genus IV.—Polystomella (Plate XVI).

469. *History.*—Of the minute shells to which the generic name *Polystomella* is at present assigned, one species, now known as *P. crispa*, seems to have early attracted the attention of conchological observers and collectors, on account both of its beauty and of the frequency of its occurrence; having been described and figured more than a century ago by Plancus and Gualtieri, and adopted by Linnæus under the designation *Nautilus* into his 'Systema Naturæ.' By this designation it continued to be generally known from the time of Linnæus to that of Lamarck; having been described and figured by Walker, Soldani, Fichtel and Moll, Montague,

* I have found, by the examination of numerous thin sections of Nummulitic limestones, that the matrix wherein the entire Nummulites are embedded is chiefly made up of more minute specimens of the same types, and of comminuted fragments of the larger ones.

Dillwyn, and many other writers of the latter part of the last and the early part of the present century. By De Montfort, indeed, the examples of this type that had been described and figured by Fichtel and Moll were erected into no fewer than six new genera; neither of these, however, was adopted by any succeeding systematist, until Ehrenberg (XL) revived the name *Geoponus* long after the present designation of the genus had been fixed. Its dissimilarity to *Nautilus* was first clearly pointed out in 1822 by Lamarck, (LX) who conferred upon it the generic distinction *Polystomella*; and his definition of the genus was as follows:—"Coquille discoïde, multiloculaire, à tours contigus, non apparens au-dehors, et rayonnée a l'extérieur par des sillons ou des côtes qui traversent la direction des tours. Ouverture composée de plusieurs trous diversement disposés." By Blainville this type was described (VI) under the name *Vorticialis*; but Lamarck's designation was restored by M. D'Orbigny (LXIX), who, however, altogether misconceived the structure of the organism to which it was applied. The aperture, which had been but vaguely indicated by Lamarck, was described by D'Orbigny (LXX) as formed by "Ouvertures nombreuses, éparses, en bordure ou formant un triangle *à la partie supérieure* de la dernière loge, et se montrant encore ouverts dans les fossettes suturales des dernières loges;" he repeated (LXXIII, p. 121) the assertion that "L'animal fait sortir des filamens non seulement par des ouvertures du dessus de la dernière loge, mais encore par des pores des côtés des dernières;" and in his latest publication on the subject (LXXIV) he more concisely reaffirms the same error as follows:—"Coquille nautiloïde, pourvue de nombreuses ouvertures sur la dernière loge et sur les côtés de la coquille; une cavité simple au loges:"—notwithstanding that the true structure of *Polystomella crispa* had in the mean time been elucidated by Prof. Williamson in his admirable memoir on that species (CVII).—Subsequently to Prof. Williamson's memoir, an elaborate account of the characters of the genus *Polystomella*, and especially of a species designated *P. strigilata* (which is only one of the multiform varieties of *P. crispa*), has been given by Prof. Max Schultze (XCVII); who had the advantage of being able to study this organism in the living state, and has thus been enabled to give a beautiful figure, not merely of the shell, but also of the pseudopodia protruded from various parts of its surface, as well as to make preparations of the sarcode-body of the animal by dissolving away the shell in dilute acid. He does not seem, however, to have had the advantage of a full knowledge of Prof. Williamson's memoir, his acquaintance with it being apparently limited to the abstract of it contained in 'l'Institut' (No. 787); and he has not availed himself as fully as is desirable of the mode of examining the intimate structure of these minute objects by the preparation of very thin sections. In every point, in fact, in which he differs from Prof. Williamson, I am satisfied that the truth lies with the latter; and this not merely on account of the entire coincidence between the results of my own inquiries into the structure of *Polystomella crispa* and those of my accomplished predecessor, but also because our views are in every respect borne out by the structure of the much larger and more highly developed form of *Polystomella* which I am presently to describe.

470. As this type presents itself under a variety of forms, which differ not only in external features, but in internal structure, it will be desirable to give separate descriptions of two of its most characteristic examples, known as *P. crispa* and *P. craticulata*; the former of which is a common inhabitant of British and other temperate seas, whilst the latter, which is a

far more highly-developed organism, is met with in the seas of warmer latitudes, my largest specimens of it being those collected by Mr. Jukes on the coast of Australia.

471. POLYSTOMELLA CRISPA. *External Characters.*—The shell of *P. crispa* is usually lenticular in form, its edge being sometimes rounded, and sometimes carinated; its diameter is usually from 1-16th to 1-25th of an inch. Not unfrequently, especially in young specimens, short spines project at intervals from its margin. Only the last whorl of the spire is anywhere visible; this, however, does not extend as far as the centre, the umbilical region being occupied by a solid deposit of shell-substance, in which minute punctations can be distinguished. The septal bands, which are convex anteriorly, are very conspicuous, dividing the surface into well-marked segments. On the exterior of each of these segmental divisions, strong transverse crenulations present themselves, which are deepest near the convex margin of the preceding septal band, where they terminate somewhat abruptly, and usually disappear before reaching the concave margin of the subsequently-formed chamber. The depressions between the elevated ridges often present the appearance of orifices; but this appearance is fallacious, since at no period in the growth of the shell is there any passage through these depressions to the cavity of the chamber; the only communication which the system of spirally-disposed chambers possesses with the exterior. being afforded by a variable number of minute orifices which are to be found near the inner margin of the sagittate septal plane (Plate XVI, fig. 5, *c*), close to its junction with the preceding convolution. These orifices, however, are often discernible with difficulty from the exterior. When the surface of the shell is examined with a sufficient magnifying power, it is observed to be crowded with minute tubercles; and this tuberculated structure is often especially evident upon the septal plane, and in the rows of depressions between the segmental divisions. These tubercles often so strongly resemble apertures, that it is only when thin sections of the shell are examined under a variety of aspects, that their real nature is determinable with certainty; and some excellent observers (amongst others Prof. Schultze, XCVII) have been deceived into the belief that they are pores.

472. *Internal Structure.*—When the shell of *P. crispa* is laid open by a section passing through the median plane, it is found to consist of a small number of convolutions, somewhat rapidly increasing in breadth; and each of these convolutions is shown by a vertical section (fig. 5) almost entirely to enclose the preceding, the alar extensions of its segments being prolonged towards the centre, until they meet the solid umbilical nucleus. When the outer walls of the chambers are examined from within (which is readily done by crushing a specimen, and mounting the fragments in Canada balsam), a series of grooves are found to correspond with the elevated ridges of the outer surface: these grooves shallow towards the anterior or concave margin of each segment, and deepen towards the posterior or convex margin; and for a short distance from the posterior septum each groove is converted into a tube by a narrow lamella given off internally from the septum (Plate XVI, figs. 5, *k'*, *k'*). These tubes, however, establish no communication between the contiguous chambers; for they are *culs de sac*, closed-in by the lamella of the septum which formed the boundary of the previously-formed chamber. In the living state they are occupied (as is shown by examination of the decalcified body, Plate IV, fig. 28), by a set of processes *b*, *b*, of sarcode (see also Plate XVI, fig. 6, *k*), which extend

backwards for a short distance from both the outer or lateral margins of each segment of the sarcode-body, and then terminate abruptly. From the neighbourhood of the inner arch of each segment, on the other hand, there proceeds a series of threads of sarcode (fig. 6, *c*) much slenderer than the "retral processes" just described, which unite each segment to the two contiguous segments before and behind, passing through the row of pores already mentioned as visible along the inner margin of the septum. The substance forming the spiral lamina is finely tubular; but no such tubuli are discernible in the septa, which exhibit only the >-shaped rows of septal pores (fig. 5, *c*, *c*), whose number progressively increases with the dimensions of the septal plane, and indications of interseptal canals, *d*, *d*, which seem to resemble those of *Operculina* in their derivation from a pair of spiral canals whose transverse sections are seen at *e*, *e*. The solid umbilical deposit, *l*, *l'*, is traversed through its whole thickness by straight parallel canals proceeding directly towards the external surface, where their terminations form the punctations already mentioned.

473. Polystomella craticulata: *External Characters.*—The Australian examples of *P. craticulata* (Plate XVI, figs. 1, 2, A, B), are remarkable not only for their comparatively large dimensions (the diameter of some of the specimens in my possession exceeding one-sixth of an inch), but for the considerable proportion of their two lateral surfaces occupied by that solid calcareous nucleus which is confined in other forms to the umbilical region. The diameter of this nucleus is usually about three-fifths of the whole diameter of the specimen; so that it covers and conceals all the earlier convolutions, meeting at its outer margin the chambers of the last-formed whorl (as is made evident by vertical sections, fig. 3, *l l*, *l' l'*), which are consequently the only chambers that show themselves externally, although the last-formed whorl does not itself extend far over the preceding. I have not unfrequently found this umbilical nucleus, however, to be sufficiently transparent (after its surface has been cleaned by a short immersion in dilute acid) to allow of the inner convolutions being discerned through it, when the microscope is focussed down to their surface and a strong light directed upon this; and it then becomes obvious that, if the solid nucleus were removed, the form of the shell would be bi-concave instead of bi-convex (figs. 1, 3), the thickness of each whorl (*i. e.* the distance between its two lateral surfaces) being greater than that of the preceding, and the later whorls not extending themselves over those previously formed. The septa are marked externally by bands which indicate their junction with the outer walls of the chambers: these bands are meridional (so to speak) in their direction, extending from the margin of the nucleus on one side to that of the nucleus on the other side; they are not usually (in adult specimens at least) either elevated above or depressed below the surface of the walls of the chambers on either side of them; but they are distinguished by their difference of texture, their substance being much more transparent and glistening than that of which those walls are composed. The surface of the central nucleus is marked at pretty regular intervals with minute punctations (fig. 2, A), each of which occupies the centre of a little dimple or depression; and rows of similar punctations are very commonly seen to extend from the nucleus on either side, in a direction corresponding to that of the septal bands (fig. 2, B), two such rows usually intervening between each septal band and that which precedes or follows it (fig. 1, *hh*, *h'h'*). In the older portion of the last-formed whorl, it is sometimes to be observed that these punctations with their surrounding dimples constitute the only interruption to the

general uniformity of the surface, the septal bands not being clearly distinguishable ; and this disposition is commonly found to prevail on the surface of the inner whorls when it is exposed by the removal of the outer (*ii′*, *ii′*). In the newer portion of the last-formed whorl, on the other hand, we may observe that instead of each punctation having a separate dimple of its own, the corresponding punctations of the two rows lie in a succession of furrows that pass transversely between the septa (*gg′*, *gg′*). In the most recently formed portions of specimens that have not attained their full growth, we find these furrows to be deeper towards the posterior than towards the anterior margin of each interseptal space ; and in the deepest portion of each of these furrows, which obviously correspond with the depressions of *P. crispa* (although much less pronounced), a minute punctation may be brought into view by careful examination, a corresponding row of punctations being also traceable on the other side of the septum.* These varieties of superficial aspect may present themselves on different parts of one and the same specimen ; and it will appear from the explanations which I shall presently have to furnish, that they are occasioned by differences in the degree in which the proper external wall of the chambers is thickened by an exogenous deposit upon its surface, continuous with that of which the central nucleus is composed (¶ 476).

474. In studying the internal structure of *P. craticulata*, I have not been dependent only upon the information afforded by sections of the shell ; for I have had the opportunity, through the kindness of Messrs. Parker and Rupert Jones, of examining the beautiful siliceous "casts" which they have obtained by treating with dilute acid specimens whose cavities had been filled by an infiltration of silicate of iron. These casts (of one of which a somewhat diagrammatized view is given in Plate XVI, fig. 9) represent, with the utmost fidelity, the forms and connections of the various parts of the sarcode-body which occupied the cavities and channels of the shell in the living state of this organism ; and for the reason already mentioned (p. 10) they really afford us more information on those points than we could obtain from the decalcified body the animal itself. In the general shape and proportions of its segments, *P. craticulata* differs remarkably from *P. crispa* as from most other nautiloid Foraminifera ; the breadth of each of the later whorls being many times exceeded by the distance between its two lateral surfaces. Thus the segments come to have somewhat of the form and arrangement which the carpels of an orange would exhibit, if, instead of lying in a single circle round a central axis, they were disposed in a succession of whorls, with a progressive increase in their dimensions. This comparison may be conveniently carried a little further. For as each carpel of the orange has its own investing membrane, so that the partitions between the adjacent carpels are double, so each segment of *Polystomella* has its own proper shelly investment ; and further, as the separate carpels of the orange are collectively invested by a general integument, which also to a certain degree dips down between them, and which fills up what would otherwise be void spaces about the two poles of the spheroid, so are the proper walls of the spirally

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

arranged segments of *Polystomella* strengthened and consolidated by a secondary calcareous deposit upon their external surface, which constitutes a "supplemental skeleton" (¶ 63).

475. The dimensions of the central chamber in which the spire of *P. craticulata* commences are extremely variable; the difference between the extremes of its size being, in fact, not less remarkable than that which I have shown to present itself in *Orbitolites* (¶ 177). Thus in one specimen we may trace a progressive diminution in the size of the chambers as we approach the central chamber, which is itself no larger than the chambers in nearest proximity to it; whilst in another not only is the size of the earlier whorls and of their component chambers considerably greater than usual, but the central cell alone occupies about the same space as the first $2\frac{1}{2}$ whorls of the preceding. The average seems to be intermediate between these two extremes. The breadth of the successive whorls increases much more gradually than in most other nautiloid Foraminifera, in this respect resembling *Nummulina*; and there is no tendency whatever, even in the oldest and most developed specimens, to that rapid opening-out of the spire, which is so marked a feature of the older specimens of *Peneroplis*, *Operculina*, and *Heterostegina*. The largest number of whorls I have met with in any individual is *eleven*: the earlier four or five of these completely invest the preceding, their chambers extending on either side to the centre of the spire, as is partly shown in the vertical section (Plate XVI, fig. 3); but as new whorls are added around these, the chambers cease to be thus prolonged over the preceding whorls, which would consequently be apparent externally if not concealed by the nucleus. The distance between the successive septa remains nearly the same after the spire has made two or three turns; and thus the size of the segments as seen in an equatorial section remains pretty much the same throughout all the later growth of the shell, while the number of chambers in the successive convolutions increases nearly in proportion to the length of their gyration. The chambers of each whorl seem normally to alternate in position with those of the adjacent whorls; so that lines drawn from the centre of the spire through the septa of one convolution would pass through the middle of the chambers of the next, and would again meet the septa of the convolution beyond. This arrangement, however, is by no means constant, being very liable to be disturbed by that *interpolation* of additional chambers which is required for the augmentation of their number in successive whorls: it will presently be seen to be related to the peculiar disposition of the canal-system (¶ 479), which here acquires a remarkable development and importance.

476. Although, however, there is but little progressive increase in the dimensions of the successive chambers, and of the segments of the sarcode-body which occupy them, as seen in sections taken through the equatorial plane, it is made obvious by sections made at right angles to this (Plate XVI, fig. 3) that a rapid augmentation takes place in what may be termed the meridional direction; the distance between the two lateral surfaces of each whorl being considerably greater than between those of the preceding, so that the chambered portion of the shell progressively increases in thickness from the centre towards the circumference. The conical hollow thus left on each side in the central portion of the shell, is entirely filled up by the solid nucleus already adverted to: the calcareous deposit of which the nucleus is composed, however, is by no means limited to it, but extends over the whole

outer surface of each whorl, except where (in well-preserved specimens) the portion last formed is as yet unconsolidated by it. For a careful examination of sections taken in different directions makes it clear that whilst the internal portion of the spiral lamina that forms the outer wall of each chamber is continuous with the nearest lamella of the adjacent septum on either side (as is shown in the portion of fig. 1 which traverses the median plane), the substance of the external portion is no less continuous with that of the calcareous nucleus. The whole thickness of the spiral lamina formed by the coalescence of these two lamellæ is generally traversed by minute tubuli, passing in a radial direction from one surface towards the other; but these have by no means either the closeness or the regularity which distinguishes the tubular structure in *Operculina* and *Cycloclypeus*, and the shell-substance is in many parts so destitute of tubuli as to be of almost glassy transparence. The furrowing of the external surface (¶ 473) is seen in vertical sections not to be produced by mere superficial excavations, but to proceed from a plicated arrangement of the spiral lamina as shown in fig. 1; and this is related to the prolongation of the posterior margin of each segment into a series of "retral processes" (fig. 9, *k*, *k*), corresponding to those of *P. crispa* (¶ 175). They are, however, much less elongated in this type, simply giving a crenulated margin to that angle of the segment, which contrasts remarkably with the smooth unbroken aspect of its anterior border. The spiral lamina which forms the outer wall of the chamber, being modelled (so to speak) upon the surface of these retral processes, presents internally a corresponding series of grooves, which are deepest towards the posterior margin, and become rapidly shallower in passing towards the anterior margin, of each chamber, as is shown at a, a^1, a^2, fig. 8; these grooves are not, however, as in *P. crispa*, completed into tubes for part of their length by an additional lamella of shell given off from the septum (¶ 472); but they are sometimes shown, in sections which happen to traverse them, to be extended into cæcal prolongations by backward inflexions of the septa at their junction with the spiral lamina. The communication between the successive segments of the same whorl is established by a number of minute processes or *stolons* of sarcode (fig. 7, *c*, fig. 9, *c'*), which pass at regular intervals between their internal margins through a series of pores that can be distinguished along the inner border of each septum (fig. 1, *c*, *c*, *c*) close to its junction with the preceding convolution. I have not detected in any instance, either in sections of the shell or in the siliceous casts which so exactly represent the sarcode-body, any other communications between the chambers or their contained segments; and I am therefore satisfied that Prof. Max. Schultze must have been misled by appearances when he stated (XCVII, p. 65) that various other parts of the septal plane are marked by similar pores,—more particularly as his figures of the decalcified body do not show that any other threads or stolons of sarcode pass between its segments, than those just described.

477. So far, then, the structure of this comparatively gigantic type of *Polystomella* accords very closely with that of the more delicate species previously described. I have now, however, to give an account of a remarkable feature in its organization, namely, its highly developed *canal-system*; which, though not entirely wanting in *P. crispa*, is so imperfectly presented there that Prof. Williamson may well be excused for having overlooked it, especially when it is borne in mind that at that period the existence of such a system in Foraminifera was altogether unknown. The general arrangement of this canal-system may be most readily appre-

hended from an examination of the delineations of the internal casts given in Plate XVI, figs. 7, 9; for the infiltrating substance which has penetrated the chambers has also found its way not only into the main trunks, but also into the minute ramifications of this system, and has thus given just that representation of their distribution and relations, which is afforded in regard to the blood-vessels of the higher animals by a well-injected and clearly dissected anatomical preparation. We observe, in the first place, that in each of what may be termed the two polar regions of the spheroidal body, there is a continuous spiral canal (fig. 9, *e*, *e*, *e*), which overlies the extremities of the segments. These two spiral canals communicate with each other by a very regularly disposed series of canals (*dd′*, *dd′*), which pass in a meridional direction between the adjacent external margins of the segments. And each of these meridional canals gives off, in its course from one polar region to the other, a uniform succession of pairs of short passages (*f*, *f*) that diverge from each other widely, one series inclining backwards over the uniform anterior margin of the segment next behind it, whilst the other series passes forwards in the intervals between the "retral processes" of the segment next in front of it. The passages which thus diverge from the meridional canals of the outer whorl speedily debouch at its surface; but if we examine into the termination of those appertaining to the inner whorls (which is best seen in such fragments as the one represented in fig. 7), we find that they become continuous with the stolons of the whorl which surrounds them, as is shown at *c′*, *c′*, fig. 9. Further, it may be perceived that each of the meridional canals receives branches from the canal-system of the segment internal to it; this point, however, can be more clearly made out in sections of the shell.

478. The spiral canals are frequently brought into view for part of their course, by sections passing through the shell in a direction parallel to the equatorial plane but at no great distance from one of its lateral surfaces; and if such a section passes through the plane of the inner convolution of the spiral canal, it often shows that the spiral canal communicates towards its centre, with an irregular set of *lacunæ*, which are excavated in the deepest part of the solid umbilical nucleus. If, again, the plane of such a section is nearer to the lateral surface, the portion of it which passes through the solid calcareous nucleus is seen to be perforated by numerous apertures disposed at pretty regular intervals, and corresponding to the superficial punctations. The relation of these to the canal-system is clearly evidenced by vertical sections, such as that represented in fig. 3; in which we see at *e*, *e* the orifices of the spiral canals transversely or obliquely divided, whilst the solid calcareous nucleus (*ll*, *l′l′*) is itself shown to be traversed by straight canals, which spring from the successive convolutions of the spiral canal, and pass directly without branching or inosculation to the external surface. That this remarkable portion of the canal-system does not fully show itself in the "casts" represented in fig. 9, is easily understood, when it is remembered that the whole substance traversed by the straight canals having been removed, their long and slender casts would be left entirely without support; and the points at which these have been broken off from the cast of the spiral canal are in fact to be seen on a careful examination.

479. It is shown by the comparison of vertical and horizontal sections of the shell with fragments obtained by fracture (fig. 8), that the meridional canals (*d d′*, *d d′*) are in reality spaces left by the divergence of the two layers of which each septum is composed, in the

immediate neighbourhood of its junction with the spiral lamina constituting the external wall of the chamber; and that they are thus homologous with the arches of the interseptal system of canals that connect together the spiral canals of *Operculina* (¶ 445)—presenting, however, a much greater uniformity and constancy in their disposition. The diverging branches given off from these pass at once into the spiral lamina, beneath the ridges of the shell which intervene between the furrows for the lodgment of the retral processes, as seen in fig. 8; and through the thickness of the spiral lamina they run obliquely towards the external surface of the convolution, usually increasing in diameter as they proceed. The divergence of the branches of each meridional canal causes those proceeding from adjacent canals to approach one another; and when the spiral lamina has attained its full development they not unfrequently open at its surface into the same depression, this being midway between the septa from which they respectively sprang; and it appears to be from the correspondence of these junctions with the intervals between the segments of the succeeding whorls, that the alternating arrangement of the chambers of consecutive whorls arises, of which mention has already been made (¶ 475), the prolongations of sarcode which occupy the diverging branches there passing into the stolons which connect the adjacent segments. It will be easily understood, however, that the position of the external orifices of these diverging branches will depend upon the thickness of the spiral lamina which they have to traverse before gaining its surface. In the newest portion of a shell which has not yet attained its full growth, we find that lamina comparatively thin; its surface is distinctly marked by the septal bands (fig. 1, *gg' gg'*); and the external walls of the chambers present an alternation of ridges and furrows passing directly across from one septal band to another—the ridges corresponding to the grooves of the internal surface that receive the "retral processes" (¶ 476), and the furrows with the internal ridges that separate these grooves. Into these furrows, which represent the deeper "fossettes" of *P. crispa*, the diverging pairs of branches from each meridional canal open by minute pores on either side of the septal band, as is shown at *gg'*, *gg'*, fig. 1. The subsequent formation of a calcareous deposit, continuous with that which solidifies the umbilical portion of the shell, upon the external surface of the spiral lamina, renders the septal bands less distinct, and obliterates the ridges and furrows of the intervening surface, as is shown in the portion *h h'* of fig. 1; and at the same time it carries the orifices of the diverging branches from the neighbourhood of the septa into closer proximity with those of the branches proceeding from the adjacent meridional canals. As the diverging branches enlarge greatly in diameter with their augmentation in length, their superficial orifices become more and more conspicuous; each is surrounded by a little pit or depression of its own (fig. 1, *ii'*, *ii'*); and the rows of these depressions, when the spiral lamina has acquired its full thickness, constitute the only markings which it presents, the septal bands being completely obliterated,—as is best seen on the surface of one of the interior whorls exposed by the removal of that which covered it. The removal of the superficial portion of the spiral lamina, however, even when it is thickest (which may easily be accomplished by the assistance of dilute acid), brings back these orifices of the diverging canals to the immediate neighbourhood of the septal bands, which then again become apparent. It is obvious, therefore, that these depressions in the thickened portion of the shell of *P. craticulata*, being related only to the distribution of the canal system, are essentially different in character and position from the superficial depressions of *P. crispa*, which intervene between the ridges that cover-in the retral processes.

480. The meridional canals are further connected with the older and more internal portions of the organism, as well as with the newer and more superficial; this connexion being established by a series of branches that pass between the two layers of septa in a radial direction (as is shown on the septum b^3, fig. 1), from the meridional canals of each convolution to the stolons which unite the segments of that convolution. These, which may be distinguished as the converging branches, are, however, much less regular in their distribution than those which pass outwards from the meridional canals to the stolons of the succeeding whorl.

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

482. The two forms of *Polystomella* now described differ from each other simply in those particulars which mark degree of development, and which the experience of similar diversities elsewhere forbids us to account as of specific value, the general plan of structure being essentially the same in both. The excess of size and turgidity which distinguish *P. craticulata*, as compared with *P. crispa*, are not more remarkable than the like excess by which the large *Dendritina* of tropical seas is distinguished from the starved-out *Peneroplis* of the Mediterranean; and the extraordinary development of the supplemental skeleton with its related canal-system in *P. craticulata* loses its value as a differential character, when the series of intermediate forms is traced out, in which the superadded parts are gradually reduced to the rudimentary condition in which they present themselves in *P. crispa*. In these forms (which have been accounted distinct species by D'Orbigny and other systematists) we meet with various kinds of surface-marking, which are related (like the diversities already described, ¶ 473, in *P. craticulata* itself) to the varying amounts of calcareous deposit which have been added to the exterior of the spiral lamina. Other species, again, have been founded on the extension

of this exogenous deposit into solid prolongations radiating from the margin of the spire. I quite agree with Prof. Williamson (CX) in regarding all these as varieties of *P. crispa*, since the specimens collected on our own shores exhibit all the modifications by which they are severally distinguished, though in a less obvious degree. Certain of these varieties have a tendency to become partially unsymmetrical, one side being quite flattened and exhibiting the whole of the spire, but the septal plane and aperture being but little affected. This is especially the case with the *P. macella* (*Nautilus macellus* of Fichtel and Moll). It is one of these unsymmetrical forms which has been described by D'Orbigny (LXXIII) from the Chalk of Maestricht under the name of *Faujasina carinata*. For additional remarks on the reputed species of *Polystomella*, I may refer to the judicious criticisms of Messrs. Parker and Rupert Jones (LXXVIII).

483. There is a group of forms, however, in which we meet with a greater departure from the ordinary type of the genus; the crenulations of the shell and the retral processes of the sarcode-body lodged in them being altogether wanting, whilst the perforations in the septal plane, instead of forming a series of isolated pores, run together into a continuous slit or fissure along the margin of the included whorl, like that of *Operculina* and *Nummulina*. The transition to this sub-generic type, which has been distinguished by the generic designation NONIONINA, is effected by the interesting form which was originally described by Fichtel and Moll (XLV) as *Nautilus striato-punctatus*, and which has been described and figured by Prof. Ehrenberg (XL) from living specimens as *Geoponus stella-borealis*. This must be regarded as in all essential characters a true *Polystomella*; for, notwithstanding its minuteness as compared with the larger forms of that type, it presents in a most complete form the canal-system by which they are specially distinguished, a row of orifices of the diverging branches being conspicuous externally (in favorable specimens) on either side of each septal band; it has, moreover, a solid umbilical deposit, perforated by canals from which pseudopodia issue in its living state; its septal aperture, though sometimes a single fissure, is very commonly subdivided by transverse bars of shell into a row of isolated pores; and the whole shell is covered with an exogenous deposit in the form of tubercles or minute granules, a feature which is especially apparent in the variety distinguished by Schultze (XCVII) as *P. gibba*. Moreover we have frequently an indication in this form (which seems like a reduced copy of *P. craticulata*) of crenulations along the posterior margin of each of the segments marked out by the septal bands. The *Nautilus faba* of Fichtel and Moll is another transitional form between the typical *Polystomellæ* and the *Nonionine* group; of which last the *Nautilus asterizans* of Fichtel and Moll may be considered a typical example. This derives its name from the radiation of the exogenous deposits from the umbilical region along the septal bands; a feature which is still more pronounced in the *N. limba* of D'Orbigny (Modèles, No. 11), and which is curiously modified with flaps in his *N. stellifera* (V, plate iii, figs. 1, 2). The reputed species of *Nonionina* need a careful investigation to ascertain how far they are conformable to what has here been given (in conformity with the views of Messrs. Parker and Rupert Jones, LXXVIII) as the true "idea" of a form which has hitherto been so vaguely defined as to lead some systematists to propose the entire suppression of it as a generic type, whilst others (CX) have proposed to include in it *Operculina* and *Assilina*.

484. *Affinities.*—Although the typical *Polystomella* differs so remarkably from any other known form of Foraminifera, yet in those varieties in which its peculiarities are (so to speak) softened down, we trace an obvious affinity to the ordinary Operculine type. Thus in *P. crispa* the reduction of the umbilical deposit to what is little more than the large tubercle often presented by *Operculina*, the lenticular form of the shell as displayed in a vertical section, and the limited distribution of the canal-system, constitute one set of links; whilst in the *P. striato-punctata* another set is established in the suppression of the crenulations for the lodgment of the retral processes, and in the conversion of the cribriform aperture into a continuous slit. Thus we may regard *Polystomella* as a sort of offset from the Nummuline series; distinguished, in its highest evolution, by the extraordinary and very regular development of its canal-system, by the crenulations for the lodgment of the retral processes of the segments, by the excessive amount and peculiar disposition of the exogenous deposit which forms its supplemental skeleton, and by the substitution of a row of separate pores for the single continuous fissure. If, however, we carefully examine into the value of any of these characters as marking an absolute difference of type, we find that they are all gradational, and are in no instance all combined in the highest degree. Thus the approximation of the canal-system in *P. crispa* to the ordinary Operculine type makes it evident that the meridional canals which are so remarkable in *P. craticulata* and *P. striato-punctata* are really nothing else than the intra-septal arches of the canal-system in *Operculina* (¶ 445); and that the rows of diverging branches of the former correspond with the extension of the intraseptal system into the marginal cord of the latter, its peculiar modification being related to the marked difference in the disposition of the layer of exogenous substance, which in the one case completely invests the external surface of the shell, whilst in the other it is limited to a narrow marginal band. Again, the retral processes which constitute the most distinctive feature of the animal in *P. crispa*, and are lodged, not only in grooves but in tubes of its shell, are far less developed in *P. craticulata*, and are almost or completely suppressed in *P. striato-punctata*. The exogenous deposit, which is generally abundant in *P. craticulata*, is sometimes present in a comparatively small amount both in that and in other forms; so that its presence or absence affords no proof of essential distinctness. And the cribriform aperture gives place in the Nonionine modification of this type to the ordinary Operculine fissure. There is nothing, therefore, to forbid the idea that this diverging form may have been the result of gradual modification.

485. *Geographical Distribution.*—This genus has a world-wide range, representatives of it being found in all seas. The predominant form in the tropical ocean seems to be *P. craticulata*; in temperate seas it is *P. crispa*; and in the arctic zone it is *P. striato-punctata*. The *Nonionine* sub-type seems to prevail especially in temperate latitudes and in shallower seas than those frequented by the typical *Polystomellæ*.

486. *Geological Distribution.*—The only example of the typical *Polystomella* that has yet presented itself earlier than the Tertiary period is that described by D'Orbigny (LXXIII) under the name *Faujasina carinata* (¶ 482), which occurs in the Upper Chalk of Maestricht. With the Eocene period, however, this generic type seems to have become more widely diffused; as it occurs in the early Tertiary strata of various parts of the world, and abounds in many deposits of the middle and later Tertiary periods, its examples being espe-

cially numerous and varied in the Vienna basin and in the Sub-Apennine strata. The geological distribution of the *Nonionine* sub-type, so far as we certainly know at present, corresponds closely with that of the typical *Polystomella*: there are, however, some Foraminifera in the Carboniferous Limestone of Russia, described by Eichwald, that very much resemble *Nonionina*.

Genus V.—Heterostegina (Plate XIX, fig. 1).

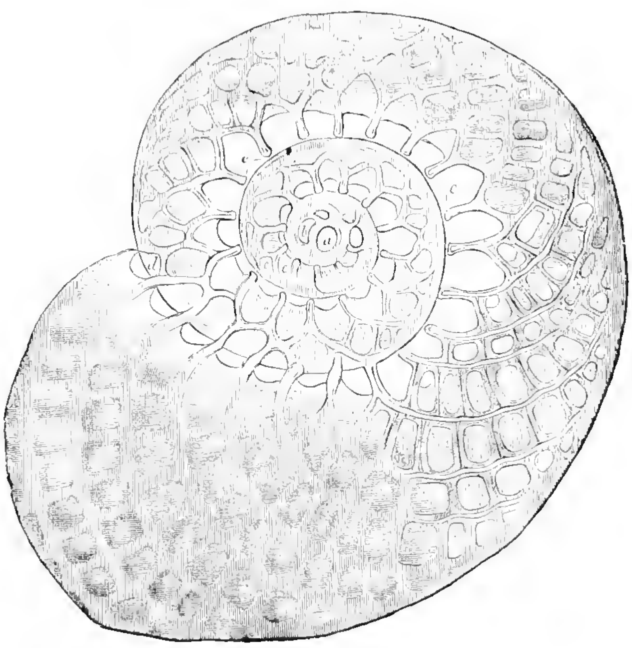
487. *History.*—Although the genus *Heterostegina* was established by M. d'Orbigny in his first systematic arrangement of Foraminifera (LXIX), its essential structure was altogether misapprehended by him, and has been misrepresented by others on his authority. Even in his latest classification (LXXIV) he continued to rank this genus in his order *Entomostègues*, placing it in close approximation to *Amphistegina*, from which he considered it to be chiefly differentiated by the subdivision of its principal chambers by transverse partitions. I have had the opportunity of examining, by the kindness of Mr. Cuming, a very extensive series of specimens of this type from the Philippine islands; many of these are of large size, attaining as much as half an inch in diameter; and the appearance of the adult specimens scarcely differs less from that of the young (which latter are alone figured by M. d'Orbigny), than it does in the case of *Orbiculina*. The dredgings of Mr. Jukes have furnished me with numerous specimens of *Heterostegina* from the Australian coast; these closely correspond with the figures of M. d'Orbigny, being of comparatively small size, and not exhibiting that peculiar mode of development which is characteristic of the adult; and as the Australian forms correspond precisely with the young of the Philippine, there can be no doubt of their specific identity. I recognise the shells of the same species as almost the sole components of a fossilized deposit, evidently belonging to the Tertiary epoch, which is very commonly met with in Malta in fissures of the rocks, but of which the precise age is uncertain.

488. *External Characters.*—The older specimens of *Heterostegina* (Plate XIX, fig. 1) present a form which, when regular, may be characterised as discoidal, and which is almost perfectly symmetrical; some degree of twisting, however, is almost constant in the larger specimens. There is a large umbilical tuberosity, somewhat excentrically placed, from which the turns of a spire are seen to commence; and the last of these becomes continuous with one part of the margin of the disk (*a*, *b*, *c*), which there possesses a thick and defined border. As this spire opens out, however, it becomes thinner and flatter; and this thinning is especially noticeable at that part of the margin of the disk (*a*, *d*, *c*) which corresponds with the opening of the spire. The whole surface of the disk, except the portion which is occupied by the umbilical tuberosity, is marked by septal bands, which follow one another at very small intervals, and are strongly curved with their convexity anterior. Not unfrequently these bands do not extend continuously across the convolution, but join themselves to other bands, so that the chamber included between them is more or less incomplete. Between each septal band and the one which succeeds it, the surface is marked by transverse lines,

disposed at pretty regular intervals; these are similar in appearance to the septal bands, and are indicative, like them, of subjacent partitions. The septal bands, and these transverse lines, like the septal bands of *Operculina*, may or may not be level with the general surface, being sometimes a little elevated above it, but being always most distinguished by the non-tubular texture of the shell, which causes them to present a glistening appearance under reflected light. Small spots of the same substance are occasionally to be seen, as in *Operculina*, in the interspaces between the septal bands; and the umbilical tuberosity sometimes has in its centre a large round spot of the same kind.

489. *Internal Structure.*—When we examine, by sections taken parallel to the surface and passing through the median plane (Fig. XLV), the structure and arrangement of that first-formed portion of the disk which is hidden beneath the umbilical tubercle, we see that, as in the helical Foraminifera generally, the first chamber (*a*) is globular, that the second (*b*) buds

Fig. XLV.



Section of *Heterostegina* through the median plane.

forth from one side of this, and that each successive chamber originates from the outer margin of the preceding, just as in *Operculina* or any other simple helical form. But before one turn of the spire is completed, each newly-formed chamber is seen to have a small portion divided off (as it were) by a transverse partition near the marginal part of the whorl, so as to consist of two chamberlets (*c*, *c*); just about the part where the second turn is completed, the gradual opening out of the spire gives room for the interposition of a third chamberlet in each row (*d*); and the number is soon further augmented in accordance with the progressive increase in the breadth of the spire and the width of the entire chambers, the dimensions of the individual chamberlets retaining a pretty close conformity to a constant average. The general plan, in fact, bears a very close resemblance to that of *Orbiculina* (¶ 139) or to that of the spirally-commencing variety of *Orbitolites* (¶ 180). The increase in the number of chamberlets in successive rows always takes place at the inner margin of the spire; some of those nearest the outer margin dying-out, as it were, without giving origin to new chamberlets in the next row. This may, I think, be connected with the fact, that there is always a free aperture (*e, e*) between one row of chamberlets and the next, at the inner margin of each spire (the situation of the aperture in *Operculina*), and that the chamberlet which abuts on the preceding whorl is nearly always much larger than the rest of the chamberlets in the same row, and gives origin to two or even three chambers in the next row. Further, it is shown by vertical sections (Fig. XLVII), that the innermost chamberlets of the whorl are not only deeper but broader, their lateral walls diverging from each other where they are to be continued over the spire they invest. Hence it is pretty obvious that this portion of the whorl is that wherein the most active increase takes place; and it is here that the marked accession to the number of chamberlets occurs, which tends to carry the later rows around the whole circumference of the spire, and thus to convert it into a disk, as in *Orbiculina* (¶ 136). After careful and repeated examination of a great number of sections, I have failed to detect any communication between the adjacent chamberlets of the same row. The chamberlets of successive rows for the most part alternate with each other in position; and each chamberlet seems, as a rule, to communicate (as shown in Fig. XLVI, *a, a*) with each of the two chamberlets against which it abuts at either extremity,

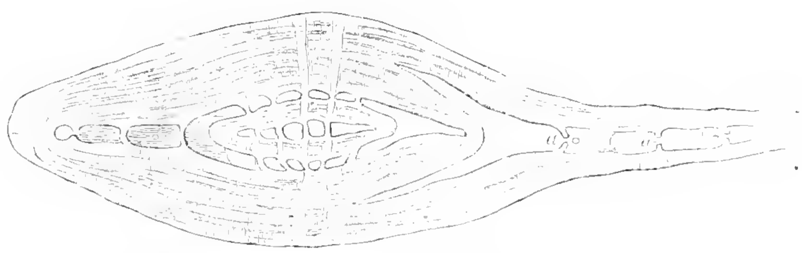
Fig. XLVI.

More enlarged portion of a section of *Heterostegina*, through the median plane: *a a*, communications between the chamberlets of successive rows; *b, b*, canal-system of the marginal cord.

in the manner to be more fully described in *Cycloclypeus* (¶ 496). Thus it would appear that each new chamber or row of chamberlets is formed by the independent gemmation of the segments of the preceding row; and hence it is easy to see why the formation of an incomplete row should be so much more frequent an occurrence in this type, than it is in those similarly-complex types in which a free lateral communication exists between the chamberlets. Each chamberlet is surrounded by its own proper wall, so that the septa which divide it both from the adjacent chamberlets of the same row, and from the chamberlets against which it abuts at its extremities, are all double. The latter (forming the septa between the principal chambers) are strengthened by the interposition of an additional deposit of shell-substance, forming an "intermediate skeleton;" but this is scarcely traceable in the former. There are distinct indications of a canal-system resembling in its general distribution that which is more fully developed in *Cycloclypeus* (¶ 498); and these are most obvious (Fig. XLVI, *b*, *b*) in the thickened marginal band, which resembles the "marginal cord" of *Operculina* (¶ 444), save in its much inferior development.

490. By examining a vertical section, such as is shown in Fig. XLVII, it is unmistakeably shown that the spire is perfectly symmetrical, and that each convolution not only surrounds but completely invests its predecessor. The investing whorl does not, in the younger part of the spire, come into immediate contact with the two surfaces of that which it includes, but is separated from it by alar prolongations of the chambers and of their septa, very much

Fig. XLVII.



Vertical section of a young *Heterostegina*, showing its symmetrical plan of growth: *a*, *a*, openings between the chamberlets of successive rows.

as in ordinary *Nummulinæ* (¶ 462), these alar prolongations showing little or no subdivision into chamberlets. But between the later whorls there are no such interspaces, and the successive laminæ come into absolute continuity with one another; both the tubuli and the cones of non-tubular substance being continued from each into the one external to it. From the time that the rapid thinning-away and opening-out of the spire commences, the investment of the previously formed whorls seems to discontinue; the spiral lamina of the last whorl being merely applied to the external margin of that of the penultimate (as in *Operculina*, ¶ 442), instead of being continued over its surface.

491. *Affinities.*—It is obvious from what has preceded, that *Heterostegina* bears precisely the same close relation to *Operculina* that *Orbiculina* bears to *Peneroplis*; the subdivision of the principal chambers into a row of chamberlets, by partitions extending transversely from each septum to the next, being the essential character of difference in each case. The relation of *analogy* between *Heterostegina* and *Orbiculina* is extremely striking; since in each type the earlier convolutions invest those which precede them, whilst the later extend themselves peripherally instead of centrally, and the mouth of the spire or "apertural plane" widens on each side so as to pass round (it may be) the whole circumference, and thus to

convert the spiral into the cyclical plan of growth. But the differences between these two types in regard to the texture of the shell, the mode of communication of the chambers and chamberlets, and the presence or absence of an intermediate skeleton and canal system, are such as most widely to separate them in any classification that is founded on characters of true physiological value. The affinity of *Heterostegina* to *Cycloclypeus* again, is extremely close; the conformity of these two types, as regards every point of minute structure, being complete; and their difference being precisely that which exists between *Orbiculina* and *Orbitolites*,—namely, that of the earlier plan of growth, which, in the former case, is spiral, with a tendency to the cyclical, whilst in the latter it is cyclical from the beginning. To *Amphistegina*, on the other hand, the relationship of this genus is very remote.

492. *Geographical and Geological Distribution.*—The genus *Heterostegina* is at present known only as an inhabitant of tropical and sub-tropical seas; having been found near various parts of the East Indian, Australian, Polynesian, and West Indian shores, but not in any colder latitude.—No other fossil examples of *Heterostegina* have yet been met with, than those which present themselves in the Vienna Tertiaries, in the Maltese deposit already adverted to, and in a limestone apparently of Tertiary age on the south-east coast of Arabia, in which Mr. Carter (XXIII *a*) has found *Heterostegina* together with *Orbitoides* and *Cycloclypeus*.

Genus VI.—Cycloclypeus (Plate XIX, figs. 2—7).

493. *History.*—This genus, first instituted by myself (XIV), is among the most interesting of all the Foraminifera at present existing, on account both of the large dimensions which it sometimes attains, and of the light which its structure throws upon that of various fossil types. The only specimens of it yet known were dredged by Sir Edward Belcher from a considerable depth of water off the Coast of Borneo. Two of these, which are now in the British Museum, are complete circular discs, measuring no less than $2\frac{1}{4}$ inches in diameter; and by the kindness of Dr. J. E. Gray I have had the opportunity of making microscopic sections of a fragment of a disk, which, when entire, must have nearly equalled these in size. Smaller disks of various dimensions presented themselves in the same dredgings.

494. *External Characters.*—The external aspect of these disks is sufficiently like that of *Orbitolites* to prevent the two genera from being readily distinguished by a superficial examination, especially when young specimens of *Cycloclypeus* are compared with *Orbitolites* of the complex type; since, on the two surfaces of the former (Plate XIX, fig. 2), there can be distinguished concentric rings of oblong chambers, which are not at all unlike the similarly disposed superficial cells of the latter. The peculiarly compact texture of the shell of *Cycloclypeus*, however, gives to its surface a smooth and glistening appearance, which is very different from that of *Orbitolites*; while the annular divisions and the radiating subdivisions are indicated not so much by any inequality of the surface (though they are usually somewhat

elevated), as by the substitution, along the septal lines, of the hyaline non-tubular shell-substance for that which is rendered opaque by its tubularity (¶ 58). And further, the forms of the two genera ordinarily differ in this—that whilst the centre of *Orbitolites* is usually rather depressed than elevated, and the thickness of the disk generally increases towards the periphery, the central portion of *Cycloclypeus* always presents a knobby elevation, on the surface of which the oblong boundaries of the chambers are superseded by rounded spots of non-tubular shell-substance (sometimes rising into tubercles), whilst the thickness of its disk gradually diminishes towards its margin, where it is so reduced as to come to a sharp edge. In older specimens of *Cycloclypeus*, the boundary markings of the chambers are scarcely distinguishable, save near the margin; their concentric annuli are marked out, however, by rows of spots resembling those of the central eminence, which will be presently shown (¶ 497) to be the bases of cones of non-tubular substance (fig. 5, *d*, *d*, *d*). In either case, it is usually observable that the breadth of the annuli is far from constant, and that the annuli are not unfrequently incomplete, extending round only a portion of the disk. This irregularity has been noticed in *Orbitolites* (¶ 171) as of rare occurrence; in *Cycloclypeus* it is so common that I have not yet met with specimens which are entirely free from it.

495. *Internal Structure.*—Whilst agreeing with *Orbitolites* in those external features which result from the *cyclical* mode of growth that is common to both forms, *Cycloclypeus* presents as wide a contrast to it in every other feature of its organization, as is anywhere known to exist within the limits of the Foraminiferous group. On making horizontal and vertical sections of the *Cycloclypeus* disk, its central plane is found to be occupied by chambers, disposed (ordinarily in a single layer) in concentric annuli; these are covered-in above and beneath by compact plates of shell, which are thicker towards the centre, thinner towards the circumference (Plate XIX, fig. 2). The typical form of these chambers seems to be a parallelogram with its angles rounded off, whose sides are to each other as $1\frac{1}{2}$ to 1, or as 2 or even 3 to 1, the longest side lying in the direction of the radius of the disk; but owing to the variation in the *length* of the chambers which results from the before-mentioned irregularity in the breadth of the annuli, the *breadth* of the chambers remaining more constant, their proportions vary greatly in different parts of the same annulus, or in adjacent parts of different annuli, as shown in fig. 7. I have occasionally met with chambers whose length was to their breadth as 4 to 1. The vertical thickness or height of the chambers seems usually to be pretty constant in different parts of the disk, except near its centre; the thinning away towards its margin being due, not so much to a diminution in the vertical height of the chambers, as to the reduction of the thickness of the shelly plates that enclose them above and below. But although the existence of only a single layer of chambers is obviously the rule in this type, yet exceptions to it are not unfrequent; a subdivision of the entire stratum into two or even three presenting itself when its thickness is above the average; whilst occasionally one or two chambers only are thus subdivided.

496. The cavity of each chamber is surrounded by a proper wall of its own, quite distinct from that of the chambers which it adjoins; and hence the septum by which each chamber is divided from the adjacent one on either side, is formed of at least two lamellæ. These come into close contact with each other at the junction of the vertical septum with the

horizontal roof and floor of the chamber; but elsewhere they diverge from one another, leaving an interseptal space, which is partly filled up by an interposed lamina of shell-substance, but is partly occupied by the *interseptal canals* to be presently described (fig. 5, *h*, *h*, *h*). A thicker space of the same kind is in like manner left between the proper walls of the chambers forming one annulus, and those of the chambers forming the annuli internal and external to it; this space is almost entirely filled up by a shelly deposit, the interseptal canals which pass between the successive annuli being less numerous than those which run between the chambers of the same annulus (¶ 498). This intervening deposit constitutes the "intermediate" or "supplemental" skeleton of this type. As in *Orbitolites*, the chambers of each annulus usually alternate in position with those of the annuli internal and external to it. But this is by no means constantly the case; since additional chambers are 'interpolated' here and there, so as to increase the number according to the augmented diameter of the annulus; and such an interpolation disturbs the regular arrangement of the neighbouring chambers. The adjacent chambers of the same annulus have not, so far as I have been able to ascertain, any direct communication with each other; an indirect communication, however, is perhaps established through the system of interseptal canals. But each chamber normally communicates with two chambers of the annulus within it, and also with two of that which surrounds it, by large passages (shown in horizontal section in fig. 7, *a b*, *a b*, *a b*, and in vertical section in fig. 5, *f*, *f*, *f*, and as seen in perspective view in fig. 5, *g*, *g*), which traverse the annular septa; of these passages there are generally two, and occasionally three, one placed directly or obliquely above the other, for each pair of chambers thus to be brought into communication. Thus at each extremity of the oblong chamber, there are normally two passages on one plane (fig. 6, *f*, *f*) leading to two chambers (*c*, *c′*, *d*, *d′*) in each of the annuli next internal or external to it; but since to each of these chambers there may be two or even three passages on different planes, the total number at each end may be four, five, or six. But since, on the other hand, each of the 'interpolated' chambers communicates with only one chamber in the annulus next internal to it, it will have but a single set of passages in place of two.

497. The shelly plates which enclose the chambered plane above and below, are formed of a succession of superimposed lamellæ (figs. 2, 5). These lamellæ, which are of tolerably uniform thickness, are most numerous in the older or more central portions of the disk, and diminish in number towards the marginal or last-formed portions; so that it seems pretty certain that new lamellæ must be added from time to time, as the disk is augmented by the formation of new annuli. I have often met with appearances which might seem to indicate that the formation of a new lamella over the entire surface of the disk, and the addition of a new annulus at its margin, were parts of one and the same act of growth, the new lamella being continued into the annular septum; but if this were constantly the case, the number of lamellæ which form the ceiling or floor of any chamber would always correspond with the number of annuli internal to it, which I do not find to hold good. Each of these lamellæ is perforated by an assemblage of parallel tubuli very closely set together, which pass from its inner towards its outward surface (figs. 3, 4); and there is such a continuity between the tubuli of successive lamellæ, that a communication is thus established between the cavity of the thickest-walled chamber and the external surface of the disk. These tubuli,

however, are very minute, their diameter being not above 1-10,000th of an inch. They are wanting in certain parts of the shell (*a*, *a*), which there presents a transparence that contrasts strikingly with the semi-opacity produced by the tubular perforations. By the comparison of vertical with horizontal sections taken in different planes, it appears that these non-tubular portions of the shell have a conical form, the base of each being on the surface of the shell, and its apex pointing to one of the angles at the outer margin of a chamber (fig. 5, *c c*, *d d*). Their gradual widening towards the surface causes the diameter of their bases to increase with every addition to the thickness of the shell; and thus it is on the older portion of the shell, and especially on its central protuberance, that they become most conspicuous as rounded spots, sometimes rising into tubercular elevations (¶ 494). In horizontal sections of the superficial lamellæ, they form a large proportion of the area; whilst in similar sections near the chambered plane they become blended with angular projections of the annular partitions, which fill up the spaces left between the proper walls of the chambers by the rounding-off of their angles (as shown in fig. 4). The lamellated structure is seen in these conical pillars (fig. 3, *a*, *a*), the lamellæ being continuous with those of the tubular part of the shell; so that at each increase in thickness a tubular and a non-tubular portion must be superimposed upon the corresponding parts of the preceding lamella. Both in the tubular structure of the shell, and in the presence of these non-tubular columns, there is an exact conformity to the structure of *Nummulina*, *Operculina*, &c.

498. I have now to speak of the system of *interseptal canals*, which is traceable throughout the whole of the solid skeleton, though less regularly distributed than in some of the preceding types. It may be conveniently described as consisting of *radial*, *vertical*, and *annular* canals. The *radial* canals are seen both in vertical and in horizontal sections (fig. 5, *h*, *h*; fig. 6, *g*, *g*,) excavated in the shelly substance which is interposed in the radiating partitions between the proper walls of adjacent chambers of the same annulus. When the canal reaches the end of the radial septum, it usually subdivides into two, which diverge at a considerable angle from each other, so as, by traversing the annular septum, to reach the two alternating radial partitions of the next annulus; and as each branch, before entering the partition (fig. 6, *i*, *i'*) towards which it runs, unites with another branch that inclines towards it from the radial canal next adjacent, it follows that just as every chamber communicates (normally) with the two alternating chambers in the annuli internal and external to it, so do the interseptal canals of every radiating partition communicate with those of the partitions alternating with it in the internal and external annuli. In each radial partition there are at least two, and very commonly three tiers of such canals, and sometimes they are yet more numerous (fig. 5, *i*). Short transverse branches, apparently communicating with the cavity of the chambers (fig. 6), are sometimes seen to proceed from the longitudinal canals; in regard to these communications I would not speak with confidence from what I have seen in *Cycloclypeus*; but that they exist in other organisms is unquestionable. The horizontal radiating canals communicate (as at *g'*, *g'*, fig. 6) with *vertical* canals, which pass directly towards the two surfaces of the disk, whereon they open; these canals are best seen in horizontal sections taken near the upper or under surface of the chambers (fig. 4), in which they present themselves in regular rows, *c*, *c*, corresponding to the radial partitions; whilst in similar sections taken nearer the surface they are seen to be less regularly disposed,

in consequence of their following a somewhat oblique direction. Still their continuity is maintained through all the successive layers of which even the thickest part of the shelly disk may be composed, and they open upon the surface along the borders of the septal bands or spots of non-tubular shell-substance (fig. 5, *e, e*). The *annular* system of canals traverses the thick band of shell-substance that usually intervenes between the successive annuli, and is continually brought into view in horizontal sections (fig. 6, *h h, h′ h′*). It appears from vertical sections traversing the annular septa, that several tiers of these annular canals may exist. I have frequently traced them running continuously for a considerable distance, without appearing either to give off any branches, or to communicate with the radial canals; but I have occasionally seen appearances which indicate that such a communication is established by means of canals passing vertically downwards at the angles of the chambers, so as to unite the three sets of canals into one continuous system, furnished with a multitude of orifices upon the surface of the disk. A representation of the whole canal-system, as I believe it to exist in this organism, is given in fig. 5.

499. *Monstrosities.*—Although the number of specimens of this type which I have had the opportunity of examining is but small, yet two among them exhibited the same kind of monstrosity as that which is common in *Orbitolites;* namely, the superposition of a vertical plate upon the horizontal disk (¶ 181). And in each it is sufficiently apparent that this plate has originated from the central cell, and that its increase has taken place *pari passu* with that of the horizontal disk.

500. *Affinities.*—There cannot be a better case than that which is afforded by the type under consideration, for testing the relative values of a classification based upon *plan of growth*, and of one based upon the *internal structure of the shell*, as affording the key to the natural affinities of an organism for which a place has to be assigned; and it will, therefore, be worth while here to review the principal facts relating to the structure of *Cycloclypeus*, and to compare them with those furnished by *Orbitolites* and its allies on the one hand, and by *Nummulina* and other members of the Nummuline series on the other. The sole point of resemblance between *Cycloclypeus* and *Orbitolites* consists in this—that the mode of growth is cyclical, the extension of the disk being effected by the formation of successive annuli, each of which is divided by radiating partitions into secondary chamberlets. But it has been shown that the lateral communication between the chamberlets of each annulus of the simple type of *Orbitolites* is so free, that the sub-segments of the animal body which occupy them are simply beaded enlargements of the continuous annular stolon that constitutes the principal segment; and that it is from the intermediate portions of that stolon, not from the sub-segments, that the radiating extensions issue which go to form a new annulus. In *Cycloclypeus*, on the other hand, the chamberlets of each annulus are completely cut off from direct communication with each other laterally, opening only into the chamberlets which lie next them in the central and peripheral directions; so that the adjacent sub-segments forming each annulus have no mutual connection, and their extension in a radial direction by means of the extensions they put forth will take place with entire independence, except as regards the coalescence of these radiating stolons after they have issued from the marginal pores.

This independence is strikingly manifested by the frequency with which incomplete annuli are added to the previous margin of the disk, extending (it may be) along not more than a third, a half, or two thirds, of the entire circumference. Thus the growth of *Cycloclypeus* is in reality rather *radial* than cyclical; the formation of concentric rings being simply due to the fact that the sub-segments occupying the last-formed annulus of chamberlets are for the most part ready to originate a new series of chamberlets at the same period. This restriction of the communication between the different parts of the sarcode-body, which is in such marked contrast with the extreme freedom that prevails throughout *Orbitolites*, is probably related to the circumstance that whilst the aggregate animal of the latter is nourished by the pseudopodia protruded through the marginal pores alone, each sub-segment of the former may imbibe its nutriment by pseudopodia passing through the tubuli of the walls of its own chamber (¶ 59). That these tubuli, notwithstanding their minuteness, serve for the passage of pseudopodia, and that these pseudopodia may coalesce on the exterior of the disk into a layer of sarcode forming a continuous investment of its surface, appears from the fact that successive laminæ are added to the *exterior* of the shell, the tubuli of which are continuous with those of the laminæ to which they are applied,—a fact which can scarcely be explained on any other supposition.

500. Thus, then, whilst in the isolation and independence of the subdivisions of its body, in the enclosure of each of them in its own proper wall, in the interposition of an intermediate skeleton and of a canal-system between the contiguous walls of adjacent chamberlets and annuli, and in the minutely-tubular structure of the shell,—all of them points of high physiological importance,—*Cycloclypeus* agrees with *Operculina* and other forms of the *Nummuline* type, its only point of accordance with *Orbitolites* or any member of the *Milioline* type is the subdivision of its principal segments into sub-segments, and the multiplication of these upon a plan which is essentially cyclical. But the subdivision in question is common, as we have seen, to *all* the principal types of Foraminifera; and we have already seen it presented in the *Nummuline* series by *Heterostegina*, the relation of whose chamberlets is exactly the same as that which exists in *Cycloclypeus*. The affinity between these two forms, in fact, is as intimate as that between *Orbiculina* and *Orbitolites* (¶¶ 143, 183), and is of precisely the same nature; for peripheral fragments of these two organisms could not be distinguished from each other; and the tendency of the later stages of growth in *Heterostegina*, as in *Orbiculina*, is to a change in the mode of increase, by the lateral extension of the growing margin, from the spiral to the cyclical.

501. *Geographical and Geological Distribution.*—We have at present no knowledge of the present existence of *Cycloclypeus* in any other locality than that already mentioned (¶ 493); and no other examples of it have yet been discovered in a fossil state than those stated by Mr. Carter (XXIII *a*) to occur in company with *Orbitoides* and *Heterostegina*, on the south-east coast of Arabia, in a white limestone apparently belonging to the early Tertiary epoch. The structure of one of Prof. Ehrenberg's "casts" (Plate XXII, fig. 5) is in every respect so conformable to that which would be presented by the body of *Cycloclypeus*, in regard to the communications between the segments and the interseptal system of canals (as

shown in Plate XIX, fig. 6*), as apparently to indicate the existence of this genus at the Nummulitic epoch to which these casts are to be referred; but, as will presently appear, this cast may not improbably represent a portion of the median layer of *Orbitoides*.

Genus VII.—Orbitoides (Plate XX).

502. *History*.—The genus *Orbitoides* was first instituted by M. D'Orbigny in 1847 for the reception of a peculiar fossil brought from the United States by Sir C. Lyell, who had noticed it ('Quart. Journ. of Geol. Soc.,' vol. iv, p. 12) under the name of *Nummulites Mantelli* previously conferred upon it by its discoverer Morton. I have not, however, been able to discover that M. D'Orbigny gave any definition of the genus previously to the publication of the second volume of his 'Prodrome de Paléontologie Stratigraphique' (1850), in which he characterises it by a portion of the description which he afterwards (1852) more fully gave in his 'Cours Elémentaire' (tom. ii, p. 194). It was then first that he instituted the order *Cyclostègues*, in which he ranked *Orbitoides* in sequence to *Cyclolina*, *Orbitolites*, and *Orbitolina*, distinguishing it from those genera by the following characters:—"Coquille discoïdale convexe des deux côtés, formée d'une seule rangée des loges autour du disque; test fortement encroûté extérieurement au milieu, et montrant soit des lineoles rayonnantes soit des granulations." Some time previously, however, I had given (xii) a nearly complete description of the *Orbitoides Mantelli*; and had further shown that a form of which small specimens had been previously described under the name of *Orbitolites Prattii* (probably the "*Discolithus*, iv, *a*," of Fortis), as well as the *Lycophris ephippium* and *L. dispansus* of Sowerby ('Geol. Trans.,' 2nd ser., vol. v, pl. xxiv, figs. 15, 16), were all referable to the same type. The genus has been adopted by Mr. Carter, who, however, in the first instance (xix), misconceived its true structure (affirming its mode of growth to be spiral instead of cyclical), and who now (xxiii *a* †) rejects from it the very type on which the genus was founded, referring it (on fallacious grounds, as I shall presently show) to the genus *Orbitolites*. The genus has also been adopted by MM. D'Archiac and Haime (i), and by Bronn (xi), who, however, re-names it *Hymenocyclus*, objecting to *Orbitoides* as a hybrid word.

503. *External Characters*.—It is impossible to discriminate *Orbitoides* from *Nummulina* by external characters alone; for although the most characteristic forms of each type cannot be mistaken for each other by any one who has familiarised himself with their respective

* The very close conformity of this somewhat diagrammatic representation to Prof. Ehrenberg's figure, might suggest the idea of its having been derived from the latter. But the former had been constructed by Mr. G. West, from specimens prepared by myself, long before the publication of Prof. Ehrenberg's researches.

† I think it well to state that Plate XX had not only been drawn, but printed, before I became acquainted with Mr. Carter's later researches.

aspects, yet specimens are often met with in which all distinctive features are so completely wanting, that nothing save an examination of their internal structure can enable their real nature to be determined with certainty. The typical form seems to be a flattened lenticular disk, as represented in Plate XX, fig. 1, which very closely resembles that of the thinner Nummulites, except in the relatively greater convexity of the central region,—in this respect corresponding closely with *Cycloclypeus* (Plate XIX, fig. 2). This convexity sometimes increases so remarkably that the central region becomes almost globular, whilst the peripheral thins-out and becomes almost flat, as in the form delineated by Sowerby (loc. cit.) as *Lycophris dispansus*. In other instances, on the contrary, the convexity of the central is not greater than that of the peripheral portion; the form being then so regularly lenticular as to afford no means of distinguishing such an *Orbitoides* from a Nummulite. Again, the disk, instead of being lenticular, may be nearly as flat as a piece of money, being commonly of the like proportionate thinness, but sometimes as thick as two or three ordinary coins laid one upon another; in either of these cases, however, there is usually a central tubercle that serves to mark the type; and the thinner forms are frequently reduced to extreme tenuity at their margin, whilst the margin of the thicker is abruptly rounded-off with little or no previous reduction. The thinner forms are often more or less contorted, and not unfrequently they assume a regularly ephippial shape, as in the *Lycophris ephippium* of Sowerby (loc. cit.). I am disposed to think that such contortion is due to the inequality of the surface to which the specimens were attached during life; for in a specimen from Biaritz kindly presented to me by Mr. S. P. Pratt, it was pretty evident that the organism had spread itself irregularly over a rock, after the manner of an incrusting Zoophyte.—The only surface-marking that can be distinguished, and this only in well-preserved specimens, is an irregular areolation, in the midst of which rounded tubercles of variable size are often disposed. These tubercles are sometimes of a more opaque white than the rest of the disk; whilst sometimes, on the other hand, they have an aspect of greater transparency. Not unfrequently they occupy the centres of groups of areolæ, which are quincuncially disposed around them, as is shown at *e*, *e*, fig. 2, Plate XX. In the smaller and thinner specimens they are most commonly absent, or, if present, they are comparatively few and insignificant. The presence of the tubercles alone would not serve to differentiate an *Orbitoides* from a *Nummulina*; but the areolation, when distinguishable, is a positive character, since nothing like it is ever presented even by the "reticulate" Nummulites.

504. *Internal Structure.*—The disk of *Orbitoides* essentially is composed (Plate XX, fig. 1) of a median plane of chamberlets arranged cyclically round a large central chamber; and of numerous layers of flattened chamberlets, having neither regularity of form nor systematic plan of arrangement, that are interposed between the multiple lamellæ of shell which enclose the median plane of chamberlets on either side.—Although the chamberlets of the median plane are disposed in concentric annuli, yet these annuli are often incomplete, as shown in Plate XX, fig. 1; thus bearing a much closer resemblance in arrangement to those of *Cycloclypeus* (¶ 499) than to those of *Orbitolites* (¶ 171). There is so decided and constant a difference as regards the form of the chambers between *O. Mantelli* and *O. Fortisii*, that, until such a gradational series of connecting links shall be discovered as unites the similarly

diversified varieties of *Orbitolites* (¶ 178), they must be retained as distinct species. The chamberlets of the former are nearly as cylindrical as are those of the simple type of *Orbitolites*, being sometimes slightly flattened against the margin of the annulus within, as shown in fig. 5, and sometimes rendered hexagonal by mutual pressure, as shown in the lower part of fig. 9. The chamberlets of the latter, on the other hand, are rectangular, and are generally considerably longer in the radial direction than they are in the tangential, as is shown in figs. 1, 3, 14; the proportion of these two dimensions, however, varies greatly in different annuli, and even in different parts of the same annulus, as I have shown to be the case in *Cycloclypeus* (¶ 495). The height of the chamberlets, that is to say, the thickness of the median layer, is no less inconstant than in the simple type of *Orbitolites* (¶ 157); sometimes being pretty uniform throughout the disk, especially in *O. Fortisii;* sometimes, on the other hand, increasing and sometimes diminishing from the centre to the periphery (see Plate XX, figs. 1, 7, 10, 11*).* The typical arrangement of the chamberlets in both species appears to be *alternate* in successive rows, as in other cyclical Foraminifera; but this arrangement, shown in figs. 3 and 5, is very often departed from. When examined with a sufficient magnifying power, the partitions between the chamberlets are seen (in well-preserved specimens) to be double, each chamberlet being everywhere surrounded by its own proper walls (figs. 3, 5); and indications of a canal-system are distinguishable in the interseptal spaces left between these. Each chamberlet normally communicates by oblique passages with two chamberlets in each of the adjacent annuli. These passages are shown at *a b*, *a b*, fig. 5, as they present themselves in sections that traverse the median plane of *O. Mantelli;* and it is observable that, like the two divergent passages which in like manner connect the columnar chambers in the complex type of *Orbitolites* (¶ 168), those of the same pair are not on the same plane, so that sometimes one of them is not brought into view by the section that displays the other. I have usually observed *three* pairs of such passages, one above the other, between each chamberlet and the two alternating chamberlets of the next annulus, as is shown in vertical section at *c*, *c*, fig. 6; and these seem to be the six "radiating sarcodal channels" described by Mr. Carter, (XXIII *a*, p. 330), of which he states that the orifices are distinguishable at the margin of the test, arranged in zigzag one above the other, as in the complex type of *Orbitolites*. Similar communications exist between the rectangular chambers of *O. Fortisii*, as represented at *c*, *c*, fig. 2, and as shown in the "cast" delineated in Plate XXII, fig. 5, which seems very likely, from its geological position, to belong to this type, to which it is referred by Professor Ehrenberg. I have not been able to distinguish in *O. Fortisii*, any more than in *Cycloclypeus*, any indication of lateral communications between the adjacent chamberlets of the same annulus; and Mr. Carter seems to have been equally unsuccessful. In *O. Mantelli*, however, such a lateral communication seems to exist close to the inner side of each chamber, as shown in fig. 5 and in the lower part of fig. 8; and along this it may be presumed that a continuous stolon of sarcode passed, like one of the annular stolons of

* By Mr. Carter it is affirmed (XXIII *a*, p. 329), that the chamberlets of *O. Mantelli* increase considerably in height from the centre to the circumference, whilst those of *O. Fortisii* (his *O. dispansa*) present no such increase. I cannot but think, however, that the examination of a larger variety of specimens would have caused him somewhat to modify this statement.

Orbitolites, so as to unite all the chamberlets of the same circle. If the "cast" represented in Plate XXII, fig. 3, be really that of an *Orbitoides*, it appears to afford a confirmation of this inference; for we there see annular stolons* passing along between the successive rows of sub-segments, on a different level from the radial peduncles, of which it will be seen that usually only one shows itself at each extremity of the sub-segment.

505. The shelly layer by which each of the lateral surfaces of the median disk is covered-in, is nearly always thickest in the centre, thinning away more or less gradually towards the margin, as shown in figs. 1, 7, 10, 11*. In some of those large, thick specimens of *O. Fortisii*, however, that occur in Scinde, in which the thickness of these superficial layers is very great in proportion to that of the median layer, there is little or none of such thinning-away towards the margin; and occasionally we find the margin itself to be covered-in by an extension of the outer portions of these superficial layers, which meet each other in such a manner as completely to enclose the median layer and the inner portions of the superficial layers, as is shown in fig. 15. This extension seems to mark the full growth of the disk, and may be considered analogous to the closing-in of the spire of *Nummulina*.—Each of these superficial layers is made up of a number of lamellæ, having inter-spaces between them, which are divided into flattened chamberlets by partitions formed by a thickening of the lamellæ, as shown in figs. 1, 2, 4, 6, 16. The form of these chamberlets is very irregular, as shown in fig. 4, in the upper parts of figs. 8, 9, and in figs. 12, 13, 14; it bears no relation whatever to the form of the chamberlets of the median disk; and there is no constant difference between the forms presented by *O. Mantelli* and *O. Fortisii* respectively, These chamberlets are usually much flattened in the direction parallel to the median plane, so that the thickness of many of them piled one on the other would not equal that of the chamberlets of the median disk, as in shown in *O. Mantelli* in fig. 6, and in *O. Fortisii* in fig. 16. But sometimes their height is considerably greater in proportion, and may equal, or even surpass, that of the chamberlets of the median disk, as in the specimen of which a vertical section is shown in fig. 11*. These chamberlets are usually arranged in piles, one upon the other, as is shown in figs. 2, 11, 16; and this arrangement seems to be peculiarly definite when the superficial layers are traversed by the cones of non-tubular substance presently to be described. The chamberlets forming any one of these piles usually alternate in level with those of the adjacent piles; and each of them communicates by a pair of oblique passages with two chamberlets, one lower and the other higher than itself, in each of the piles surrounding its own, as shown in figs. 2, 6, 11. These communications are seen also, as brought into view by a section parallel to the surface, in the upper part of fig. 9. The lamellæ of shell which form the floors and ceilings of these flattened chamberlets are themselves tubular, as shown in figs. 2, 4, 6. Their tubuli are not so minute or so closely set as those of *Nummulina*, *Operculina*, or *Cycloclypeus*; but they are much less coarse, on the other hand, than those of *Tinoporus*, the arrangement of whose piled chambers is almost exactly similar (¶ 394). This tubular structure (it seems desirable to mention) is often obscured, as in

* I am by no means certain that these are not really the representatives of annular *canals* passing along interseptal spaces, rather than of stolon-passages uniting the cavities of the chambers.

Nummulites, by the changes in the texture of the shell which have taken place in fossilization.

506. In both forms of *Orbitoides*, and not (as stated by Mr. Carter) in *O. Fortisii* only, we often find the superficial layers traversed by columns of non-tubular substance, which are of conical form, having their bases on the two surfaces (where they commonly form prominent tubercles), whilst their apices rest on the vertical partitions of the chambers of the median layer (fig. 2, *e*, *e*). These columns are most developed in the large, thick *O. Fortisii* of Scinde, in which they are both large and numerous (figs. 10, 11); and being usually rendered opake by peculiar changes in fossilization, they present the appearance, in sections parallel to the median plane, of opaque spots, *e*, *e*, figs. 12, 13, the diameter of which in proportion to that of the chamberlets varies according to the depth at which the section has passed, being of course greater as its plane is nearer to the surface. In the small, thin varieties of this fossil which present themselves abundantly in Southern Europe, the columns are frequently wanting altogether, and if present are very insignificant in size. In the American variety of *O. Mantelli* I have not met with any indication of the presence of these columns; but they are very conspicuous in some of the Scindian specimens of that type, although entirely absent in others,—this variation in their development being in harmony with the similar variation that occurs among Nummulites. The columns, when present, always occur at the points of junction of three or more of the partitions between the chamberlets, as is shown in figs. 2, 12, 13, 14, and may be regarded as formed by an augmented development of shell-substance at those points, as shown at *e*, *e*, fig. 16. When they are brought into view by vertical sections of thick specimens, it very often happens that they are only traversed by the plane of section for a part of their length, as shown in figs. 10, 15; but it must not be supposed that they really stop short, as they seem to do, since there can be no reasonable doubt of their continuity through the successive laminæ of the superficial layer, as shown in the lower part of fig. 10.

507. The indications of a canal-system which I have met with in *O. Fortisii* have been sufficient, when interpreted by the distribution of that system in *Cyclocypeus*, to justify the belief that it is essentially the same in the former case as in the latter. I have been able clearly to make out annular canals intervening between the successive rings of chamberlets, and cross branches connecting these which run between the two lamellæ of the partitions between the chamberlets, as shown in fig. 3; and I can also perceive indications (as in figs. 10, 11), that the conical columns were traversed by branches of the same system, which pass in them towards the surface. Even in the partitions between the superficial chamberlets I have been able to detect traces of canals (shown in the upper part of fig. 9), just as in the partitions that subdivide the alar prolongations of the chambers of the reticulate Nummulites. The interseptal canal-system of the median plane is nearly as well displayed in the "cast" represented in Plate XXII, fig. 5, as it is in my ideal figure of that system in *Cycloclypeus* (which was drawn without the least knowledge of Prof. Ehrenberg's casts); so that if the former really represents an *Orbitoides*, which there is no reason to question, the entire conformity in structure between the median chambered planes of these two organisms is extraordinarily close.—I have not succeeded in making out the canal-system of *O. Mantelli* with

the same distinctness. It seems to form a reticulation which includes each chamberlet in one of its meshes, as shown in fig. 5 and in the lower part of fig. 9; but I have not been able to satisfy myself of the existence of distinct annular canals.*

508. *Affinities.*—In the general plan of structure of *Orbitoides* we are reminded on the one hand of *Cycloclypeus* (Plate XIX, fig. 2), and on the other of *Nummulina* (Plate XVIII, fig. 9); for (as will be apparent on a comparison of the figures just referred to) if the superficial chambers of an *Orbitoides* were obliterated by the approximation of their laminæ, it would be converted into a *Cycloclypeus;* whilst, on the other hand, if its growth were spiral instead of cyclical, it would come to resemble one of those *Nummulinæ* in which the alar prolongations of the chambers have been broken-up into insulated chamberlets by the inosculation of their septa. This is much more than a mere superficial resemblance, such as exists between the arrangement of the chamberlets of the median plane in *Cycloclypeus* or *Orbitoides*, and that of the chamberlets of the disk of the simple type of *Orbitolites;* the affinity of *Orbitoides* to *Cycloclypeus* and to *Nummulina* being marked by its approximation to those types in all the characters which have been heretofore specified as of the most fundamental importance, such as the minutely tubular structure of the shell, the doubleness of the septa (each chamber possessing its own proper wall), and the interposition of a canal-system between their two lamellæ. In all these particulars it is equally removed from *Orbitolites*, with which it has nothing whatever in common save its cyclical plan of growth, and the mode of communication between the chambers of its median disk which appears to exist in *O. Mantelli.*† In the arrangement of the chamberlets of its superficial laminæ, *Orbitoides* is so closely related to certain forms of *Tinoporus* (Plate XV, figs. 3, 4), that if the chambers of the latter were more compressed vertically, and were more completely differentiated from those of the median plane, they would resemble those of *Orbitoides* in every essential particular save the want of a

* In the description of the canal system of *O. Mantelli* given by Mr. Carter (XXIII *a*, p. 330) there seems to me a confusion which I am unable to unravel, between the apertures which connect the cavities of the chambers and gave passage during life to stolons of sarcode that united the segments of the body, and the system of interseptal canals which has little connection with the cavities of the chambers, being confined to the spaces between the two lamellæ of their partitions.

† I must confess myself at a loss to understand the grounds on which Mr. Carter considers that *O. Mantelli* should be removed from this genus and placed in near proximity to *Orbitolites*, though he would no longer (as formerly) rank it with that type. There is absolutely no difference that I can discover between the *superficial* layers of the *O. Fortisii* and the *O. Mantelli;* the difference between the forms and proportions of the chamberlets of the median plane in these two types are clearly of not more than specific value, even if they amount to that; and if there should prove to be a lateral communication between the chamberlets of *O. Mantelli* which does not exist between those of *O. Fortisii*, and the canal-systems in the two types should prove to be distributed on distinct plans, such differences would assuredly not render necessary the generic separation of organisms which resemble each other so closely in all other respects. In approximating *O. Mantelli* to *Orbitolites*, it is clear that Mr. Carter has not appreciated the grounds on which *Orbitoides* and *Orbitolites* are placed, according to the plan of classification jointly adopted by Messrs. Parker, Rupert Jones, and myself, in two different primary divisions of Foraminifera.

canal-system. Of all existing Foraminifera, *Tinoporus* most approximates *Orbitoides* in the structure of its superficial laminæ, as *Cycloclypeus* does in that its median plane.

509. *Geological Distribution.*—This genus seems to have made its first appearance in the Maestricht Chalk, but to have been more fully developed in association with *Nummulina* in most of the localities in which that type attained its extraordinary predominance at the commencement of the Eocene period. Its smaller forms, chiefly belonging to the species *O. Fortisii*, present themselves abundantly in the Nummulitic limestone of the Western Pyrenees, in that of Northern Italy, and in that of the borders of the Black Sea; the larger and more developed examples of both species occur intermingled with Nummulites and Orbitolites in Scinde and other parts of northern India; but this type is found in the greatest abundance in the American Continent, the so-called "Nummulite limestone" of Alabama, which extends over an immense area in that state, being almost entirely made up of the remains of *O. Mantelli*. It occurs also in Madagascar, and is abundant in Jamaica, where it is associated with Nummulites.

Genus VIII.—Fusulina (Plate XII, figs .24—29).

510. *History.*—The genus *Fusulina* was instituted in 1829, by Fischer de Waldheim ('Oryctograph. Moscou,' p. 126), for the reception of a group of fusiform Foraminifera occurring in great abundance in the white Carboniferous Limestone of Russia. It was first adopted by D'Orbigny, in his palæontographical contribution to Sir R. Murchison's 'Geology of Russia,' and was subsequently associated in his systematic treatises (LXXIII, LXXIV) with *Nonionina* and *Nummulina*, to which he stated it to correspond in its single median fissured aperture, and in the absence of subdivision in its chambers, notwithstanding the close approximation which its form presents to that of *Alveolina*. By Prof. Ehrenberg, on the other hand, the most elongated forms of *Fusulina* were described and figured (XLII) under the name of *Alveolina*, whilst to the more globular forms he gave the name *Borelis*, which he adopted from Montfort (¶ 146); though it is not a little singular that among the specimens which he figured are internal 'casts' which very clearly indicate the Nummuline affinities of this type. Messrs. Parker and Rupert Jones (LXXX *a*) have associated *Alveolina* and *Fusulina* as allied, if not identical generic forms; but in so doing they have been misled, as I conceive, by a resemblance which is certainly more striking than D'Orbigny recognised between the plans of growth of these two types; whilst they have not given what I consider to be adequate value to the essentially Nummuline character of the aperture, which will be found to harmonise with the best information I have been able to obtain respecting the texture of the shell.

511. *External Characters.*—The ordinary form of *Fusulina*, well expressed by its name, bears a very close general resemblance to that of *Alveolina* (¶ 147); and, as in that genus, we find that it may, on the one hand, be elongated into a cylinder, or, on the other, be shortened to a prolate spheroid. The *F. hyperborea* of Salter ('Belcher's Arctic Voyage,' 1855, vol. ii,

p. 380), the *Borelis constricta*, Ehr., has been supposed to be differentiated by a constriction in the middle of its length; but this is only an occasional modification. When the shell can be sufficiently freed from its matrix for the characters of its surface to be distinguished, this is seen (Plate XII, fig. 27) to be marked out by parallel septal bands running in the direction of the axis, into a succession of segments of nearly uniform breadth; but these segments are not crossed on the surface, as they are in *Alveolina*, by regular and distinct secondary furrows, though there is sometimes an external indication of that subdivision of the principal chambers which will be shown to exist in the interior. The form of the septal plane (fig. 27, *c, c*) very closely corresponds with that of *Alveolina*, as it is comparatively narrow in the centre of its length, and spreads out widely at its extremities; but the nature of the aperture differs completely. For instead of a single or multiple series of pores extending along its entire length, we here find only a single slit-like fissure (fig. 27, *a*) limited to its middle region; the limitation of the communication between the successive elongated segments, and between the last of these segments and the exterior, thus contrasting very strongly with the freedom which we have seen to prevail in the segmental communications of *Alveolina*, whilst it closely corresponds with that which is characteristic of the Nummuline series.

512. *Internal Structure*.—In this, as in most other fossils of the Carboniferous Limestone, the ultimate texture of the shell has been so far altered by molecular change as to make it impossible to speak with certainty as to its character. But in several of the sections which I have made, I find an appearance (fig. 26) indicative of a porosity resembling that of the Nummuline and Rotaline shells; this appearance, so far as I can judge, having been produced by closely set, parallel tubuli, intermediate in diameter between the fine tubuli characteristic of the former group and the coarse pores usually seen in the latter. In the very numerous sections which I have made of *Alveolina* and other porcellanous Foraminifera, fossil as well as recent, I have never seen any appearance which at all corresponds to this; and I cannot but think it much more probable that it indicates a definite structure which has been in great degree altered by molecular change, than suppose that the homogeneous texture of a porcellanous shell has given place to one in which differentiation of some kind is so distinctly marked. The general structure of the interior of the most developed forms of this type will perhaps be best understood from the "cast" figured by Prof. Ehrenberg (XLII) from one of its simpler forms; for we see in this (fig. 24), an arrangement very like that which the segments of a simple Nummuline shell would present if their alar prolongations were to extend themselves on either side in a line with the body of each segment, instead of folding-in towards each other as they do in discoidal shells. The difference between this and the ordinary more complex type, of which sections are represented in figs. 25—29, consists essentially in this, that in the latter each of the elongated alar prolongations is broken up into a necklace-like series of sub-segments connected by a longitudinal stolon. In the transverse section taken across the median portion of the shell, represented in fig. 25, we see the spiral succession of the principal chambers, which are divided from each other by septa formed by the inflection of the external wall; these septa, which are composed of a single lamella, do not reach the surface of the penultimate whorl, but leave a fissured passage (*a*), through which the chambers communicate with each other (as is better seen at *a, a*, fig. 26), just as in the ordinary shells of the Nummuline type. The same transverse sections show the

separation of the principal chambers from their lateral extensions by the transverse septa (*c*, *c*), which are perforated close to the external side of the chambers, by the large, round, or oval apertures (*b*, *b*), for the passage of the longitudinal stolons. The alar extensions are themselves subdivided by similar septa, so that when they are laid open longitudinally, as at *d*, fig. 27, we see a succession of rounded chamberlets, connected by a continuous gallery, as is shown on a larger scale in fig. 27, *b*, *b'*. The chamberlets of successive chambers alternate with one another in position, as seen at *d*, fig. 27, and on a larger scale in fig. 28; and hence arises a peculiar appearance presented by sections, by which at first I was considerably perplexed. In fig. 29 it will be seen that whilst at *b*, *b* the stolon-passages open into the cavities of the chamberlets, they seem at *b'*, *b'* to lie between lamellæ of the septa, which separate to give them passage; but it becomes obvious, from a comparison of this figure with fig. 28, that whilst a section across the line *a a'*, will traverse the open cavity (*c*) of the chamberlets of one row, it will traverse the narrow gallery (*b'*) between the alternating chamberlets of the next row: and thus the apparent lamellæ are really two distinct septa, which here close together around the connecting stolon, but which presently separate again to form a chamberlet. The alar prolongations widen out greatly towards their extremities; and their secondary septa (as shown at fig. 27, *f*, *f*), instead of crossing them transversely to the axis of the shell, come to lie very obliquely to it, giving rise to a variation which is at first very perplexing in the appearances presented by sections dividing this part of the shell either transversely or longitudinally. The appearance of divarication between two septal lamellæ, for the purpose of giving passage to the longitudinal stolons, is here such (fig. 29, *b'*, *b'*) as very strongly to suggest the idea of a canal-system; but I am satisfied that this appearance is to be explained by the alternation already described as existing between the chamberlets of one row and those of the next: so that if we could trace onwards any one of these passages, it would be found immediately to open-out into a chamberlet. I have not been able to discover in this type any real indication of the existence of a canal-system.

Affinities.—It is not without hesitation that I have assigned to this type the position in which I have here placed it; Messrs. Parker and Rupert Jones having strongly expressed themselves (LXXX *a*), in favour of its intimate relationship to *Alveolina*. The balance of evidence, however, appears to me decidedly in favour of its Nummuline character: for although the tubularity of the shell cannot be certainly affirmed, yet it is very strongly indicated; and its indications are confirmed by the Nummuline character of the aperture, as well as by the very close conformity to the general structure of the Nummuline type, which is admitted by Messrs. Parker and Rupert Jones themselves to be presented by the simpler forms of *Fusulina*. It appears to me, therefore, that the relation of *Fusulina* to *Alveolina* is one of 'isomorphism' only, each type representing the other in its own series; and thus a very interesting parallelism is completed between the four principal plans of conformation which are presented by the higher types of the Porcellanous and the Vitreous series respectively:

	Porcellanea.	*Vitrea.*
Simple complanate spiral	Peneroplis.	Operculina.
Spiral, with the chambers subdivided into chamberlets . .	Orbiculina.	Heterostegina.
Cyclical, with annuli subdivided into chamberlets . .	Orbitolites.	Cycloclypeus.
Spiral with elongated axis, chambers subdivided into chamberlets	Alveolina.	Fusulina.

The apparent absence of a canal-system, and the ostensible singleness of the septal lamellæ, may be due to the molecular change to which the shell has been subjected; but even admitting them to be real, they do not negative the title of *Fusulina* to a place in the Nummuline series, since, as we have seen, the same characters of degradation are presented by *Amphistegina*.

Geological Distribution.—This type is not known to present itself in any other formation than the Carboniferous Limestone, occurring especially in that of Russia, a particular bed of which is in great part made up of vast accumulations of its fossilized shells; it occurs also in the same formation in the State of Ohio (North America, CIV), and in the Arctic regions.

APPENDIX.

The following Table exhibits the names assigned by Messrs. Parker and Rupert Jones to the species and varieties described and figured in Professor Williamson's 'Monograph on the Recent Foraminifera of Great Britain.' This nomenclature is founded on the principles set forth by those authors in their successive memoirs "On the Nomenclature of the Foraminifera" in the 'Annals of Natural History,' and adopted, with some modifications, in the present work. Their rule has been to retain the *specific* names assigned by the systematist by whom the *type* was first properly designated. Hence some of the names of types and varieties which have since been differently designated, are those assigned by D'Orbigny in his first memoir ('Ann. des Sci. Nat.,' tom. vii) to the forms delineated by Soldani, whose figures have been carefully collated. Another reason why some altered names appear, is because Messrs. Parker and Rupert Jones have been led by the wider range of their studies to adopt in several instances a different style of type from that furnished by the simple forms of the British Fauna surveyed by Professor Williamson; their aim having been to adopt those forms as types of species, which give a fair representation of all or nearly all the characters that seem properly to belong to each.

Plate.	Fig.	Names used in Prof. Williamson's Monograph.	Names now proposed.	
1.	1.	Proteonina fusiformis	Single joint (last) of Lituola nautiloidea, *Lamarck*, *var.* scorpiurus, *Montfort.*	
	2, 3.	— pseudospiralis	Lituola nautiloidea, *Lam.* (Feeble form.)	
	4.	Orbulina universa	Orbulina universa, *D'Orb.*	
	5.	Lagena vulgaris	Lagena levis, *Montagu.*	Type, Lagena sulcata, *Walker & Jacob.*
	6.	— — *var.* clavata		
	7.	— — ,, perlucida		
	8.	— — ,, —	L. semistriata, *Williamson.*	
	9.	— — ,, semistriata		
	10.	— — ,, striata	L. sulcata, *Walker and Jacob.*	
	11.	— — ,, interrupta		
	12, 13.	— — ,, gracilis	L. striata, *Montagu.*	
	14.	— — ,, substriata		
	15, 16.	Entosolenia globosa	L. globosa, *Montagu.*	
	17.	— *var.* lineata.	L. caudata, *D'Orbigny.*	
	18.	— costata	L. sulcata, *W. and J.*	
	19—21.	— marginata	L. marginata, *Montagu.*	
	22, 23.	— — *var.* lucida		
	24.	— ,, ornata		
	25, 26.	— — ,, lagenoides		
	27, 28.	— ,, quadrata		
	29.	— squamosa	L. squamosa, *Montagu.*	
	30.	— — *var.* scalariformis		
	31.	— — ,, catenulata	L. melo, *D'Orb.*	
	32.	— — ,, hexagona	L. squamosa, *Montagu.*	

Plate.	Fig.	Names used in Prof. Williamson's Monograph.	Names now proposed.	
II.	33—35.	Lingulina carinata	Lingulina carinata, *D'Orb.*	Type, Nodosaria raphanus, *Linn.*
	36—38.	Nodosaria radicula	Nodosaria longicauda, *D'Orb.*	
	39.	— pyrula	N. pyrula, *D'Orb.*	
	40, 41.	Dentalina subarcuata . . .	Dentalina communis, *D'Orb.*	
	42.	— — *var.* jugosa .	D. acicula, *Lamarck.*	
	43, 44.	— — ,, — . .	Nodosaria raphanus, *Linn.*	
	45.	— legumen	Vaginulina linearis, *Montagu.*	
	46—49.	— — *var.* linearis .	(Vaginulina linearis, *Montagu.*)	
	50.	Frondicularia spathulata . . .	Frondicularia complanata, *Defrance.*	
	51.	— Archiaciana. . .	F. Archiaciana. *D'Orb.*	
	52, 53.	Cristellaria calcar	Cristellaria rotulata, *Lamarck.*	
	54.	— — *var.* rotifer . .	(Cristellaria rotulata, *Lamarck.*)	
	55.	— — ,, oblonga . .	C. crepidula, *Fichtel and Moll.*	
	56—59.	— subarcuatula . .	(C. crepidula, *Fichtel and Moll.*)	
	60, 61.	— — *var.* scapha .	C. Italica, *Defrance.*	
	62.	— — ,, elongata	Marginulina lituus, *D'Orb.*	
	63.	— — ,, costata .	M. raphanus, *D'Orb.*	
	64—67.	— ,, — .	Planularia strigilata, *Reuss.*	
III.	68, 69.	Nonionina Barleeana	Nonionina umbilicatula, *Mont.* (*Var.* of N. asterizans, *Fichtel and Moll.*)	Type, Polystomella crispa, *Linn.* sp.
	70, 71.	— umbilicatula	N. depressula, *Walker and Jacob.* (*Var.* of N. asterizans, *F. and M.*)	
	72, 73.	— Jeffreysi	Lituola Canariensis, *D'Orb.* (*Var.* of L. nautiloidea, *Lamarck.*)	
	74, 75.	— elegans	Operculina ammonoides, *Gronovius.* (*Var.* of Nummulina planulata, *Lam.*)	
	76, 77.	Nummulina planulata	Nummulina planulata, *Lamarck, var.* radiata, *Fichtel and Moll.*	
	78—80.	Polystomella crispa	Polystomella crispa, *Linn.*	
	81, 82.	— umbilicatula . . .	P. crispa, *Linn., var.* striato-punctata, *F. & M.*	
	82A.	— — *var.* incerta.	(P. crispa, *Linn., var.* striato-punctata, *F. & M.*)	
	83—85.	Peneroplis planatus	Peneroplis planatus, *F. and M.*	
	86—89.	Patellina corrugata	Patellina corrugata, *Williamson.* (*Var.* of P. concava, *Lamarck.*)	
IV.	90—92.	Rotalina Beccarii	Rotalia Beccarii, *Linn.*	
	93, 94.	— inflata	Trochammina inflata, *Montagu.* (*Var.* of T. squamata, *Parker and Jones.*)	

Plate.	Fig.	Names used in Prof. Williamson's Monograph.	Names now proposed.
	95—97.	Rotalina turgida	Nonionina asterizans, *F. & M.*, *var.* turgida, *Williamson.* (Type, Polystomella crispa, *Linn.*)
	98—100.	— oblonga	Pulvinulina auricula, *F. and M.* (*Var.* of P. repanda, *F. and M.*)
	101—103.	— concamerata	Pulvinulina repanda, *F. and M.*
	104, 105.	— — Young . .	Discorbina turbo, *D'Orb.*, *var.* globularis, *D'Orb.*
	106—108.	— nitida	Rotalia Beccarii, *Linn.*, *var.* nitida, *Williamson.*
	109—111.	— mamilla	Discorbina turbo, *D'Orb.*, *var.* rosacea, *D'Orb.*
	112.	— ochracea	Discorbina turbo, *var.* ochracea, *Williamson.*
V.	113.	— —	
	114, 115.	— fusca	Valvulina triangularis, *D'Orb.*, *var.* Austriaca, *D'Orb.*
	116—118.	Globigerina bulloides	Globigerina bulloides, *D'Orb.*
	119, 120.	Planorbulina vulgaris	Planorbulina farcta, *F. and M.*, *var.* Mediterranensis, *D'Orb.*
	121—123.	Truncatulina lobatula	Truncatulina lobatula, *W. and J.* (*Var.* of Planorbulina farcta, *F. and M.*)
	124, 125.	Bulimina pupoides	Bulimina Presli, *Reuss*, *var.* pupoides, *D'Orb.*
	126, 127.	— — *var.* marginata .	B. Presli, *Reuss*, *var.* marginata, *D'Orb.*
	128.	— ,, spinulosa .	B. Presli, *Reuss*, *var.* aculeata, *D'Orb.*
	129, 130.	— ,, fusiformis .	B. Presli, *Reuss*, *var.* ovata, *D'Orb.*
	131.	,, compressa .	Virgulina Schreibersii, *Czjeck.* (Type, Bulimina Presli, *Reuss.*)
	132, 133.	— ,, convoluta .	B. Presli, *Reuss*, *var.* convoluta, *Williamson.*
	134, 135.	— elegantissima	B. Presli, *Reuss*, *var.* elegantissima, *D'Orb.*
	136, 137.	— arenacea	Verneuilina polystropha, *Reuss.* (Type, Textularia agglutinans, *D'Orb.*)
	138, 139.	Uvigerina pygmaea	Uvigerina pygmaea, *D'Orb.*
	140.	— angulosa	U. pygmaea, *D'Orb.*, *var.* angulosa, *Williamson.*
VI.	141, 142.	Cassidulina laevigata	Cassidulina laevigata, *D'Orb.*
	143, 144.	— obtusa	C. laevigata, *var.* crassa, *D'Orb.*
	145.	Polymorphina lactea	Polymorphina lactea, *W. and J.*, *var.* compressa, *D'Orb.*
	146, 147.	— —	P. lactea, *Walker and Jacob*
	148.	— — *var.* acuminata .	P. lactea, *varieties.*
	149.	— — ,, oblonga .	
	150.	— — ,, fistulosa .	P. lactea, *var.* tubulosa, *D'Orb.*
	151, 152.	— ,, concava .	
	153—155.	— ,, communis .	P. lactea, *varieties.*
	156, 157.	— myristiformis . .	
	158, 159.	Textularia cuneiformis	Textularia sagittula, *Defrance.* (Type, T. agglutinans, *D'Orb.*)
	160, 161.	— — *var.* conica .	T. trochus, *D'Orb.* (Type, T. agglutinans, *D'Orb.*)
	162, 163.	— variabilis	T. agglutinans, *D'Orb.*, *var.* variabilis, *Williamson.*
	164, 165.	— — *var.* spathulata	T. agglutinans, *D'Orb.*, *var.* pygmaea, *D'Orb.*
	166, 167.	— — ,, difformis .	T. agglutinans, *D'Orb.*, *var.* difformis, *D'Orb.*

Plate. Fig.	Names used in Prof. Williamson's Monograph.	Names now proposed.	
168.	Textularia variabilis *var.* levigata .	T. agglutinans, *D'Orb.*, *var.* variabilis, *Williamson.*	
169—171.	Biloculina ringens	Miliola seminulum, *Linn.*, *var.* ringens, *Lam.*	
172—174.	— — *var.* carinata .	Biloculina compressa, *D'Orb.*	Type, Miliola seminulum, *Linn.*
175, 176.	— — „ Patagonica. .	B. elongata, *D'Orb.*	
177.	Spiroloculina depressa . . .	Spiroloculina limbata, *D'Orb.*	
178.	— — *var.* rotundata.	Sp. complanata, *Lamarck.*	
179.	— — „ Cymbium	Spiroloc. canaliculata, *D'Orb.*	
180—182.	Miliolina trigonula	Triloculina trigonula, *Lamarck.*	
183—185.	— seminulum . . .	Miliola seminulum, *Linn.*	
186, 187.	— — *var.* oblonga .	Triloculina oblonga, *Montagu.*	Type, Miliola seminulum, *Linn.*
188, 189.	— „ disciformis	Quinqueloculina secans, *D'Orb.*	
190—194.	— bicornis	Quinqueloculina bicornis, *W. and J.*	
195.	— — *var.* elegans .	Triloculina Brongniartii, *D'Orb.*	
196.	— — „ angulata .	Quinqueloculina Ferussacii, *D'Orb.*	
197, 198.	Vertebralina striata . . .	Vertebralina striata, *D'Orb.*	
199—201.	Spirillina foliacea	Cornuspira foliacea, *Phillippi.*	
202.	Spirillina perforata	Spirillina vivipara, *Ehrenb.*	
203.	— arenacea	Trochammina squamata, *P. and J.*, *var.* incerta, *D'Orb.*	
204.	— margaritifera . . .	Spirillina vivipara, *Ehrenb.*, *var.* margaritifera, *Williamson.*	

CORRIGENDA.

Page 17, lines 15 and 20, and page 21, line 21, for RETICULOSA read RETICULARIA.

Page 18, *note*. The author has been informed by Prof. Kolliker that he did not employ the term "nucleus" in its technical signification, but that by the terms "cortical" and "nuclear" substance he meant only what is described in the text as "ectosarc" and "endosarc."

Page 53, line 20, the words "the duplication of the septal partitions" to be omitted; the author having found since writing them that this structural feature is limited to the higher types of the hyaline Foraminifera, instead of being common (as he at first believed) to the whole series.

Page 105, last five lines. In here stating *Cycloline* to be a variety of *Orbitolites*, the author was misled by Mr. Carter, who had described under the name *Cyclolina* a fossil which (as he has since discovered, p. 230, *note*) does not really accord with D'Orbigny's type of that genus. Mr. Carter's *Cyclolina* is a true *Orbitolites*, as stated in § 186; but D'Orbigny's *Cyclolina* is probably a *Patellina* (p. 233). Further, of the forms to which D'Orbigny's designation *Orbitolina* has been applied, a part seems referable to the genus *Tinoporus*, and another part to *Patellina*, as explained in the account of those genera.

Page 171, line 7, for "ENALLOSTÈGUES" read "ENTOMOSTÈGUES."

Page 191, line 8 from bottom, for "*Bigerina*" read "*Bigenerina*."

Page 198, line 5, for "plan" read "plane."

Page 201, line 2 of explanation of Fig. XXXII, for "Montague" read "Montfort."

Page 202, line 1 of § 347, for "genus" read "group."

Page 207, line 7 of § 359, for "20" read "201."

Page 215, line 1, for "it is neither abundant nor of more than half its ordinary size," read "although abundant, it is not of more than half its ordinary size."

Page 229, line 1 of § 402, for "*Geographical*" read "*Geological*."

Page 232, line 1 of explanation of Fig. XXXVII, for "*lenticularis*" read "*concava*."

INDEX.

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EXPLANATION OF THE PLATES.

PLATE I.

In this Plate is represented a series of typical forms of RHIZOPODA, chiefly belonging to the Orders LOBOSA and RADIOLARIA.

FIG.

1.—*Actinophrys sol,* with its radiating pseudopodia; *v,* contractile vesicle. (After Claparède.)

2.—*Actinophrys sol,* in the act of engulphing a Vorticella, *a*: at *v* is seen the contractile vesicle. (After Weston.)

3.—*Actinophrys sol,* in the act of nearly completed self-division (or incipient conjugation?); *v, v,* two contractile vesicles. (After Weston.)

4.—*Actinophrys sol,* in an earlier stage of self-division (or more complete conjugation?); *v, v,* two contractile vesicles. (After Claparède.)

5.—*Euglypha alveolata.* (After Dujardin.)

6.—*Plagiophrys cylindrica.* (After Claparède.)

7.—Central portion of *Acanthometra tetracopa.* (After Müller.)

8.—Central portion of the siliceous framework of *Acanthometra echinoides*; *a,* furrowed entrance to the canal of one of the rays. (After Claparède.)

9.—*Haliomma hexacanthum.* (After Müller.)

10.—*Sphærozoum punctatum*; at *a, a* is seen the gelatinous investment in which are imbedded the spheroidal bodies *b, b.* (After Müller.)

11.—One of the spheroids of *Sphærozoum punctatum* more highly magnified, showing its spicular framework. (After Müller.)

12.—*Thalassicolla morum.* (After Müller.)

13.—One of the spicules of *Thalassicolla morum.* (After Müller.)

14.—Siliceous test of *Collosphæra Huxleyi.* (After Müller.)

15.—*Amœba radiosa,* under four different forms, A, B, C, D; *n,* nucleus. (After Auerbach.)

16.—*Amœba princeps,* under three different forms, A, B, C. (After Auerbach.)

17.—*Amœba bilimbosa,* under two different forms, A. B; *n,* nucleus. (After Auerbach.)

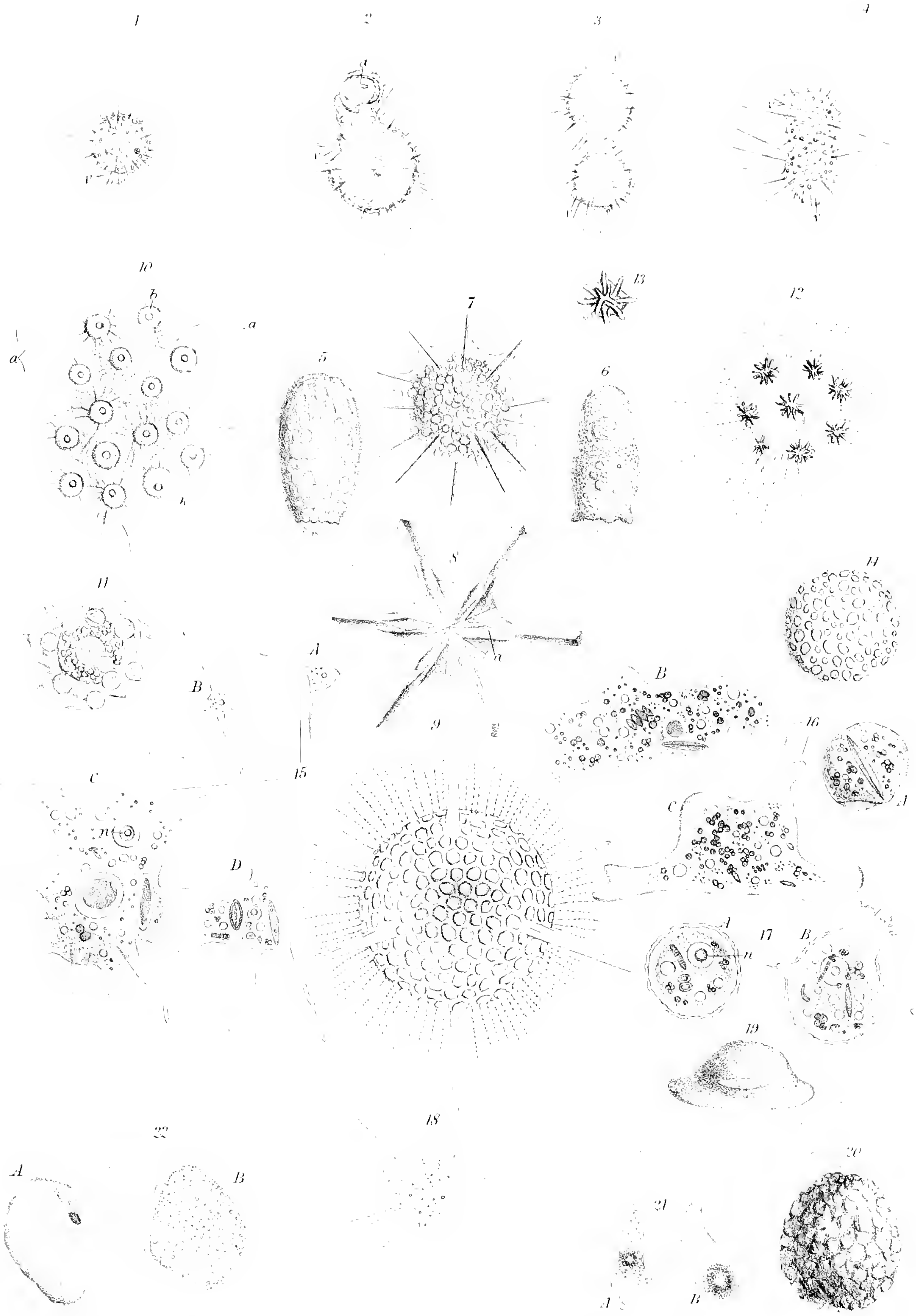
18.—*Amœba* (?) *porrecta.* (After Schultze.)

19.—*Arcella vulgaris.* (After Ehrenberg.)

20.—*Difflugia globulosa.* (After Ehrenberg.)

21.—*Lagynis baltica,* with the animal expanded at A, and retracted at B into the posterior extremity of the test. (After Schultze.)

22.—*Squamulina lævis*; A, its attached surface; B, its free surface, showing its oral aperture and the pseudopodia extending themselves from it. (After Schultze.)



FIGS 1–6. ACTINOPHRY[illegible] [illegible] 8. ACANTHOMETR[illegible] [illegible] [illegible] 10–14. THALA[illegible]
15–20. AMŒBINA. 21. LAGYNIS. 22. [illegible]

PLATE II.

This Plate represents *Lieberkühnia Wageneri*, the naked type of the Order RETICULARIA, with its pseudopodia extended to no more than a third of the proportional length they often exhibit. (After Claparède.)

PLATE III.

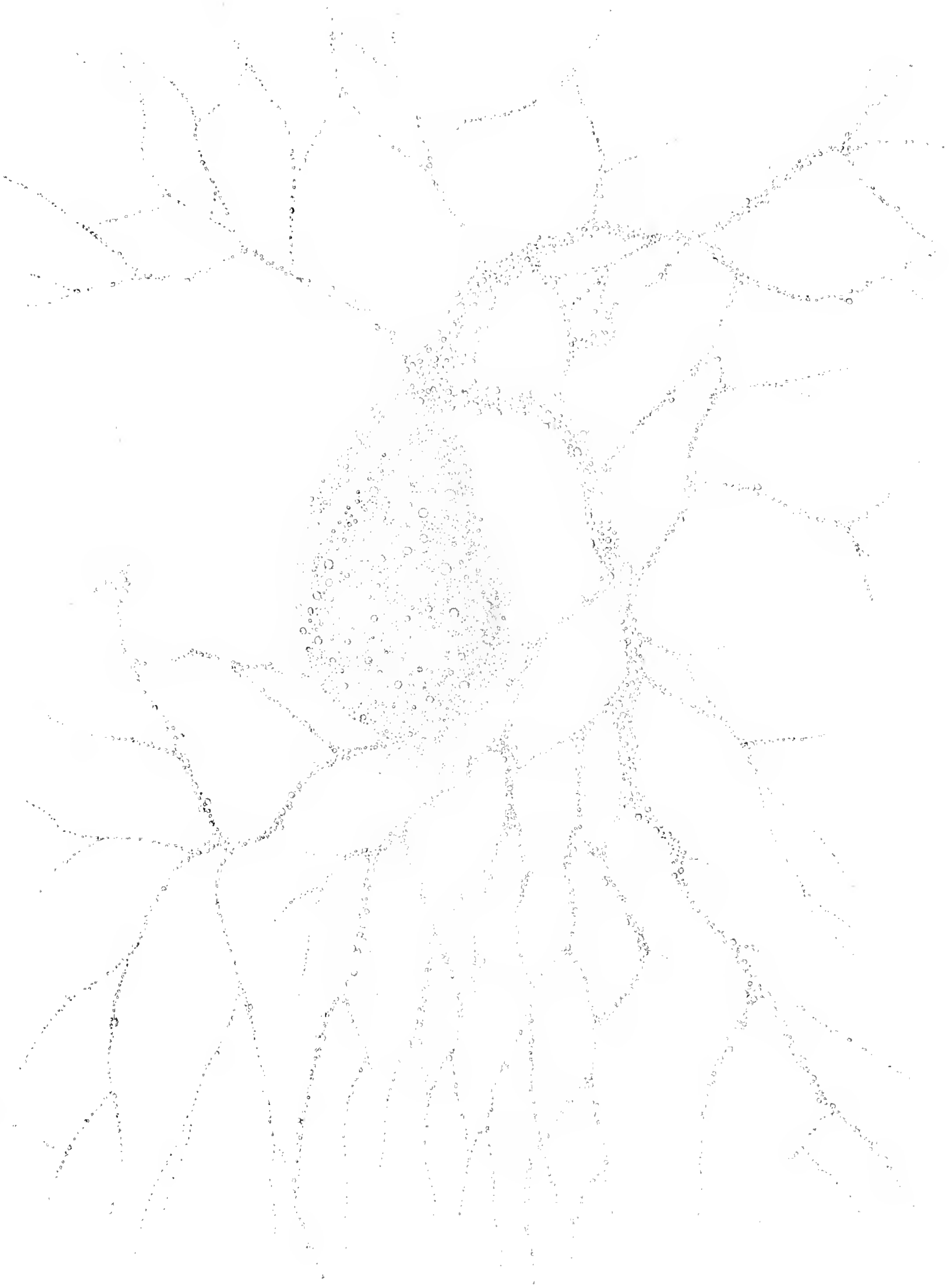
In this Plate are shown three typical examples of testaceous RETICULARIA

FIG.

1.—*Discorbina globularis* (*Rosalina varians*, Sch.), with its pseudopodia put forth from the pores of the lateral surface of the shell, as well as from the apertural plane. (After Schultze.)

2.—*Gromia oviformis*, with its pseudopodia put forth, not only from the aperture, but from the extension of the sarcode-body which invests the whole surface of the "test." (After Schultze.)

3.—*Miliola tenera*, with its pseudopodia put forth from the aperture only. (After Schultze.)



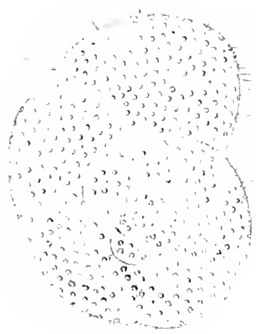


PLATE IV.

This Plate is chiefly devoted to illustrations of the various forms of Reproduction among Rhizopoda generally, and to representations of the sarcode-bodies of *Orbitolites* and *Polystomella.*

Fig.

1.—Portion of the body of an *Orbitolites* of the complex type, in which the sarcode has broken up into spherules; *a, a,* superficial segments; *b, b,* part of the annular stolon: 180 diam.

2.—Peculiar bodies (gemmules or ova?) found in the substance of different parts of the sarcode-body of *Orbitolites,* showing successive stages *a, b, c, d, e, f,* of binary subdivision; *g,* other bodies of somewhat larger size, found in one of the superficial chamberlets of a vertical section: 130 diam.

3.—*Rotalia,* whose sarcode-body has dark spherules imbedded in it. (After Schultze.)

4.—Reproduction of a triloculine *Miliola:* A, parent giving off young; B, one of the young, more highly magnified. (After Schultze.)

5.—Decalcified specimen of *Truncatulina: a, a,* membranous basis of shell; *b,* sarcode; *c, c, c, c,* ova (?) with germinal vesicles and germinal spots; *d, d,* two segments destitute of ova. (After Wright.)

6.—*Amœba radiosa,* with its nucleus (*a*) beginning to enlarge and become granular, preparatory to the development of sperm-cells. (After Carter.)

7.—One of the sperm-cells of *Amœba radiosa,* more highly magnified, in its actinophorous stage, previously to the hardening of the pellicle and the development of the spermatic granules. (After Carter.)

8.—*Amœba verrucosa,* of which the body is converted into an ovisac filled with granuliferous germ-cells. (After Carter.)

9.—*Euglypha alveolata,* in the interior of which have been evolved from the nucleus delicate granuliferous sperm-cells. (After Carter.)

10.—*Euglypha alveolata,* of which the body is converted into an ovisac filled with germ-cells. (After Carter.)

11.—*Euglypha alveolata,* in which sperm-cells (*a*) and germ-cells (*b*) are developed within the same test; *c,* supernumerary scales. (After Carter.)

12.—Portion of the sarcode-body *a, a,* of a *Polystomella,* extruded by pressure from the fractured shell; *b, b,* detached spheroids of the same; *c,* another detached spheroid beginning to put forth pseudopodial extensions resembling those of *a, a.* (After Schultze.)

13.—Nuclear (?) bodies imbedded in the sarcode of *Gromia.* (After Schultze.)

14.—Entire sarcode-body of an *Orbitolites* of the simple type, the shell having been removed by maceration in dilute acid; in the peripheral portion the segments of the sarcode-body are wanting, and the structureless basis of the shell is alone seen: 40 diam.

Fig.

15—20.—Central portions of the sarcode-bodies of *Orbitolites,* showing varieties of the mode in which the first annulus originates from the circumambient segment; *a,* primordial segment; *b, b′,* circumambient segment; *c,* segments of first annulus; *d,* peduncle connecting primordial with circumambient segment; *e, e,* peduncles connecting circumambient segment with first annulus: 84 diam.

21.—Central portion of the disk of an *Orbitolites* of the simple type, showing an abnormal commencement of growth.

22.—Primitive disks produced by a large *Orbitolites* of complex type, as seen at A on one of their lateral surfaces, and at B edgewise, showing the marginal pores.

23.—Part of the peripheral portion of Fig. 14 enlarged, to show the ordinary mode in which the segments *c, c,* of each zone are connected by radiating peduncles *e, e,* with the annular stolon *h, h,* of the preceding zone, so as to alternate with its segments; showing also the occasional interpolation of additional segments *c″, c″,* whose peduncles, *e′, e′,* come off from the *segments* of the preceding zone: 90 diam.

24.—Portion of one of the superficial strata of the sarcode-body of an *Orbitolites* of complex type, as seen from above; *a a′, a a′, a a′,* zones of superficial segments, connected at their two extremities with the annular stolons *b b′, b b′*: 150 diam.

25.—Portion of the sarcode-body of *Orbitolites* of complex type, as seen in vertical plane; *a a, a′ a′,* upper and lower rows of superficial segments, each connected at its two extremities with the annular stolons *b b,* and *b′ b′,* of two zones; the annular stolons *b b, b b,* connect the extremities of the columnar segments *c, c, c, c,* which occasionally inosculate with each other, and which communicate with the alternating columns *c′, c′,* of the zone behind (whose extremities are in like manner connected by the annular stolons *b′ b′*) by rows of oblique peduncles alternately passing towards one side and the other: 150 diam. (N.B. This figure is somewhat ideal, being made up from several preparations; but for every point which it represents, these preparations give warranty.)

26.—Disk of *Orbitolites* repaired after fracture; *a, a,* the new zone by whose extension around the broken margin the reparation has been effected: 35 diam.

27.—Disk of *Orbitolites* reproduced from a detached fragment; *a, a,* the zone from which the reparation seems to have proceeded: 35 diam.

28.—Sarcode-body of the animal of *Polystomella crispa,* showing at *a, a, a* its segments, and at *b, b* their retral processes. (After Williamson.)

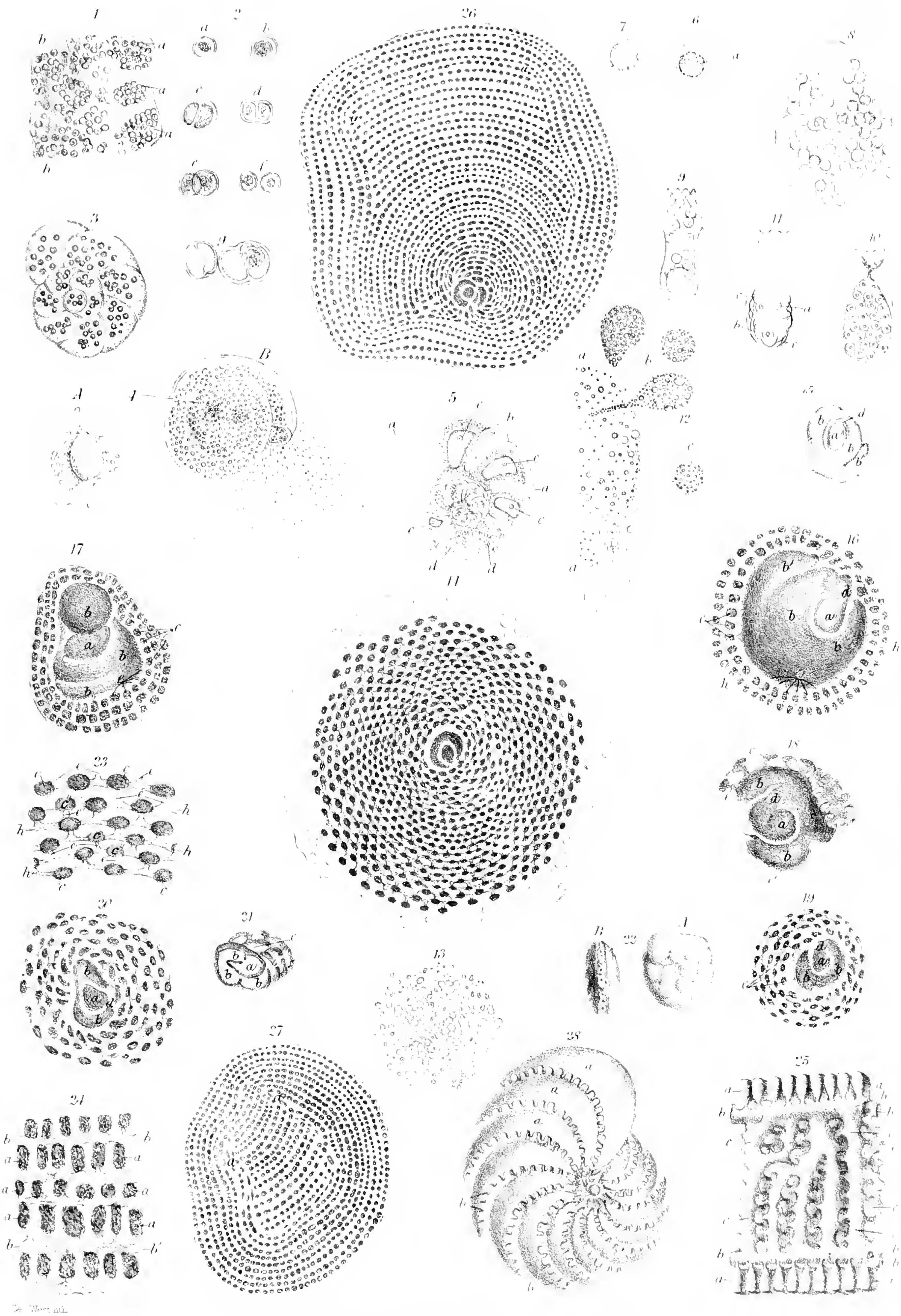


PLATE V.

This Plate is chiefly devoted to illustrations of the varieties of form and development presented by the Genera *Nubecularia* and *Vertebralina*. All the figures of each genus are drawn under the same magnifying power, to show the remarkable variation which they exhibit in the size of their component parts.

Fig.

1.—Interior of a specimen of *Nubecularia* in which the spiral mode of growth continues with unusual regularity. (See Fig. 6.)

2.—Interior of a specimen in which the regular spire has very early given place to a succession of large, irregularly-disposed chambers.

3.—Interior of a specimen in which the regular spire has early given place to an assemblage of chambers arranged without any successional regularity whatever.

4.—Under surface of a specimen in which the dimensions of the chambers, which follow one another in a regular spiral for about two turns, are at first unusually small, and then suddenly increase.

5.—Interior of a specimen in which the chambers are unusually large from the commencement.

6.—External surface of a specimen resembling that of which the interior is shown in Fig. 1.

7.—Interior of a specimen in which the original spiral has very early given place to a rectilineal series of very large chambers, the highest of which seems not only to have continued the series in nearly the same direction, but also to have given forth an elongated chamber, which doubles back (on the left side of the figure) along the line of the preceding chambers.

8.—Exterior of a specimen formed by the acervuline clustering of chambers around the horny stem of a Zoophyte.

9.—Exterior of a specimen formed by the acervuline clustering of chambers around a small branch of *Isis hippuris*.

10.—Interior of part of a specimen in which a uniserial plan of growth is giving place to a more extended arrangement; the lowest chamber opens into the next by a single aperture, but the succeeding aperture is divided into two, both leading to one chamber, the aperture of which again is single. This chamber, however, opens by two apertures into two separate chambers, each of which seems from its direction to have given origin to a distinct series.

Fig.

11.—Under side of a specimen in which a spiral succession of very small chambers is maintained with great regularity for several turns; near its margin the chambers show a disposition to become elongated, as in Fig. 13, in which case the spiral would probably give place to a cyclical plan of growth.

12.—Interior of a specimen in which a uniserial is converted into a biserial arrangement of chambers, apparently in accordance with the branching of the stem of a Zoophyte, probably an *Isis*, to which it was attached.

13.—Exterior of a specimen growing on the surface of a flat shell, in which the chambers are extraordinarily extended laterally.

14.—Under side of a similar specimen, showing the manner in which the original spiral plan of growth soon gives place to another, in which a series of chambers, extended laterally (as in the preceding figure), communicate with each other by multiple orifices.

15.—Interior of a specimen which connects such aberrant forms with the more general type, the chambers not departing much from the form they usually have in the uniserial arrangement, but communicating with each other by multiple orifices instead of by a single wide aperture.

16.—*Cornuspira foliacea*. (After Williamson.)

17.—Small milioloid variety of *Vertebralina striata*, from the Tertiary sand of Baltjik.

18.—Renuline variety of *Vertebralina striata*, from the Eocene at Hauteville.

19.—Articuline variety of *Vertebralina striata*, from the Tertiary sand of Baltjik.

20.—Arrested variety of *Vertebralina striata* (the *V. cassis* of D'Orbigny).

21.—Irregular specimen of the typical form of *Vertebralina striata*.

22.—Typical specimen of *Vertebralina striata*.

23.—Stunted specimen of *Vertebralina striata*.

24.—Dwarfed specimen of *Vertebralina striata*, from a depth of 360 fathoms.

25.—Broad, compressed specimen of *Vertebralina striata*.

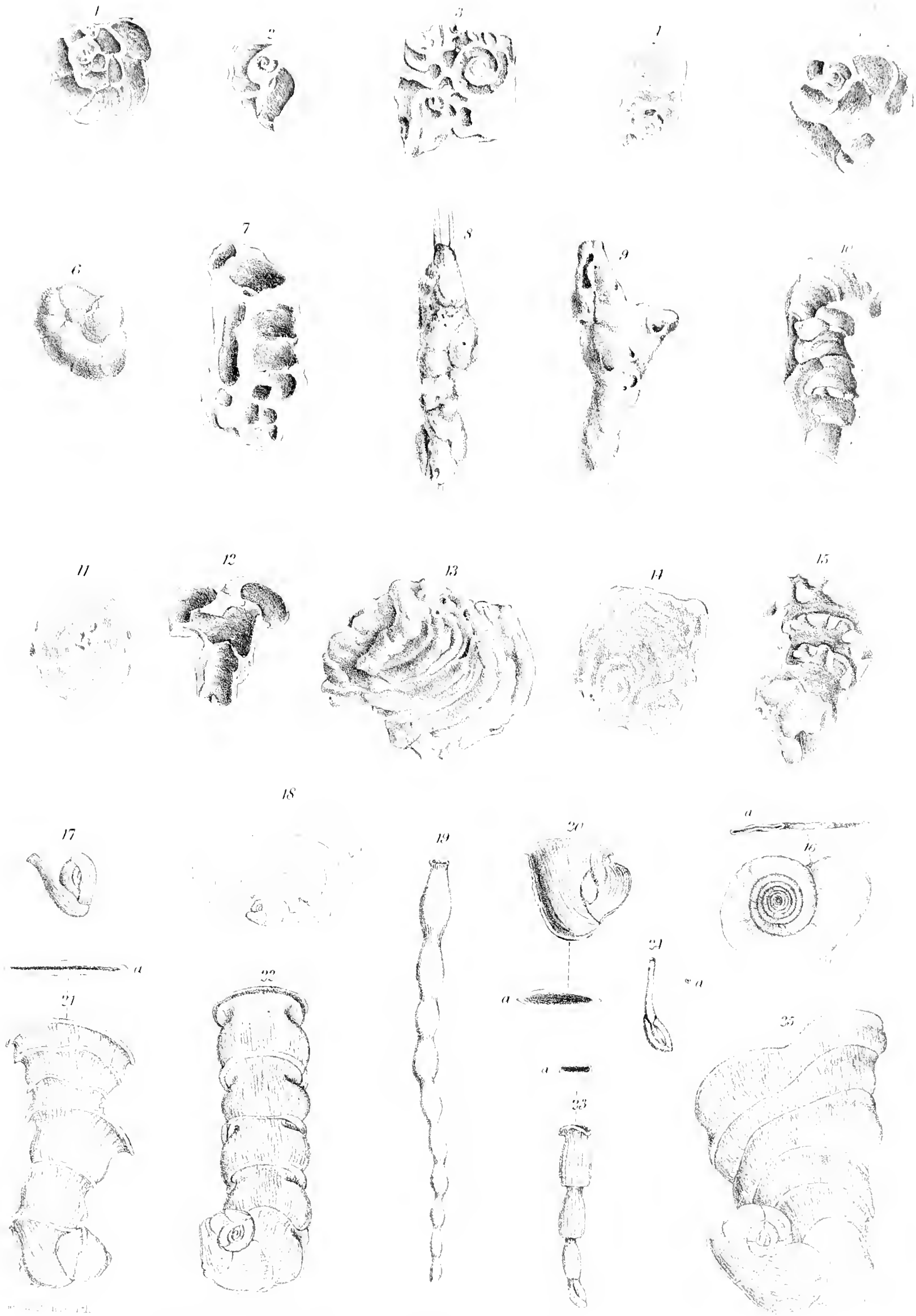

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PLATE VI.

With the exception of the last eight Figures, which represent different forms of *Lituola*, this Plate is devoted to a series of illustrations of the principal varieties of the *Milioline* type.

Fig.

1.—Lateral view of a *Spiroloculina*, of nearly circular outline and almost continuously spiral mode of growth.

2.—Similar view of a *Spiroloculina*, of very elongated form and narrow aperture.

3.—Similar view of an elongated *Quinqueloculina* with longitudinally furrowed surface.

4.—Similar view of a more rounded *Quinqueloculina*, with longitudinally furrowed surface.

5.—Similar view of a *Quinqueloculina*, with strong transverse plications.

6.—Similar view of a *Quinqueloculina*, whose exterior is arenaceous.

7.—Front view of a *Biloculina*, with smooth surface.

8—12.—Outline views of *Biloculinæ*, to show the variety in the forms of their apertures. (After D'Orbigny.)

13.—Lateral view of *Triloculina*, with strong, superficial reticulation.

14.—Lateral view of *Triloculina*, whose surface is indented by minute pits.

15.—End view of *Cruciloculina*. (After D'Orbigny.)

16—18.—Apertures of *Spiroloculina* and *Triloculina*, showing three stages in the development of the lingula.

19—32.—Apertures of different specimens, and of different parts of the same specimens, of a large *Biloculina* from the Philippines, which is represented with the last chamber laid open in Fig. 33.

34.—Section of *Hauerina*, through the median plane.

35.—Lateral view of a deeply plicated *Hauerina*.

36.—A, Lateral view of *Hauerina*; B, its cribriform aperture.

Fig.

37.—A, Lateral view of *Fabularia*, with its surface abraded in parts, so as to lay open the passages immediately beneath; B, end view, showing its cribriform aperture.

38.—Transverse section of *Fabularia*, showing its general biloculine plan of growth (the chambers at the opposite sides meeting each other along the line *a*, *b*), and the occupation of the principal part of its chambers with solid shell-substance, which is channelled out by inosculating passages; A′, portion of this section more enlarged, showing the junction along the line *a*, *b* of the interior tuberculated wall of one chamber with the external pitted wall of the preceding; A, a small portion of the internal layer, showing the minute tubercles projecting from its surface; B, a small portion of the external layer, showing the pits of its internal surface, into which the tubercles of the subjacent layer are received.

39, 40.—Lateral and front views of *Lituola canariensis* (*Nonionina Jeffreysii*, Will.)

41.—Portion of the shell of the same, highly magnified, to show the manner in which it is made up of agglutinated grains of sand.

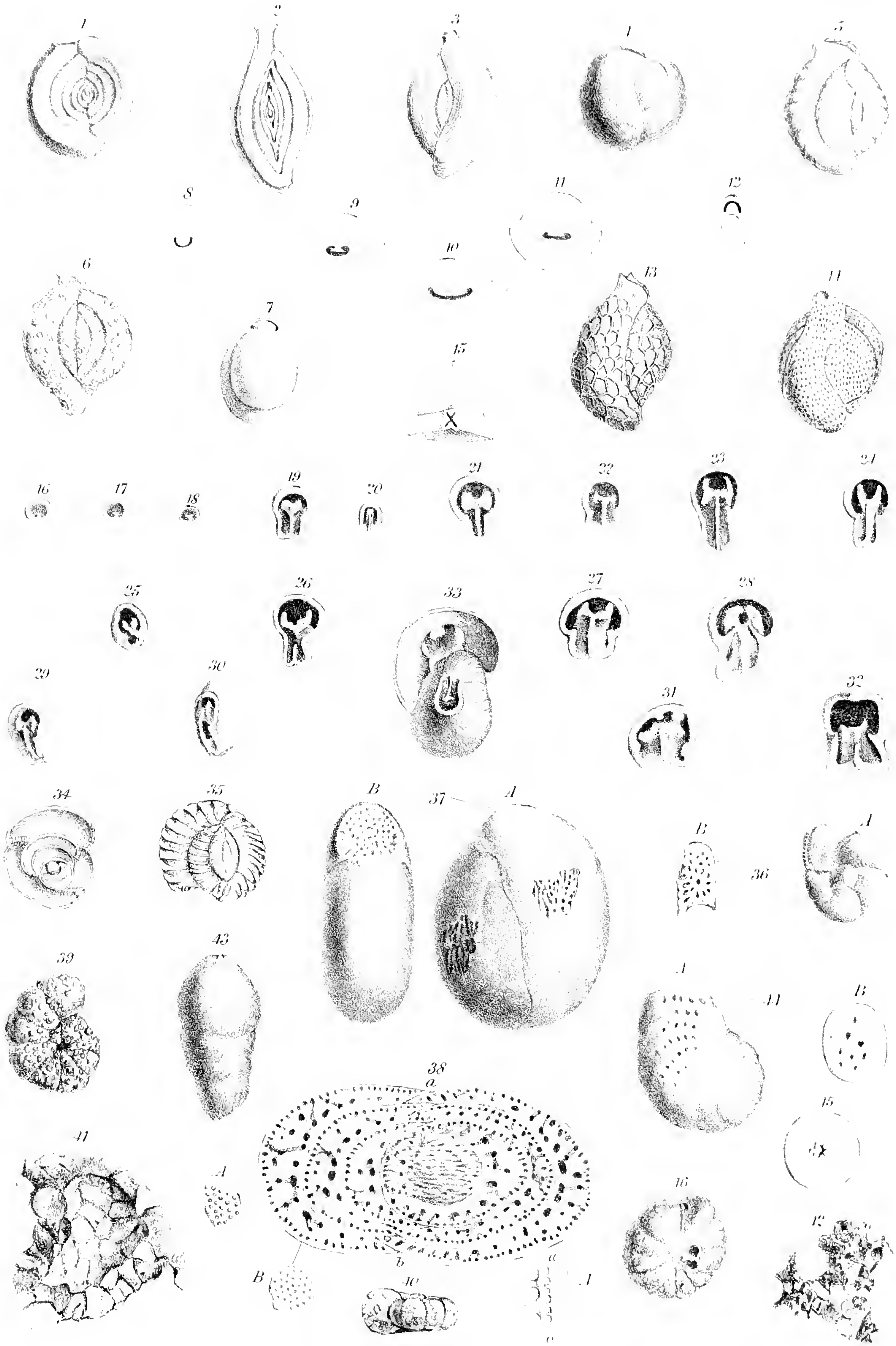
42.—Portion of the shell of *Lituola Soldanii*, highly magnified, showing the larger arenaceous particles to be imbedded in a cement composed of amorphous particles united by an adhesive exudation.

43.—*Lituola Soldanii*.

44.—*Lituola nautiloidea*; A, lateral aspect, showing the interior partly laid open by attrition; B, septal plane.

45.—Septal plane of another variety of the same.

46.—Another variety of the same.



Geo West del et lith

PLATE VII.

Peneroplis, with its *Dendritine* and *Spiroline* varieties.

FIG.

1.—Ideal figure of the *Dendritine* variety of *Peneroplis*, partly laid open, so as to show the arrangement of its chambers, the nature of their communication by a single fissure of irregular form (simpler in the earlier whorls, or even replaced by a set of multiple pores), the investment of the earlier whorls by the alar prolongations of the chambers of the later, and the detachment of the last convolution from the preceding.

2.—Portion of the surface of a specimen of *Peneroplis* on which the plications are obsolete, but the punctations are arranged in rows corresponding to them in distance: 100 diam.

3.—Portion of the surface of a specimen of *Peneroplis* over which the punctations are scattered without definite arrangement: 100 diam.

4.—Lateral view of *Spiroline* variety of *Peneroplis*: at *a* is seen the septal plane of its rectilineal extension: 40 diam.

5.—Septal plane of another *Spiroline* form, showing a transition between the isolated pores of *Peneroplis* and the coalesced fissures of *Dendritina*: 40 diam.

6.—Lateral view of a young specimen of *Peneroplis*, showing the greater turgidity of the spire and the greater breadth of the septal plane (*a*) in that stage, with a corresponding arrangement of the multiple pores: 40 diam.

7—10.—Front views of young specimens of *Peneroplis,* showing various departures from the normal type in the form of the septal plane and the disposition of the multiple pores: 40 diam.

11.—Lateral view of a young specimen of *Peneroplis*, showing in the disposition of the apertures of its septal plane (*a*) a tendency towards the *Dendritine* variety: 40 diam.

12.—Lateral view of a specimen of *Peneroplis,* of which the later growth is rectilineal, as in the *Spiroline* variety, but of which the form is compressed and the pores quite distinct from each other, though arranged in a double row, as seen at *a*: 40 diam.

FIG.

13.—Lateral view of a typical specimen of the *Dendritine* variety: 40 diam.

14.—Septal planes of the same—*a*, from the last chamber; *b*, from the preceding whorl; *c*, from an earlier whorl,—showing the progressive increase in the complexity of the dendritic aperture; *al*, *al*, alar prolongations of the chambers of the earlier convolutions: 40 diam.

15.—Septal plane of a specimen resembling in general form that represented in Fig. 13, but showing a want of coalescence of the fissures of which the dendritic orifice is made up; the ridge-and-furrow arrangement of the walls of the chambers is here prolonged in an unusual manner over the borders of the septal plane: 100 diam.

16.—Lateral view of a typical specimen of *Peneroplis*; at *a* is seen its long, narrow, septal plane, with a single row of isolated pores arranged at pretty regular intervals: 40 diam.

17.—Front view of a *Dendritine* variety of peculiarly turgid form, showing the lateral extension of its aperture in accordance with the shape of its septal plane: 40 diam.

18.—Ideal figure of *Peneroplis,* partly laid open, so as to show the arrangement of its chambers, the nature of their communications by isolated pores, and the differences in the arrangement of these in the earlier and in the later convolutions, in accordance with the form of the septal plane.

19.—Front view of a *Dendritine* variety of peculiarly compressed form, showing the narrowing of its aperture in accordance with the shape of its septal plane: 40 diam.

20.—Portion of the ordinary surface of *Peneroplis*, showing its ridge-and-furrow plication and its rows of minute punctations: 100 diam.

21.—Portion of the ordinary surface of a *Dendritina*, showing precisely similar characters: 100 diam.

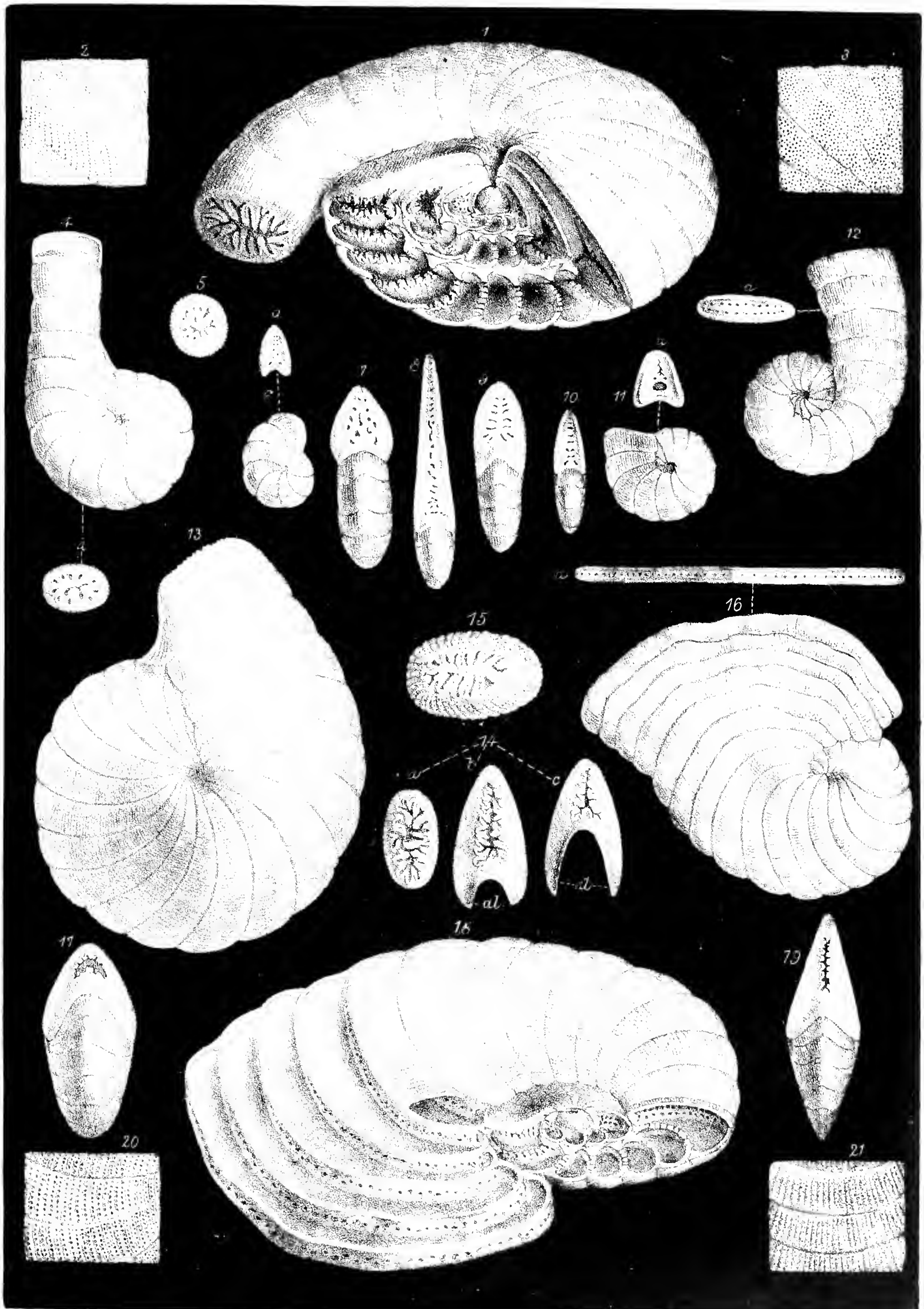


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PLATE VIII.

Orbiculina and *Alveolina.*

FIG.

1—5.—Successive stages of growth of the cyclical type of *Orbiculina adunca,* showing the transition from the spiral to the cyclical plan of growth: 16 diam.

6.—Horizontal section of a disk in which the cyclical type has been completely attained, the original spiral being surrounded by a succession of annuli: 16 diam.

7—9.—Successive stages of growth of that type of *Orbiculina adunca* in which the spiral plan is maintained through life; *a*, centre of the spire, which forms the inner extremity of every new zone; *c*, its peripheral extremity; *a b c*, apertural surface: 16 diam.

10.—Horizontal section of a large spiral example of *Orbiculina adunca*: 16 diam.

11.—Portion of the foregoing section much enlarged, showing the chamberlets and their communications; *a a′*, *a a′*, *a a′*, *a a′*, four zonal partitions, perforated by the transverse passages *b*, *b′*, which communicate between the successive galleries *c c′*, *c c′*, *c c′*, that connect the rows of chamberlets *d*, *d*, *d*, which are divided by the transverse partitions *e*, *e*, *e*, *e*: 100 diam.

12.—Vertical section of disk of *Orbiculina adunca,* passing through its centre, 1, and showing the mode in which this is invested by the successive whorls, 2 2, 3, 3, 4, 4; *a*, multiple zonal galleries between the columnar chambers; *b*, marginal openings of the radial passages connecting successive zones: 100 diam.

FIG.

13.—External aspect of *Alveolina Quoii,* showing its longitudinal septal furrows, the spaces intervening between which are crossed by secondary furrows; the elongated apertural plane is seen to be perforated with rows of rounded pores, of which those lying along the external margin are smaller and more closely set than the rest; the apertural plane widens out greatly at its two extremities, and the number of rows of pores is greatly augmented, but they are less regularly arranged: 10 diam.

14.—Transverse section of *Alveolina Quoii,* showing the division of the spire into principal segments indicated by the inflection of the superficial laminæ at *a*, *a*, *a*: each of these segments is divided by the laminæ *d*, d^1, d^2 into a series of superposed chamberlets, *e*, e^1, e^2, e^3, which open at their two extremities into vertical spaces *f*, *f*, that extend through the entire depth of the segment; and in each of these spaces are seen the orifices *b*, *c*, of two galleries which pass along the entire length of the shell, and connect the vertical spaces with each other laterally: 80 diam.

15.—Longitudinal section of *Alveolina Quoii,* showing the mode in which the spire is arranged around the primordial chamber, and in which, by the irregular multiplication of chamberlets at the two extremities, its length is augmented much more rapidly than its diameter. Each convolution of the solid spire is seen to be perforated along its external margin by a closely set row of minute pores, which are the transverse sections of the long, narrow, superficial chamberlets; and beneath these are several rows of larger and less approximated pores, which are the transverse sections of the subjacent chamberlets: 40 diam.

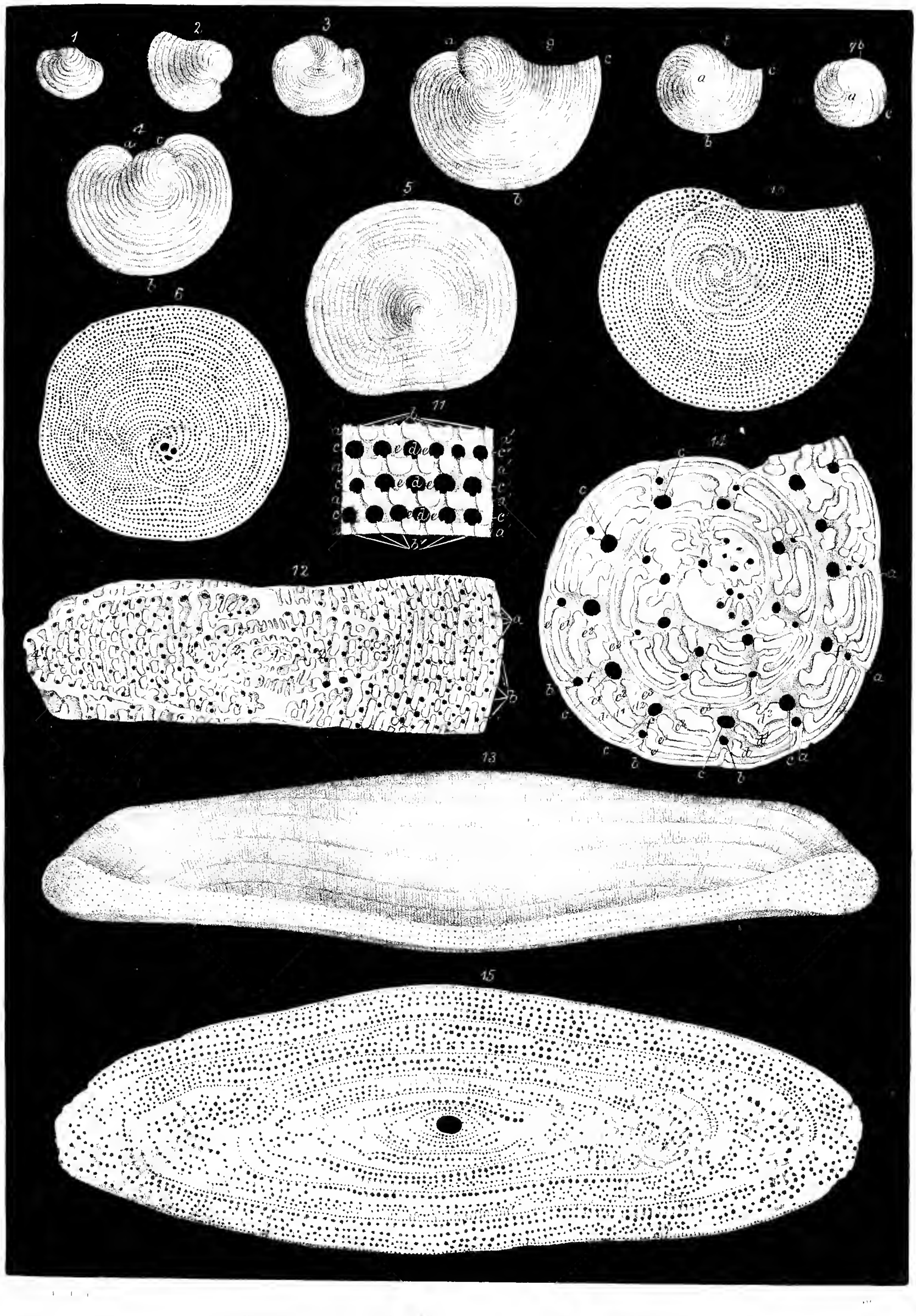
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PLATE IX.

All the figures in this Plate illustrate the structure of the calcareous disks of *Orbitolites;* and the same letters are used to mark corresponding parts throughout.

a. Primordial chamber.

b b b'. Circumambient chamber.

c, c. Chamberlets of the concentric zones; *c', c', c', c'*, the same, as seen in vertical section.

d. Passage from the primordial to the circumambient chamber.

e, e, e. Radiating passages, connecting the chamberlets of successive zones.

f, f, f. Marginal pores on the external surface of the last annulus, in which the radiating passages terminate.

g, g, g. Inner surface of annulus separated by fracture from the outer surface of that to which it was applied, showing the incompleteness on their inner side of the proper walls of the chamberlets, into each of which a wide fissure is seen to open.

h, h, h. Annular galleries, connecting the chamberlets of their respective zones; where the galleries are double, as in figs. 7, 8, 9, *h', h', h'*, point to the second series, and the space between the two constitutes the intermediate stratum.

i, i, i. Superficial chamberlets, with the two passages at their extremities; *i', i', i'*, the same as seen in vertical section.

FIG.

1.—Ideal representation of a disk of the *simple* type, the details of the different parts made up from actual specimens; showing the natural surface, with the external indications of the concentric zones of transversely oval chamberlets; the natural margin, with the single row of pores *f, f*, between the protuberances of the chamberlets; a portion of the interior *c, c, e, e*, as displayed by a (horizontal) section parallel to one of the surfaces; another portion *c', c'*, as displayed by a (vertical) section perpendicular to this, passing in a radial direction; and another portion *g, g*, as displayed by a fracture following the circular course of one of the zones.

2.—Vertical section of a disk of simple type: 30 diam.

3.—Horizontal section of a disk of simple type, showing the excentricity of its early growth: 35 diam.

4.—Horizontal section of a disk of simple type, showing a regularly concentric growth from very large central and circumambient chambers: 35 diam.

5.—Horizontal section of a disk of simple type, showing a regularly spiral commencement: 90 diam.

6.—Portion of a horizontal section of a disk of simple type, enlarged to show the mode of connection of the chamberlets *c, c, c*, by annular galleries *h, h, h*, from which come off the radiating passages *e, e, e*, that lead to the succeeding zones; at *c'', c''* are seen two interpolated chamberlets, whose radiating passages come off from chamberlets of the zone within: 120 diam.

7.—Ideal representation of a disk of *complex* type (a portion of which is shown on a larger scale in fig. 9), the details of the different parts made up from actual specimens; showing the natural surface, with the external indications of concentric zones of narrow, rectilineal chamberlets; the natural margin, with its multiple rows of pores lying in furrows *f, f*, between the protuberances of the chamberlets; horizontal sections of the interior through different planes, so as to lay open, at *i, i*, the superficial chamberlets, at *h, h, h*, the annular galleries into which these open beneath, at *e, e, e*, the cylindrical chamberlets of the intermediate stratum, connected by the radiating passages, and at *h' h'*, the lower set of annular galleries; at *c', c', c'*, a vertical section in the radial direction; and at *g, g, g*, the inner surface of an annulus, separated by concentric fracture from that to which it was applied.

8.—Vertical section of a disk of *complex* type: *k*, first differentiation of superficial chamberlets from intermediate stratum; *l*, summits of interzonal partitions, forming the floors of the superficial chamberlets; *m, m*, passages of communication between the superficial chamberlets and the annular galleries; *n*, first duplication of the annular galleries, and differentiation of the intermediate stratum: 30 diam.

9.—Portion of fig. 7, more enlarged.

10.—Marginal surface of a thick fossil disk, showing the rows of pores *f, f*, lying in the furrows between the protuberances of the cylindrical chamberlets, the irregular junctions and subdivisions of these, and the incomplete differentiation of the superficial chamberlets from the intermediate stratum: 35 diam.

11.—Inner surface of a zone from the same disk, separated by concentric fracture from that which it enclosed: 35 diam.

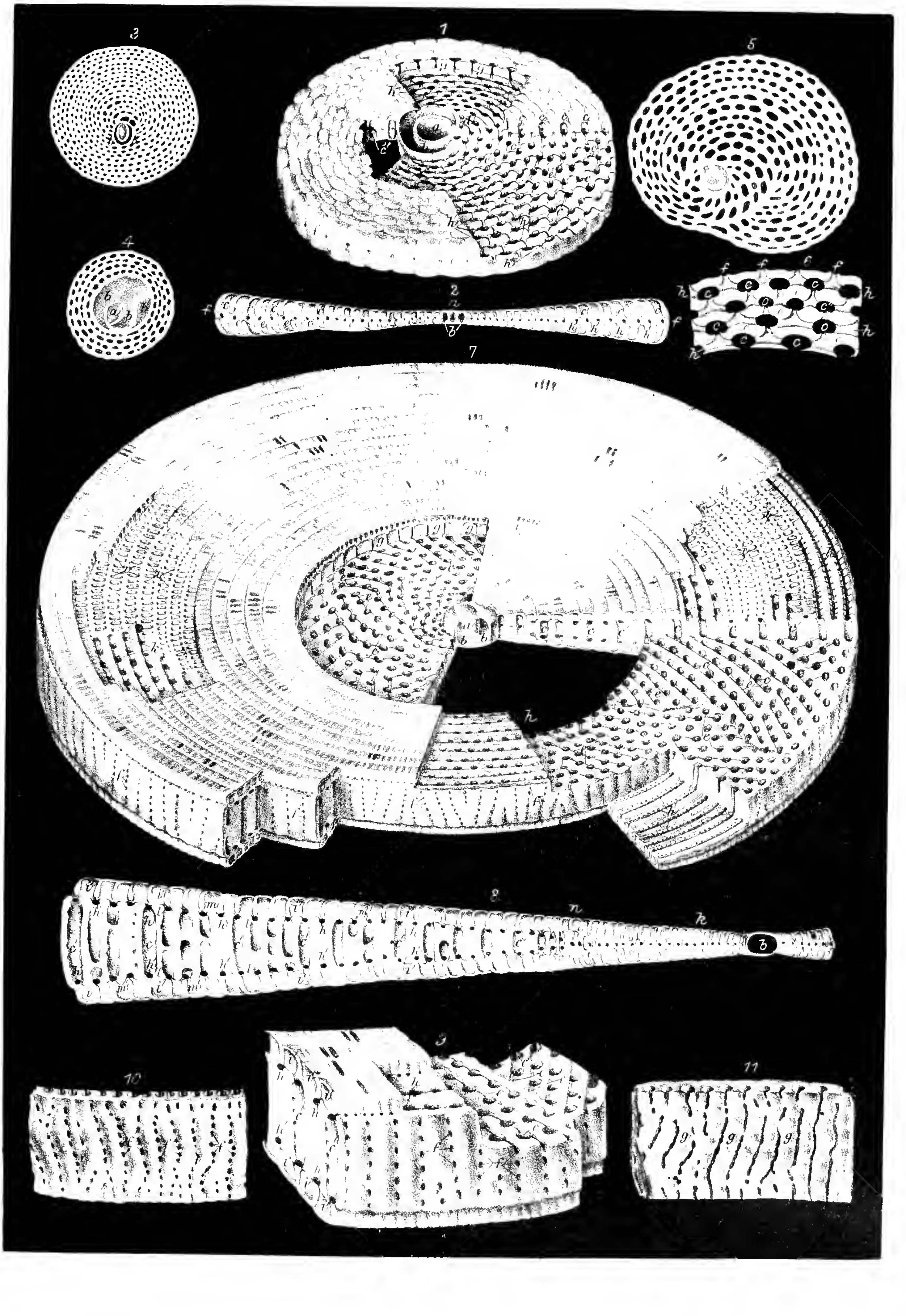
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PLATE X.

All the figures in this Plate illustrate the structure of the different forms of *Dactylopora*.

Fig.

1—8.—Varietal forms of *Dactylopora eruca*, magnified 30 diameters, except Fig. 4 A, which is enlarged to 60 diameters. All these are from *recent* specimens, except Figs. 4 and 8.

9—14.—Varietal forms of *Dactylopora annulus*; 40 diam.

15.—*Dactylopora clypeina*, magnified 15 diameters; A, small portion magnified 40 diameters.

16.—Fragment of *Dactylopora digitata*: 15 diam.

17.—*Dactylopora reticulata*; at A, magnified 15 diameters, and at B, enlarged to 40 diameters; *a a'*, junctural interspaces, as seen externally; *b b'*, interior furrow, in which are seen the internal entrances to the junctural interspaces; *c*, *c*, outer walls of the chambers; *c' c'*, cavities of the chambers laid open from the outside by the attrition of their walls; *d*, *d*, cavities of the chambers laid open by vertical section; *e*, apertures of the chambers.

18.—Another variety of *Dactylopora reticulata*, showing the outer wall of each annulus between the junctural interspaces *a a'*, strengthened with projecting ribs: 40 diam.

19.—The same viewed from above.

20.—Specimen of the simplest variety of *Dactylopora cylindracea*, magnified 15 diameters;—A, portion of its external surface, enlarged to 40 diameters; B, portion of its fractured edge, enlarged to 40 diameters, showing the gallery *a a*, into which the chambers of the chambered portion *b*, *b* open.

21.—Variety of *Dactylopora reticulata*, in which the chambers are not arranged in regular annuli; thus leading towards *D. glandulosa*: 15 diam.

22.—Portion of a specimen resembling that shown in Fig. 20, laid open by acid from its exterior, so as to show the cavities of the chambers, of which the internal orifices are seen at *a*, *a*, and which are surrounded by passages diverging from the necks of those orifices, the cross sections of which are seen at *b*, *b*: 40 diam.

23.—Portion of a specimen of the more complex type of *Dactylopora cylindracea* shown in Fig. 29, of which the external surface has been removed by attrition: 15 diam.

24.—Portion of a specimen of *Dactylopora cylindracea*, resembling that shown in Fig. 20, but more highly developed, showing at *a' a'* the gallery formed by the coalescence of the junctural interspaces, communicating internally with the general cavity of the cylinders by a row of orifices in nipple-shaped protuberances, and opening externally into the chambers, *b*, *b*, which are laid open by vertical section; around the neck of each of these chambers there originates a set of diverging branches, *d*, *d*, which pass round the chamber to reach the external surface, where they open into its funnel-shaped depressions seen in section at *c*, *c*, *c*, *c*. At A the same parts are represented as seen in a horizontally fractured surface; its difference from Fig. 20 A consisting in the more complete continuity of the internal gallery, *a*, *a*, and in the development of a thick wall of solid shell-substance on the outside of the chambered portion *b*, *b*: 40 diam.

25.—Portion of the edge of a fractured specimen of *Dactylopora glandulosa*, showing at *a*, *a*, the internal orifices of the chambers, and at *b*, *b*, the junctural interspaces left between the projections of their external walls: 40 diam.

26.—Portion of the internal surface of a specimen of *Dactylopora glandulosa* (the chambers of which are much smaller than the average) showing at *a*, *a*, the mammillary protuberance in which the orifices of the chambers are situated, and at *b*, *b*, the junctural interspaces here narrowed to pores: 40 diam.

27, 28.—Portions of the external and internal surfaces of the ordinary form of *Dactylopora glandulosa*: *a*, *a*, internal orifices of the chambers; *b*, *b*, junctural interspaces: 40 diam.

29.—Portion of the most complex type of *Dactylopora cylindracea*, as seen under various aspects: *a*, *a*, cavities of the chambers laid open; *b*, *b*, junctural canals, opening into the general cavity of the cylinder by the orifices *c*, *c*, *c*, *c*: at *d*, *d*, are seen the dilated *culs de sac* of the junctural canals, from which originate the diverging branches, *e*, *e*, which run towards the surface, where they terminate in the funnel-shaped depressions shown at *g*, *g*; in the lower part of the figure the diverging branches are seen in cross section at *e'*, *e'*, whilst at *f*, the external sheath has been so far removed as to lay open the *culs de sac* of two of the principal canals from which they originate: 30 diam.

30.—Portion of the solid sheath of a specimen of the same type of the preceding, which has been subjected to the action of acid; showing a division by sutural lines into *areolæ*, in each of which are seen the transverse sections of the diverging branches of one of the junctural canals: 40 diam.

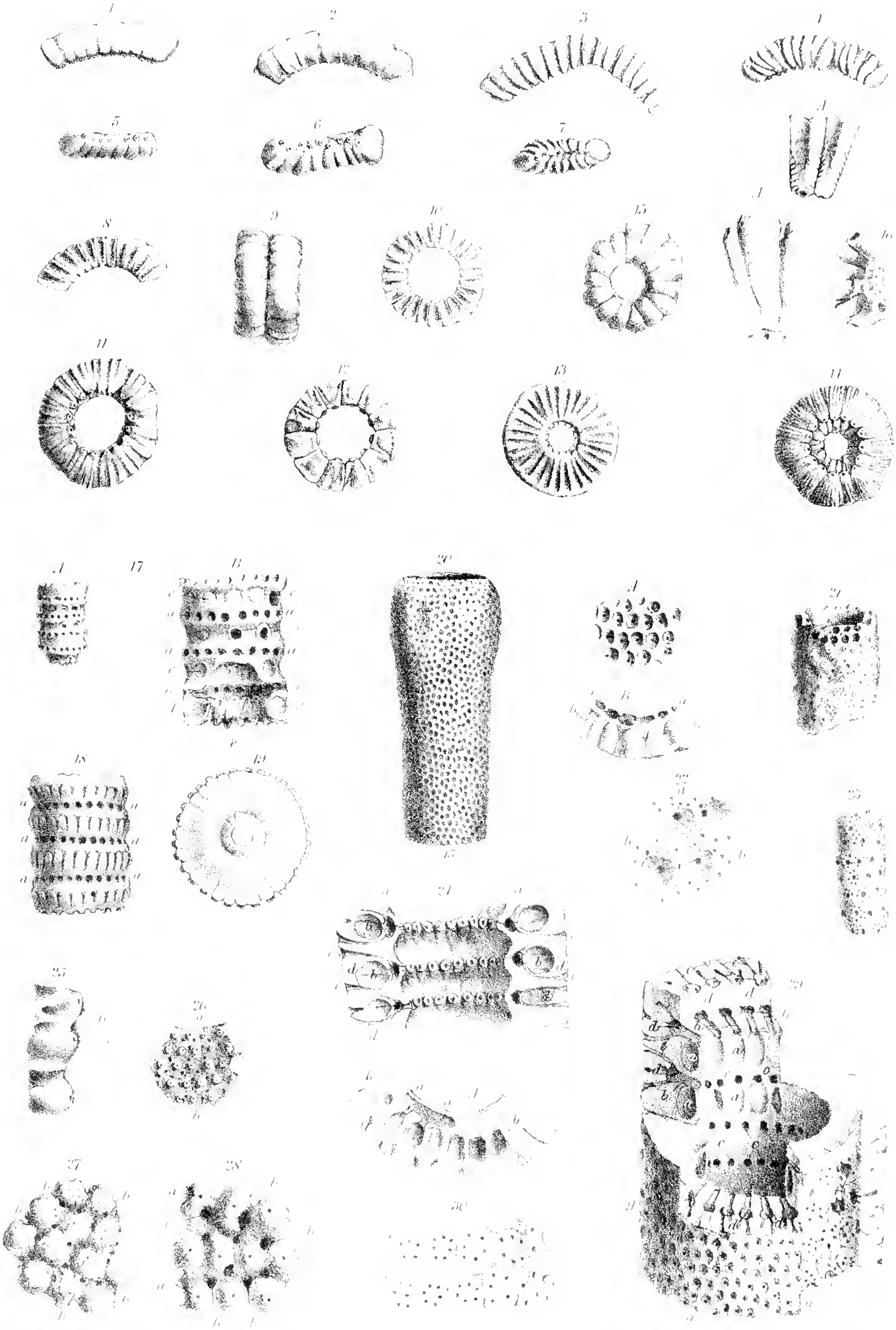


PLATE XI.

Trochammina, Lituola, Valvulina, and *Acicularia.*

FIG.

1—10.—Various forms of *Trochammina,* magnified 50 diameters.

1.—*Trochammina squamata.*

2.—*Trochammina incerta.*

3.—*Trochammina charoides*

4.—*Trochammina gordialis.*

5.—*Trochammina inflata.*

6—10.—Various forms of *Trochammina irregularis.*

11—14.—Placopsiline forms of *Lituola cenomana*; magnified 15 diameters.

15—26.—Various forms of *Valvulina*; magnified 15 diameters.

15.—Typical example of *Valvulina triangularis* as seen from its apex.

16.—Depressed variety of *Valvulina*; the mouth of the same shell is shown in Fig. 23.

17, 18.—Clavuline varieties of *Valvulina.*

19, 25.—Bulimine varieties of *Valvulina.*

20, 26.—Mouths of other examples of the same.

FIG.

21, 24.—Large valvular mouths of semioval variety of *Valvulina.*

22.—Portion of the shell of one of the outer chambers of *Valvulina,* showing the perforations in its proper shelly layer in the part from which the arenaceous incrustation has been most completely removed.

27—31.—Various forms of *Acicularia,* showing the openings of the chambers, each of which, in specimens whose natural surface has not been destroyed by attrition, is surrounded by a lip, as shown in Fig. 28; in Fig. 29, the attrition has proceeded so far as to lay open the cavities of the chambers; magnified 20 diameters.

32.—Cylindrical specimen of *Acicularia,* of which the chambers have been laid open by attrition, and in which they present a honeycomb arrangement; magnified 40 diameters.

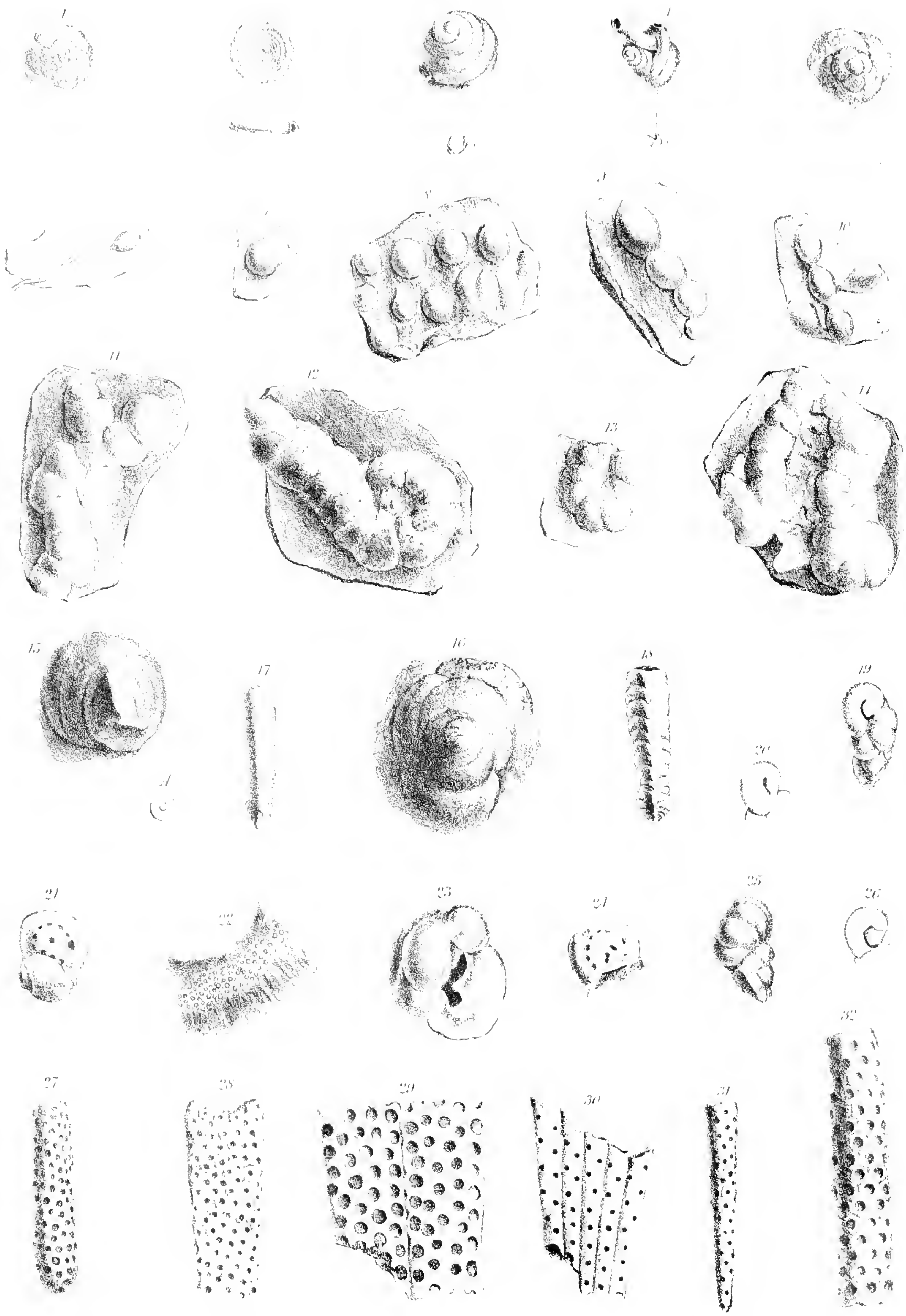


PLATE XII.

The figures in this Plate represent various forms of the *Nodosarine, Globigerine*, and *Textularine* types, and illustrate the structure of *Fusulina*.

Fig.

1.—*Lingulina costata*. (After D'Orbigny.)

2.—*Nodosaria hispida*. (After D'Orbigny.)

3.—*Cristellaria* (*Robulina*) *echinata*. (After D'Orbigny.)

4.—*Rimulina glabra*. (After D'Orbigny.)

5.—*Glandulina lævigata*. (After D'Orbigny.)

6.—*Flabellina cordata*. (After Reuss.)

7.—*Orthocerina* (*Triplasia*) *Murchisoni*. (After Reuss.)

8.—*Orbulina universa*; at *a*, is seen a small portion of its surface more highly magnified, showing its tuberculated aspect; and at *b*, a small portion reduced in thickness, and more highly magnified, to show its two sets of pores.

9.—*Ovulites margaritifera*; *a*, a small portion enlarged, showing the hexagonal areolation of its surface, with a pore in each areola.

10.—*Ovulites elongata*.

11.—*Globigerina helicina*.

12.—*Pullenia bulloides*.

13.—*Sphæroidina austriaca*. (After D'Orbigny.)

14.—Animal of *Textularia*. (After Schultze.)

15.—*Valvulina gramen*. (After D'Orbigny.)

16.—*Chrysadilina gradata*. (After D'Orbigny.)

17.—*Cuneolina paronia*. (After D'Orbigny.)

18.—*Bulimina Presli*. (After Reuss.)

19.—*Bulimina Buchiana*. (After D'Orbigny.)

20.—*Bulimina pyrula*. (After D'Orbigny.)

21.—*Bulimina* (*Robertina*) *arctica*. (After D'Orbigny.)

22.—*Bolivina costata*. (After D'Orbigny.)

23.—*Cassidulina* (*Ehrenbergina*) *serrata*. (After Reuss.)

24.—Cast of the chambers of a *Fusulina* of simple type, showing the alar prolongations extending on either side nearly in straight lines from the median segments. (After Ehrenberg.)

Fig.

25.—Transverse section of *Fusulina*, through its centre, showing at *a*, *a*, the aperture connecting together the principal chambers *c*, *c*; and at *b*, *b*, the origins of the alar prolongations from the principal chambers.

26.—Portion of the same section more enlarged, showing an appearance of tubularity in the outer walls of the chambers.

27.—Ideal view of *Fusulina* laid open in different modes, to show its internal structure; at *a*, is seen the single fissured aperture situated in the centre of the length of the shell (of which nearly a half on the left hand has been removed by a transverse section), communicating with *c*, *c*, the principal chambers laid open from the surface; near the right hand extremity the septal plane *e*, *e* has been removed to show the subdivision of the alar prolongations by the elongated secondary septa *f*, *f*, which do not quite reach the spiral lamina, a continuous gallery being left at *b*, *b*, by which the chamberlets are connected; at *d* the interior has been laid open by the removal of the septal plane, showing the necklace-like form of the alar prolongations, and their alternating arrangement.

28.—A portion of this last more enlarged, showing at *c*, *c*, *c′*, the cavities of the chamberlets, and at *b′*, *b*, *b* the communicating passages; a section in the line *a a′* will pass alternately through the chamberlet *c′*, and the gallery *b′*, giving rise to the appearances shown in fig. 29.

29.—Transverse section taken near the extremity, showing the elongation of the septa, and their apparent divarication to give passage to the narrow galleries *b′ b′* connecting the chamberlets, of the alar prolongations.

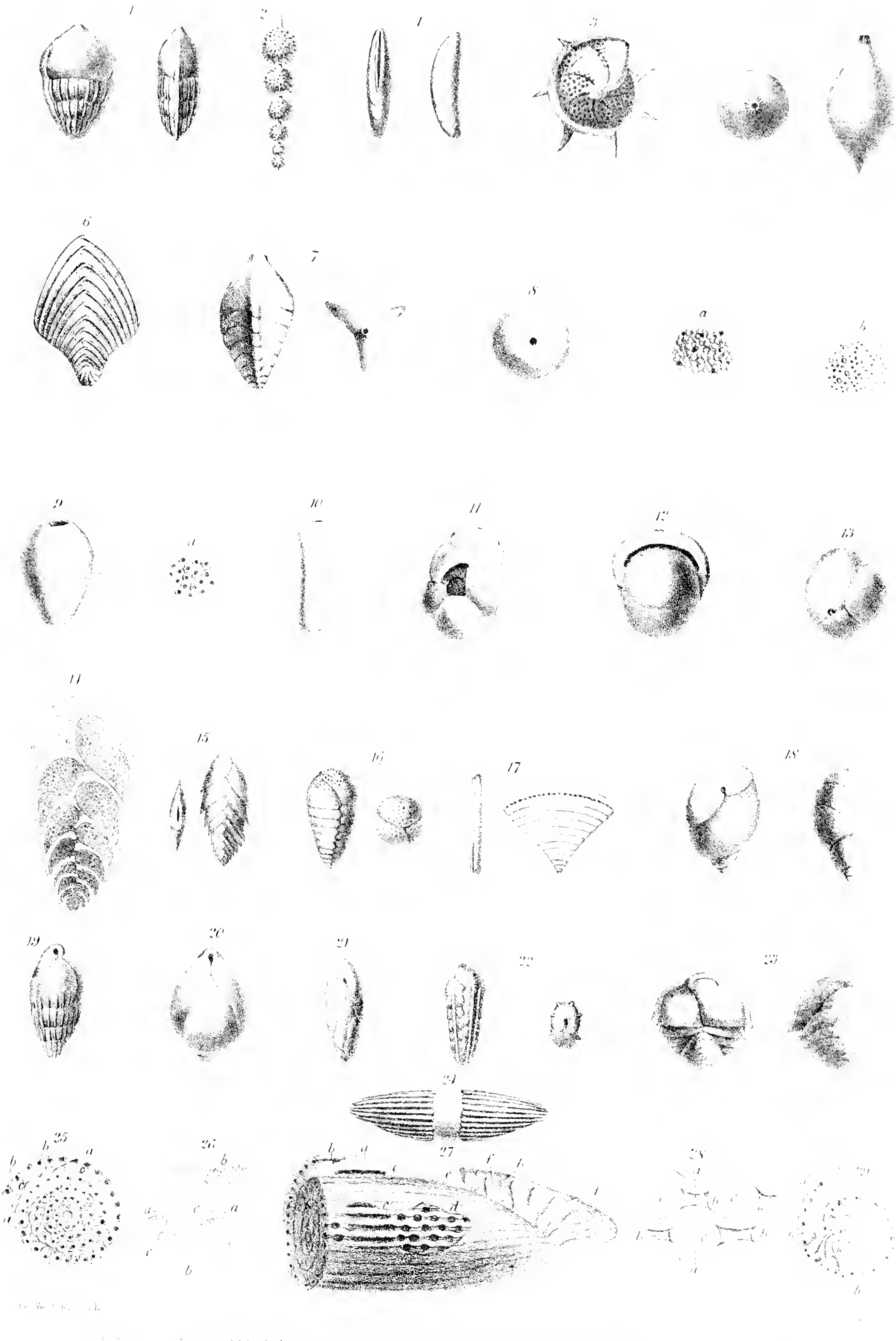


PLATE XIII.

The figures in this Plate represent various forms of the *Rotaline* type, and illustrate the structure of *Amphistegina*.

Fig.

1.—Portion of the shell of an Acervuline *Planorbulina*, much enlarged, as seen at A in its superficial aspect, and at B in vertical section. (After Schultze.)

2.—*Discorbina vesicularis*, seen on its upper side.

3.—The same, as seen on its lower side.

4.—*Pulvinulina vermiculata*, seen on its upper side; at *a* is shown a small portion more enlarged (seen as an opaque object), showing its granular surface.

5.—The same, as seen on its under surface.

6.—Portions of the under surface enlarged, showing at *a* its large orbuline pores, and at *b* its minute tubuli arranged in clusters.

7.—*Rotalia Schroeteriana*, viewed obliquely.

8.—Transverse section of the same; *a*, bifurcation of the canals.

9.—Vertical section of the same.

10.—Side view of *Cymbalopora* (*Rosalina*) *Poeyi*.

11.—Basal view of the same.

12.—Basal view of another specimen of the same.

13.—*Planorbulina vulgaris*, as seen on its attached side.

14.—Portion of the margin of the same, much more enlarged, showing the communication of the chambers by the apertural necks *a*, *a*.

15.—Portion of the free surface of tropical variety of *Planorbulina vulgaris*, showing its prominent tubercles.

16.—*Patellina corrugata*, as seen from its upper surface, showing a central and circumambient chamber resembling that of *Orbitolites*, surrounded by annular rows of chamberlets.

17.—The same viewed from the under side, showing the prolongation of the chamberlets towards the centre, and the filling-up of the umbilical cavity by a secondary growth.

18.—*Polytrema rubra*; *a*, globular form; *b*, arborescent form.

19.—Portions of its surface more enlarged; *a*, porous areolæ bounded by solid shell-substance; *b*, openings of large canals at the ends of the branches.

Fig.

20.—Sections of the same, showing at *a*, *a*, large canals formed by the coalescence of chamberlets, and at *b*, *b*, solid columns formed by the deposit of calcareous matter in excess.

21.—*Calcarina calcar*. (After D'Orbigny.)

22.—Upper surface of *Amphistegina mammillata*. (After D'Orbigny.)

23.—Lower surface of the same.

24.—End view of the same, showing the mouth, and the superficial granular deposit in its neighbourhood.

25.—Horizontal section of *Amphistegina*, showing the disposition of the chambers, the singleness of the septa, and the tuberculated surface of the septal planes and of the external surface of the penultimate whorl; A, small portion more enlarged, to show the free openings of the tubuli on the internal surface of the chambers.

26.—Vertical section of the same; showing at *a a*, the alar lobes of the upper surface, and at *a′ a′* the alar lobes of the lower surface; *b*, *b′*, the upper and lower umbilical bosses; *c*, c^1, c^2, c^3, non-tubular portion of the spiral lamina at the margin of the successive convolutions; *d*, *d′*, thin chamber-wall of the last convolution; *e*, *e′*, thickened chamber-wall of penultimate convolution; *f*, the aperture; *g*, *h*, line marking the declination of the spire; *i*, apparent subdivision of the outer wall of the convolution, resulting from the backward elongation of the chambers.

27.—Cast of the interior of *Amphistegina*, showing the disposition of the alar prolongations of the upper side.

28.—Cast of the interior of *Amphistegina*, showing the nearly complete detachment of the alar prolongations on the under side from the principal segments, with which they are only connected by the narrow necks *a*, *a*, and their intercalation as "astral lobes."

29.—Cast of the interior of *Amphistegina*, showing a subdivision of the alar lobes of the upper side by incomplete partitions.

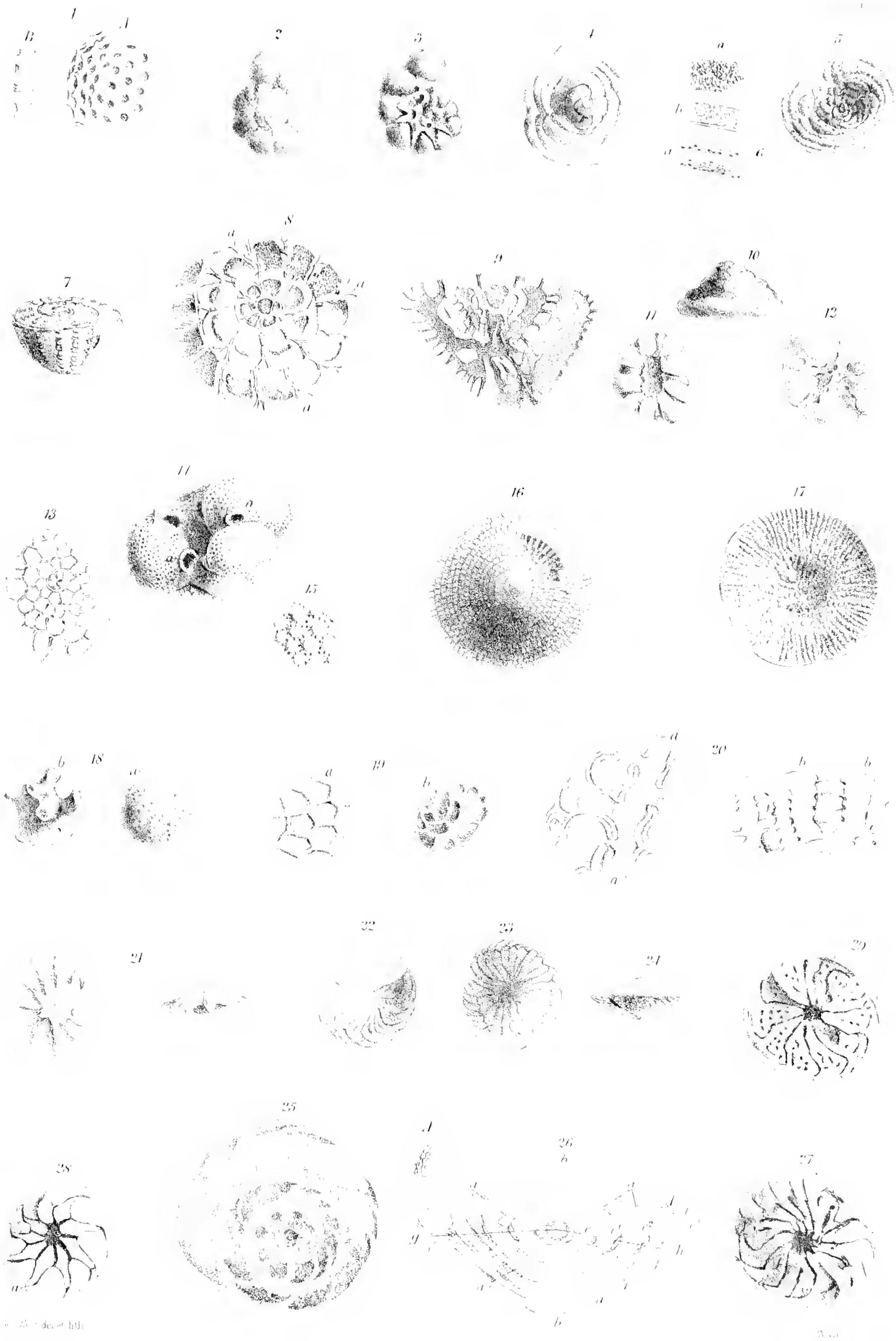


PLATE XIV.

All the figures in this Plate illustrate the structure of *Calcarina*.

Fig.

1.—Characteristic specimen of the Maltese variety of *Calcarina Spengleri*, showing its large club-shaped radiating outgrowths, the tubercles of the central part of its surface, and the septal divisions of the last half turn of the spire, hidden elsewhere by the overgrowth of the intermediate skeleton; magnified 12 diameters.

2.—Characteristic specimen of the Philippine variety of *C. Spengleri*, showing the tendency to elongation and subdivision of its radiating outgrowths; magnified 12 diameters.

In the succeeding figures, the same letters are used to indicate corresponding parts, as follows:

a, a^1, a^2, a^3, a^4, interior chambers of successive convolutions; b, b, b, external surface of the proper walls of the chambers, shown in section at $b' \ b' \ b'$.

c, c, c, septal pores, constituting the only communication between the chambers.

d, d, d, intermediate or supplemental skeleton, the progressive increase of the thickness of which in the last convolution is shown at d, d^1, d^2, d^3, fig. 4.

e, e, e, e, summits of the solid tubercles, which are seen in section at e', e', e'.

f, f, f, radiating outgrowths, of which the furrowed surface is shown in fig. 8, whilst their canal-system and its connections are better displayed in fig. 4, where also is shown the difference in the stage of growth at which the radiating outgrowths $f, f^1, f^2, f^3, f^4, f^5$, respectively originate from the intermediate skeleton.

3.—Section of the disk of *Calcarina* taken through the axis of the spire; magnified 50 diameters.

4.—Section of the disk and radiating outgrowths of *Calcarina* taken through the later whorls (thereby passing over the inner ones) transversely to the axis of the spire; magnified 50 diameters.

5.—Small specimen of *Calcarina*, of which the spire has detached itself from the disk, and has "run wild;" magnified 12 diameters.

6.—Young specimen of hispid variety of *Calcarina*: magnified 30 diameters.

7.—Portion of the surface of the preceding specimen, more highly magnified, showing that the spines are tubular, being formed around the pseudopodia as they issue from the shell.

8.—Ideal representation of *Calcarina*, laid open to show the relations of its different parts, the apex of its turbinoid spire being placed downwards for more convenient display.

9.—Portion of a section passing through the intermediate skeleton in the immediate neighbourhood of one of the chambers, showing the free distribution of the canal-system; magnified 75 diameters.

8.—Portion of a section passing through the intermediate skeleton near the surface of the disk, showing the distribution of the orifices of the canals around the solid cones, transversely divided at e, e, e; magnified 75 diameters.

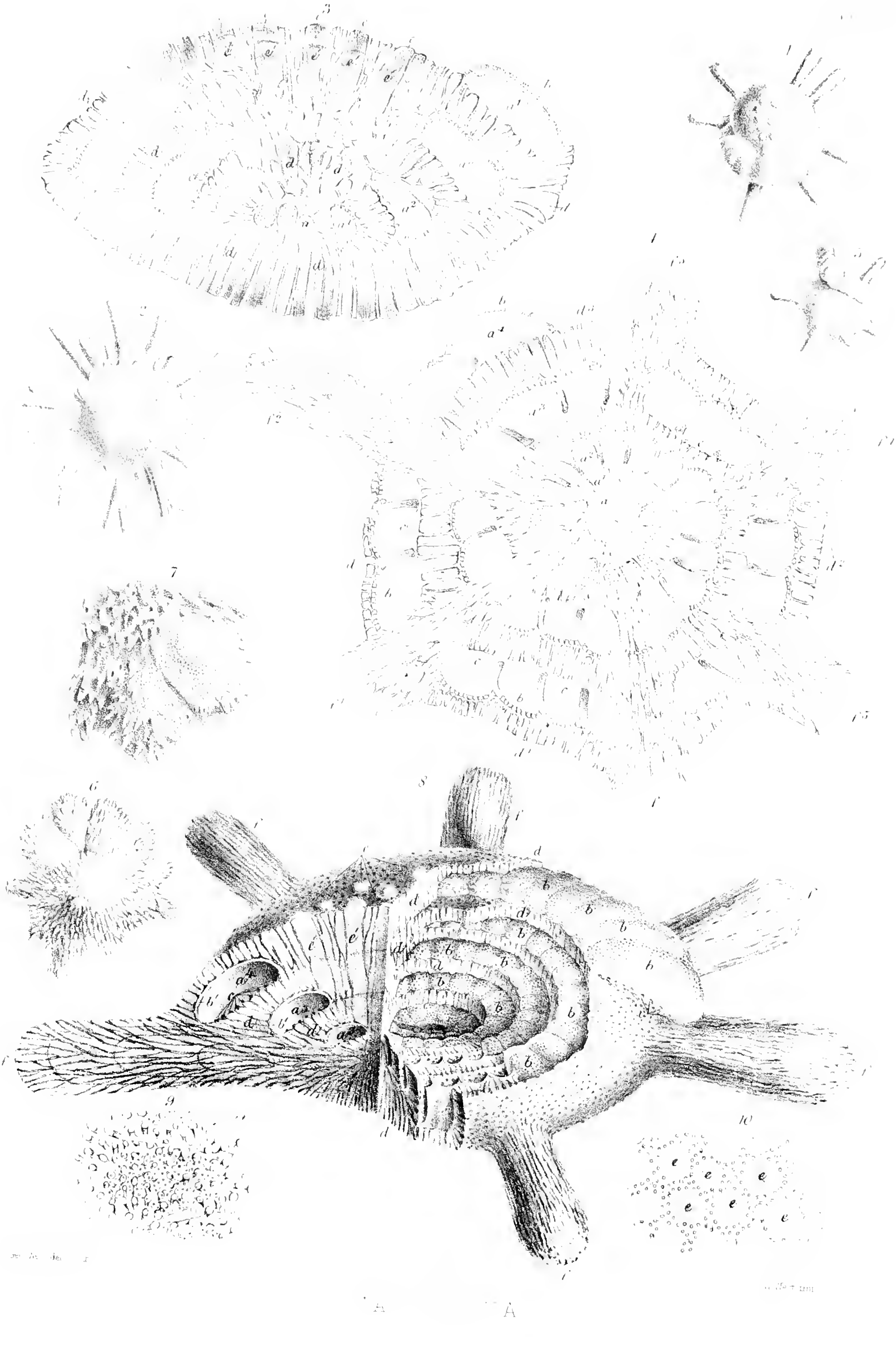


PLATE XV.

All the figures in this Plate illustrate the structure of *Tinoporus*.

Fig.

1.—External view of a conical specimen of *Tinoporus vesicularis*; magnified 25 diameters.

2.—Portion of a section of the same, parallel to the base, showing an irregularly concentric arrangement of chambers, the floors of which are perforated with numerous foramina; magnified 50 diameters.

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

4.—Ideal representation of a portion of the same, to show the relations of the chambers, which are divided from each other horizontally by cribriform floors, and laterally by solid walls, in which there are large apertures, *a*, *a*, *a*, opening into adjacent chambers.

5.—Australian variety of *Tinoporus baculatus*, enlarged 50 diameters, to show the areolated character of the surface of the disc, with elevated tubercles disposed between the areolæ, and the furrowed surface of the radiating prolongations.

6, 7.—Other specimens of the same variety, showing marked differences in conformation; magnified 20 diameters.

8, 9.—Specimens of the Philippine variety of the same; magnified 12 diameters.

10.—Portion of a section of the Philippine variety, showing at *a* the canal-system interposed between the chambers, and at *b* its reticular distribution in the solid commencement of one of the radiating outgrowths.

11.—Section of the basal portion of one of the radiating outgrowths of *T. baculatus*, showing the manner in which the chambers are clustered round the axis, and in which the axis is traversed by canals radiating from its centre to its circumference.

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

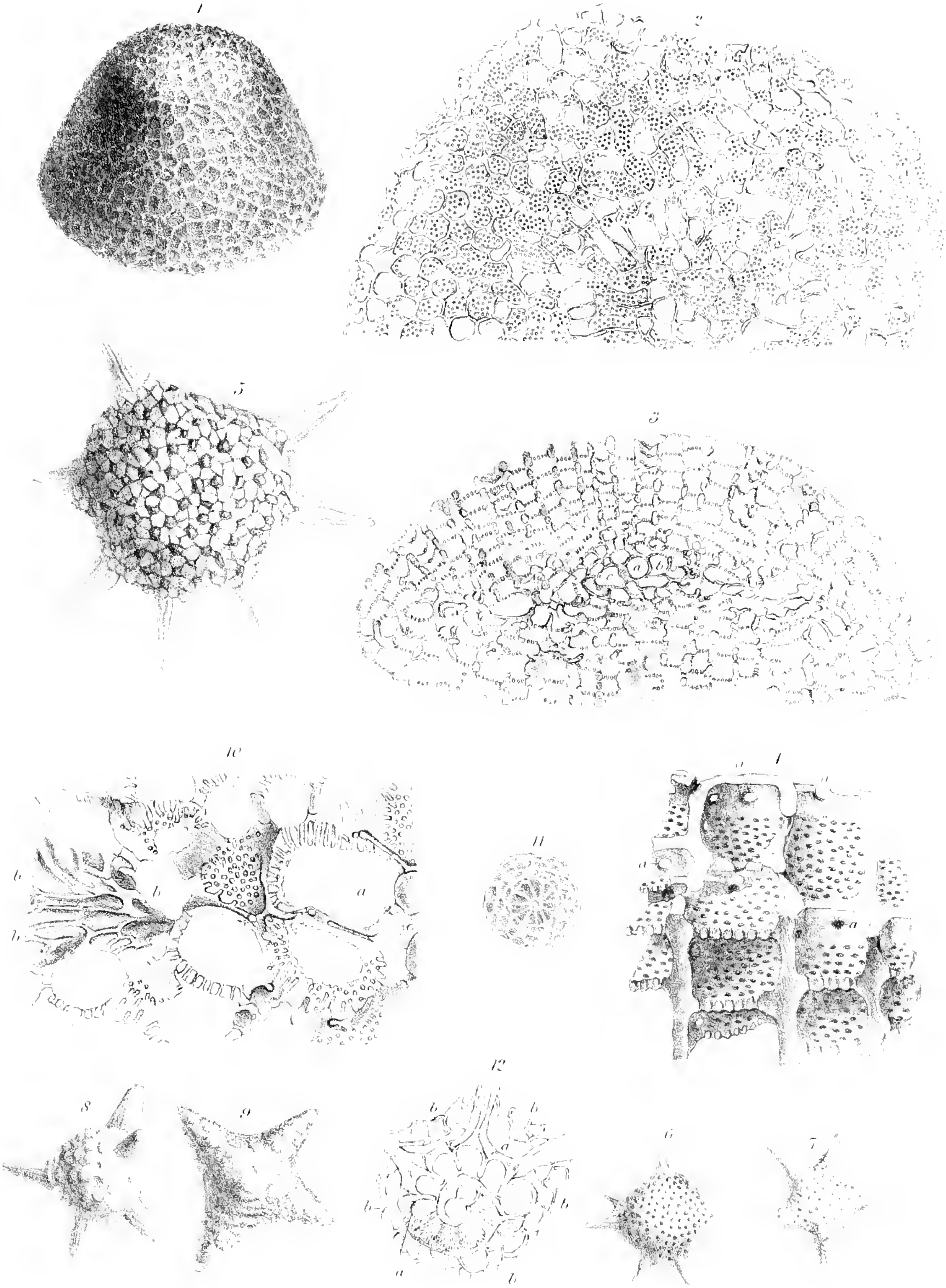


PLATE XVI.

All the figures in this Plate illustrate the structure of *Polystomella,* and the same letters are used to mark corresponding parts throughout.

a, a^1, a^2. Chambers of successive whorls; in figs. 7, 8, 9, consecutive segments of the same whorl.

b, b^1, b^2, b^3. Septa of alternating whorls.

c, c, c, c. Septal apertures; in figs. 7, 9, c' c', the stolons passing through those apertures.

d d', d d'. Meridional canals.

e, e. Spiral canals; e' e', the same transversely divided.

f, f. Diverging canals.

g g', g g'. Surface of the last-formed portion of the spiral lamina, showing a row of furrows passing across the septal bands, into which the diverging canals open in immediate contiguity to them.

h h', h h'. Older portion of the spiral lamina, showing the replacement of each series of furrows by two rows of punctations.

i i', i i'. Surface of the interior whorl, showing the obliteration of the septal bands, and the rows of dimpled depressions into which the diverging canals open.

k, k, k. Retral prolongations of the segments; in fig. 5, k', k', mark the *culs de sac* in which they are lodged in the shell of *Polystomella crispa.*

l l, l' l'. Exogenous deposit of shell filling up the depressions in the umbilical regions of both lateral surfaces, and traversed by straight vertical canals.

FIG.

1.—Ideal representation of a specimen of *Polystomella craticulata,* laid open to show its internal structure, and the umbilical deposit removed from its upper surface to show the spiral canal.

2.—*Polystomella craticulata,* as viewed at A in its lateral aspect, showing the septal ridges and the intermediate double rows of punctations, and the irregular distribution of similar punctations over the umbilical deposit of exogenous substance; the same shown in front at B, so as to bring into view the septal plane, and its row of multiple apertures.

3.—Vertical section of *P. craticulata;* magnified 20 diameters.

4.—Side view of *P. crispa,* showing the fossettes along the anterior margin of each septal band; magnified 25 diameters.

5.—Vertical section of *P. crispa:* magnified 50 diameters.

6.—Segments from two consecutive whorls of the animal body of *P. crispa,* showing their forms and connections; magnified 100 diameters.

7.—Portion of a cast of three adjacent segments of the same whorl of *P. craticulata,* showing their forms and connections; magnified 40 diameters.

8.—Fragment of *P. craticulata,* showing the furrowed internal surface of three of the chambers, and the relation of the furrows to the diverging canals; magnified 40 diameters.

9.—Internal cast of the chambers and canals of *Polystomella craticulata,* representing the form of the body and the distribution of the canal-system; magnified 40 diameters.

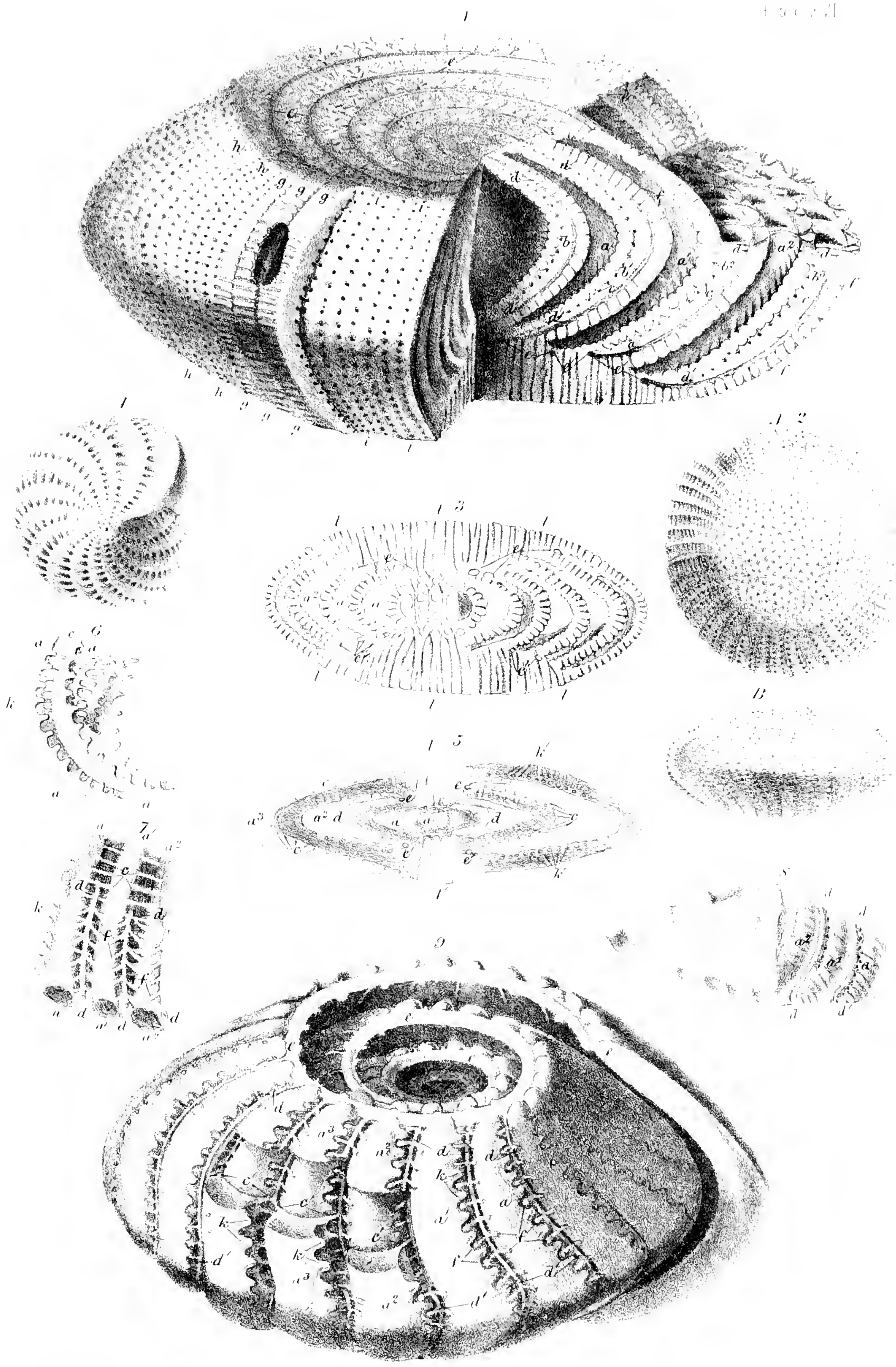


PLATE XVII.

All the figures in this Plate illustrate the structure of *Operculina complanata.*

FIG.

1.—Ideal figure of *Operculina,* laid open to show its structure: *a, a, a,* marginal cord, divided transversely at *a′*, so as to show the orifices of its canals, the distribution of which is seen at *a″ a″* in tangential section, and at *a‴ a‴* in section through the median plane; *b, b, b,* external surface of the chambers, marked out by the septal bands; *c, c,* interior of the chambers of the outer whorl, the alar prolongations of which extend, as shown at *c′, c′*, over the surface of the inner whorl, towards the centre of the spire; *d, d,* septa dividing the chambers, formed by two lamellæ, between which lie the interseptal canals, whose smaller branches are seen irregularly divided in the septa *d′, d′*, while in the septum *d″, d,″* one of the principal trunks is laid open through its whole length; at the approach of each septum to the marginal whorl is seen the fissure, *e, e, e′, e′*, which forms the principal communication between the chambers; *f, f,* the secondary orifices; *g, g,* the distribution of the interseptal system of canals, which branch from the two spiral canals *h, h*: and at *i, i* are seen the conoidal columns of non-tubular shell-substance that overlie the septa, forming tubercular projections on the surface, and frequently penetrated by branches of the interseptal canals.

2.—Portion of the outermost and penultimate convolutions, laid open by vertical fracture: *a, a′, e, e′, f, g, g, h, h,* as in the last figure; *h′, h′*, transverse sections of spiral canals; *k, k,* spiral lamina, that of the last whorl coalescing with that of the penultimate whorl at *k′, k′*, and augmenting its thickness; 75 diameters.

3.—Portion of the marginal cord, *a‴, a‴*, as seen in a section passing through the median plane, showing the fusiform spaces formed by the inosculation of the canals; 120 diameters.

4.—Portion of a section through the median plane, showing the connection of one of the interseptal canals *g,* lying in the midst of non-tubular substance, with the reticulation of the marginal cord *a‴ a‴*; 100 diameters.

5.—Exterior of the marginal cord, showing at *a, a* its furrowed surface, *a a′* the transverse section of its canal system, and at *h′ h′* the transverse sections of the spiral canals which lie just at its junction with the ordinary tubular substance *k, k,* forming the lateral walls of the chambers.

6.—Section through the median plane of a very young *Operculina,* showing the origin of the spire from a globular primordial chamber, and showing the presence of the spiral canal and of its extensions even in the very first convolutions; 75 diameters.

7.—Portion of a vertical tangential section passing near the margin of the innermost convolution of a young *Operculina,* and affording a most advantageous view of its canal-system; *a′, a′*, marginal cord of the inner convolution; *g, g,* interseptal canals, springing from *h, h,* the spiral canals; *i, i,* cones of non-tubular substance which take the place of the ordinary tubular substance of the spiral lamina, *k, k,* at the parts where this is joined by the septa; 80 diameters.

8.—Portions of the spiral lamina magnified 250 diameters, showing at A its prismatic appearance, with a tubulus in the centre of each prism, and at B the large orifices of the tubuli upon its internal surface.

9.—Very thin section of a portion of the spiral lamina, showing the ordinary appearance of its tubuli divided transversely, with a delicate areolation between them; 100 diameters.

10.—Vertical section of the inner convolutions, which has happened to pass close to the primordial chamber and the one that springs from it, and which shows at *a, a′*, the two spiral canals running along their exterior; 80 diameters.

11.—Vertical section of a small *Operculina,* showing the general distribution of its interseptal canal-system, and the marked difference in thickness between the spiral lamina of the last and that of the penultimate convolutions; 40 diameters.

12.—Section of the spiral lamina of a tuberculated variety, showing the partial deficiency of the tubuli in certain spots, *b, b,* as well as in the septal bands *a a, a′ a′*, with their crowding together in the neighbourhood of these; 120 diameters.

13.—Internal surface of the spiral lamina of another chamber of the same, showing the uniform distribution of the tubuli, except along the septal bands, and the comparatively large size of their orifices; 120 diameters.

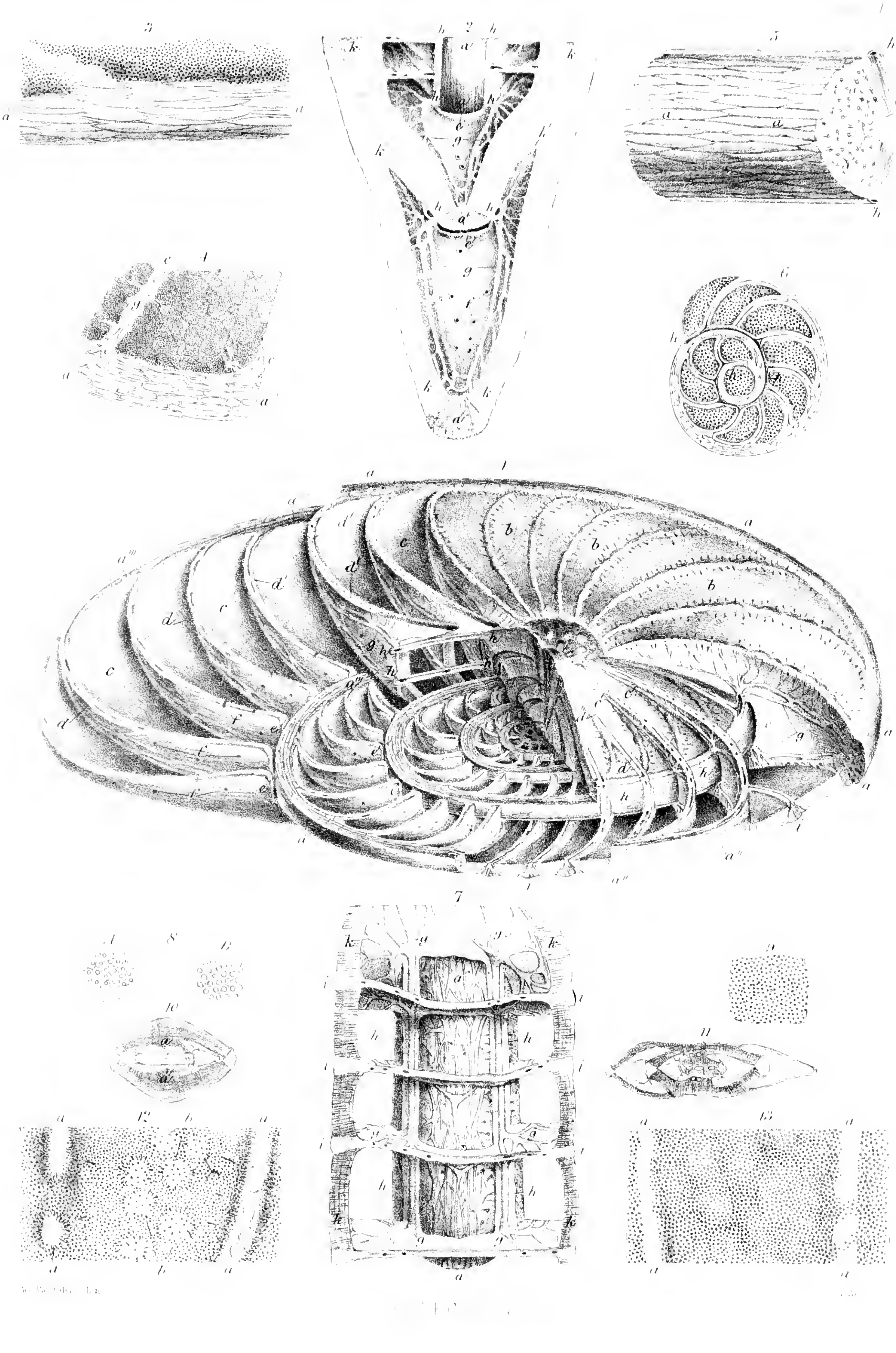


PLATE XVIII.

All the figures in this Plate illustrate the structure of *Nummulina*; and the same letters indicate corresponding parts throughout.

a, a. Marginal cord, as seen in section through the median plane; *a′, a′,* the marginal cord, as seen in sections dividing it transversely; *a″*, furrowed surface of the marginal cord.

b, b. Septa dividing the chambers of the median plane; *b′, b′,* prolongations of those septa over the lateral surface of the included whorl; *b″, b″,* bifurcating prolongations.

c. Apertural fissure.

d, d. Spiral lamina enclosing the chambers of the median plane; *d′, d′,* investing layers of the spiral lamina.

e, e. Columns of non-tubular substance, divided longitudinally by sections at right angles to the median plane; *e′, e′,* the same divided by transverse sections.

f, f. Interseptal canals, as seen traversing the septa longitudinally; *f′, f′,* the same, as seen in transverse section.

Fig.

1.—Portion of *N. gizehensis*, showing the alar prolongations of the marginal chambers over the included whorl. (After D'Archiac.)

2.—Portion of a vertical section of *N. lævigata*, showing the tubular structure of the spiral lamina, with non-tubular columns interposed, the canal-system of the marginal cord as seen in a transverse section, and the apertural fissure.

3.—Portion of *N. garansensis*, showing the reticular disposition of the alar prolongations of its septa, forming numerous isolated chamberlets. (After D'Archiac.)

4.—Small portion of a thin section of *N. lævigata* through the median plane, showing the distribution of the canal-system in the septa and marginal cord.

5.—Larger portion of the same section, less highly magnified, showing the general disposition of the spiral convolutions.

6.—Portion of another section taken parallel to the median plane, highly magnified, showing the tubular structure of the spiral lamina, the transparent, non-tubular structure of the septal bands, and the distribution of the canals in the septa and marginal cord.

7.—Portion of *N. lævigata* laid open by a vertical fracture, showing the furrowed surface of the marginal cord of the included whorl, and parts of two large spiral canals, from which proceed the interseptal canals that pass towards the marginal cord of the outer convolution.

8.—Portion of *N. lævigata* as laid open by vertical fracture in the direction transverse to the radius of the disk, showing the interseptal canals transversely divided, and the columns of non-tubular substance commencing on the septa of the median layer, and extending to the surface through the successive layers of the spiral lamina.

9.—Portion of *N. lævigata*, showing the sub-reticular disposition of the alar prolongations of the septa.

10.—Vertical section of *N. lævigata*, showing the septa and apertural fissures of the chambers of the median plane, the continuity of the successive layers of the spiral lamina over both lateral surfaces, the interposition of the alar prolongations of the chambers, with their dividing septa between those layers, and the columns of non-tubular substance which pass sometimes through one or two of them, sometimes through several.

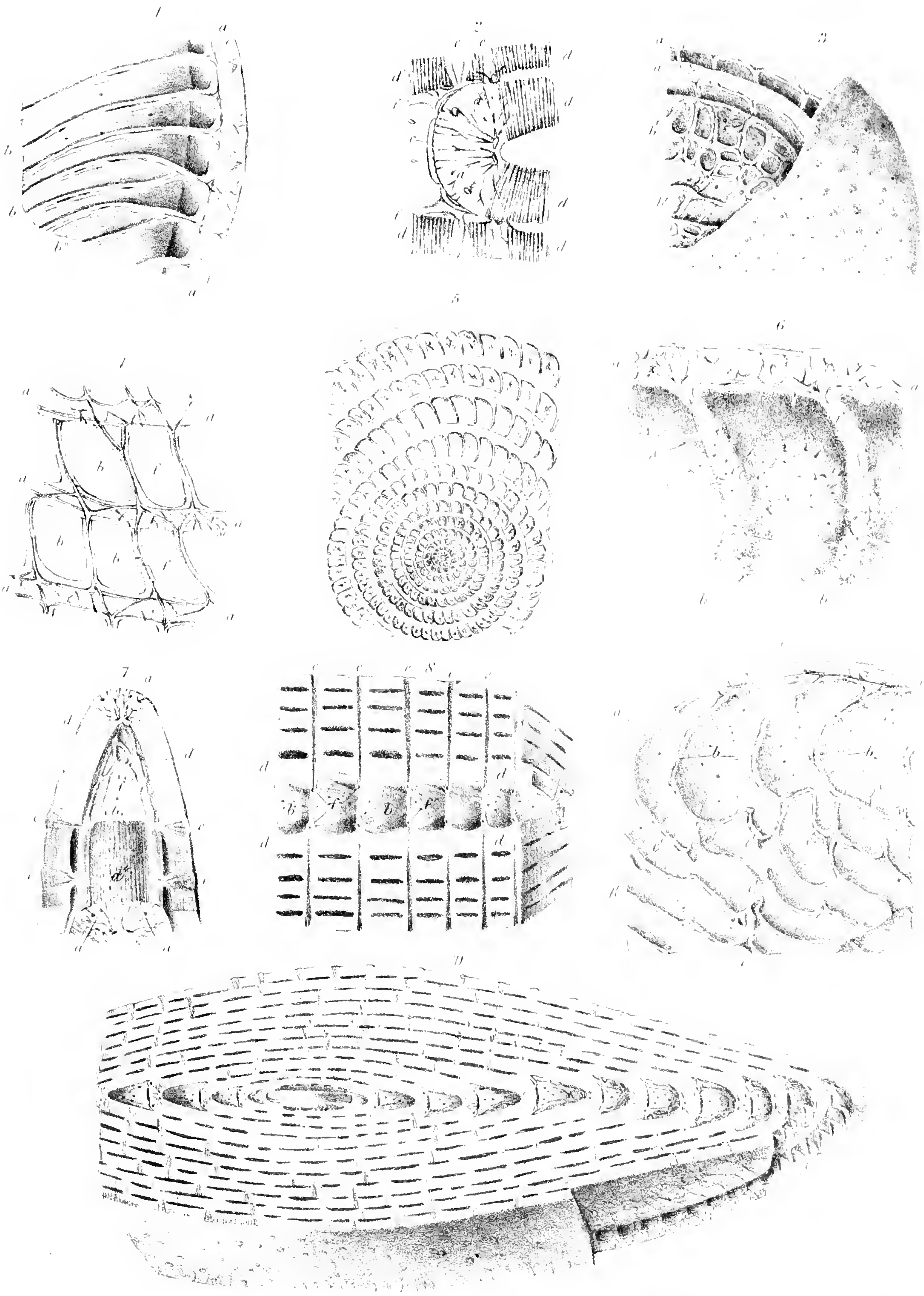


PLATE XIX.

Heterostegina and *Cycloclypeus*.

FIG.

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

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

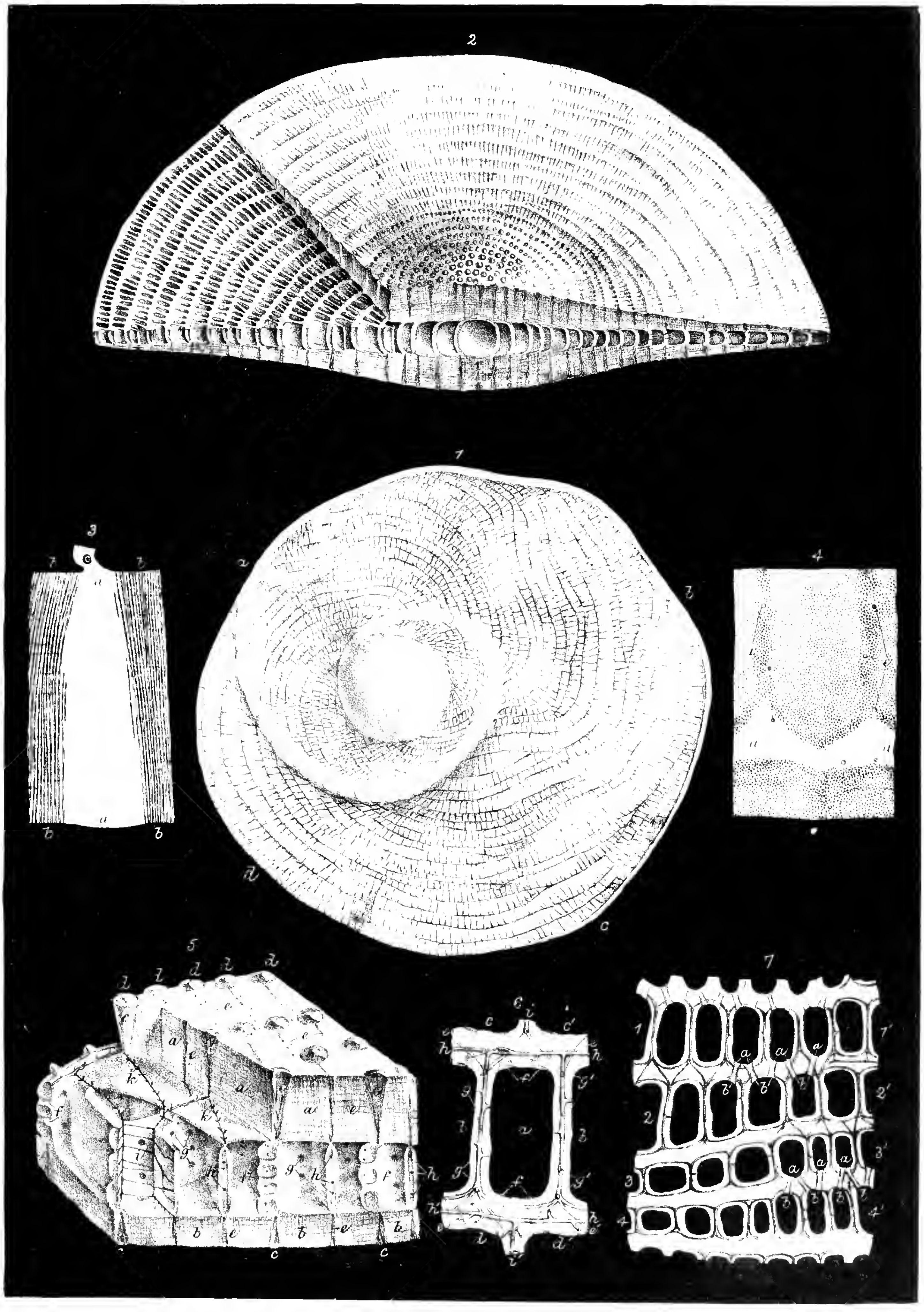
3.—Vertical section of the shelly lamina enclosing the chambers of *Cycloclypeus*, showing its lamellated structure; *a, a*, one of the cones of non-tubular substance replacing the ordinary tubular substance *b, b*, over the septa; *c*, section of one of the interseptal canals: 150 diam.

4.—Thin section of the same lamina taken parallel to the surface of the disk, showing its minutely tubular structure, except where it overlies the annular septum *a a*: at *c c* are seen the divided ends of vertical branches of the interseptal system of canals: 100 diam.

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

6.—Diagram of a single chamber of *Cycloclypeus*, showing its relations to other chambers and to the interseptal system of canals; *a*, cavity of chamber; *b, b*, adjacent chambers of the same annulus, each separated from *a* by a double septum; *c, c'*, and *d, d'*, chambers of external and internal annuli, separated from *a* by the partitions *e e, e' e'*, but communicating with it by the passages *f, f, f, f*; in the septa between *a* and *b, b*, are seen the interseptal canals *g, g*, each of which sends two oblique branches across the annular septa, to communicate with corresponding canals *i, i'* in the septa dividing *c, c'* and *d, d'*; these interseptal canals seem to communicate by short, lateral twigs with the cavities of the adjacent chambers, whilst at *g' g'* they become connected with vertical branches, which unite them with those of other planes; at *h, h, h', h'* are seen the canals proper to the annular septa.

7.—Section of *Cycloclypeus* passing through its median chambered plane, showing portions of four annuli, 1 1, 2 2, 3 3, 4 4, with the general relations of their chambers and their connection by the passages *a b, a b*, the double septa by which they are separated, the thickening of the annular partitions by intermediate deposit, and (in parts) the interseptal system of canals: 36 diam.



2
1
3
4
5
7

PLATE XX.

All the figures in this Plate illustrate the structure of *Orbitoides.*

Fig.

1.—Ideal representation of a half disk of *O. Fortisii,* laid open by vertical and horizontal sections, showing the resemblance of its median chambered plane to that of *Cycloclypeus,* and the interposition of flattened chamberlets between the lamellæ enclosing them on either side: 20 diam.

2.—Ideal representation of a small portion of a similar disk, more highly magnified; *a, a, a,* interior of the chambers of the median plane; *c, c,* their passages of communication with the chamberlets of the annuli internal and external to them; *d, d,* oblique passages of communication between the chamberlets of the superficial layers; *e, e,* non-tubular cones; *h, h,* canal system: 60 diam.

3.—Section of the chambered structure of the median plane, showing the septa to be composed of two lamellæ, with an interseptal canal-system: 50 diam.

4.—Section of the chambered structure of the superficial plane, showing the irregular form of the chamberlets, and the tubularity of the horizontal partitions: 50 diam.

5.—Section of the chambered structure of the median plane of *O. Mantelli,* showing the communications of the chambers of successive annuli by the oblique passages, *a b, a b,* and showing also an appearance of communications between the adjacent chambers of the same annuli at their inner margin: 60 diam.

6.—Vertical section of *O. Mantelli,* showing at *a, a,* the chambered structure of the median plane; *c, c,* apertures of communication between its chambers; *d, d,* oblique passages between the chamberlets of the superficial layers; *f, f,* interseptal canals: 60 diam.

7.—Vertical section of a small specimen of *O. Fortisii,* showing a strong resemblance to a corresponding section of *Nummulina*: 20 diam.

8.—Portion of section of *O. Mantelli,* passing somewhat obliquely from the chambers of the median plane, seen in the lower part of the figure, to those of the superficial layer seen in the upper part; showing in the former the lateral communications between the chambers: 50 diam.

9.—A similar section from another part of the same specimen, showing at its lower part a different form of the chambers of the median plane and the interseptal canals between the two lamellæ of their septa, and showing at its upper part the communications between the chambers of the superficial layer: 50 diam.

10.—Vertical section of a large, thick specimen of *O. Fortisii,* showing the very small proportion which its median chambered plane bears to its superficial layers (that of the under side having been partly broken away), and showing the conical pillars of solid shell-substance, traversed by canals: 10 diam.

11.—Portion of the same section more enlarged, showing at *e, e,* one of the solid pillars, traversed by branches of the canal-system: 100 diam.

11*.—Vertical section of a very small specimen of *O. Mantelli,* showing the very large size of its primordial chamber, and the unusual height of the chamberlets of its superficial layers: 20 diam

12.—Section of the superficial layer of *O. Fortisii,* taken parallel and near to the surface, showing the very large size of the solid pillars *e, e, e*: 100 diam.

13.—Similar section, taken nearer the median plane (being part of the section represented on a smaller scale in fig. 14), showing the smaller size of the pillars, and their penetration by branches of the canal-system: 100 diam.

14.—Section of *O. Fortisii,* taken in the same direction as the preceding, but much less enlarged, and passing in part through the chambered median plane, and in part through one of the superficial layers; in the former is seen the incompleteness of several of the annuli: 20 diam.

15.—Vertical section of a large, thick specimen of *O. Fortisii,* showing the median chambered plane divided transversely, the great thickness of the layers by which it is invested, and the prolongation of the superficial parts of these so as to meet at the margin and thus completely to enclose the median portion: 16 diam.

16.—Portion of a similar section more enlarged, showing the chambers *a, a, a,* of the median plane, divided by double septa, between the lamellæ of which are seen indications of interseptal canals; above these are seen the piles of flattened chamberlets of the superficial plane, communicating by the oblique passages *d, d,* and partly separated from each other by the columns *e, e,* of solid shell-substance: 40 diam.

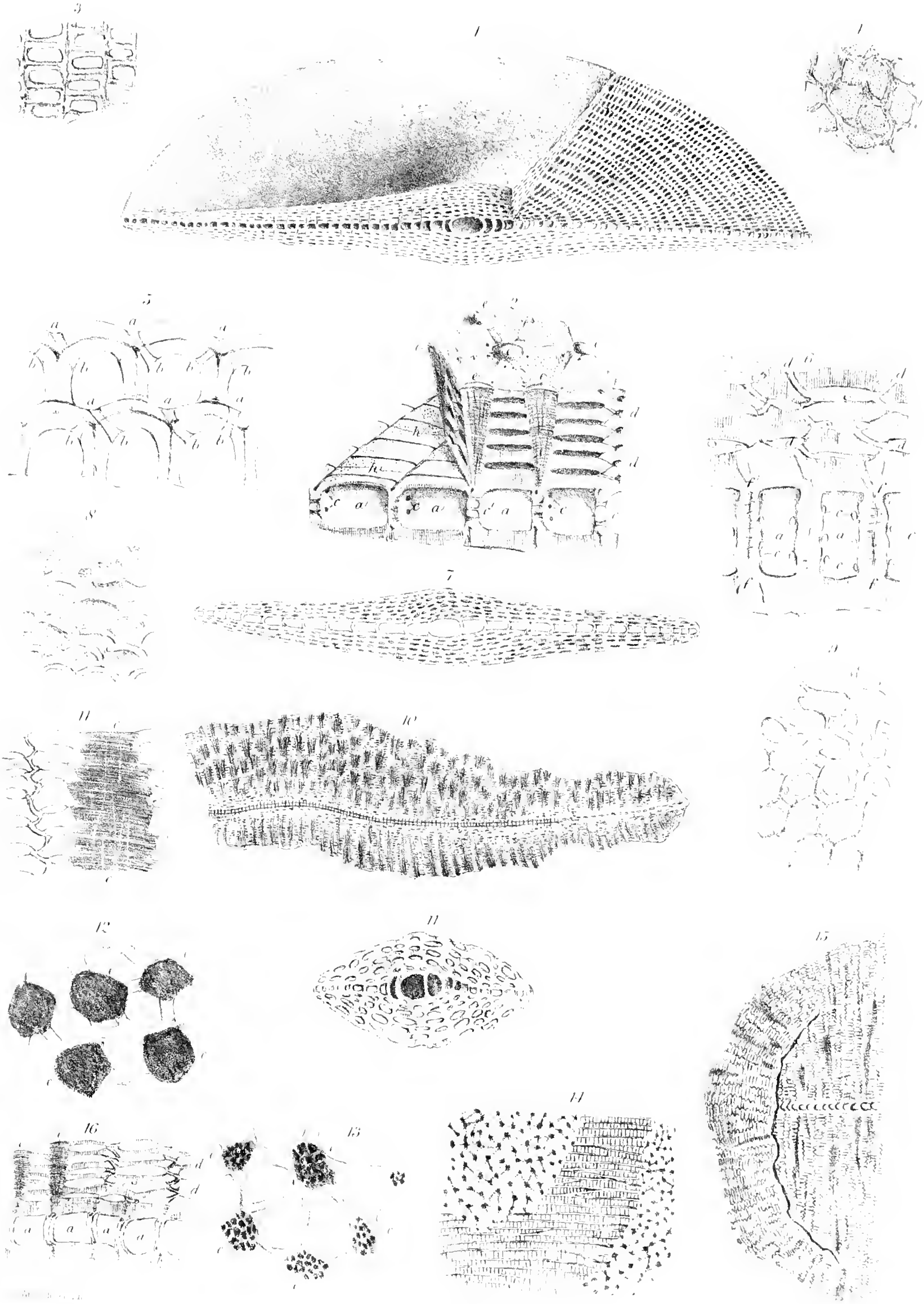


PLATE XXI.

All the figures in this Plate illustrate the structure of *Carpenteria*.

FIG.

1—5.—Interior of the first-formed chambers of five specimens, showing their Globigerine character and arrangement; at *a*, *a*, are shown the remains of the yellowish-brown spongeous substance by which those chambers were occupied: 50 diam.

6.—Portion of a group attached to the surface of *Porites* (Coral): 5 diam.

7.—Isolated specimen growing on the shell of *Pecten*, in which the chambers of the last whorl diverge so widely at the base of the cone as to be in great degree separated from each other: 25 diam.

8, 9.—External apertures at the apex of the cone of two specimens, showing their peculiarly Milioline character: 20 diam.

10.—Portion of a specimen partially laid open by grinding away the apical portion of the cone; showing at *a* the vertical funnel transversely divided, at *b* its communication with the last chamber, at *c* its communication with the penultimate chamber; *d*, d^1, and d^2, three of the complete septa dividing the principal chambers; *e*, e^1, e^2, secondary septa, partially dividing the principal chambers, but not extending to their central portion; *f*, f^1, f^2, incomplete septa projecting inwards from the external wall, but not crossing the cavity of the chamber to reach the opposite wall: 20 diam.

11.—Section of a very flat specimen, parallel to the base of its cone, but not far from its apex; *a*, *b*, *c*, *d*, as in the last figure; *g* and g^1, portions of the canal-system: in some of the chambers are seen spicules resembling those of Sponges: 20 diam.

12.—Portion of the external wall, showing the areolated aspect it derives from the gentle convexities into which it rises between the reticulations that project on its internal surface; at *a* is shown the natural external surface on which the foramina are regularly disposed; at *b* that surface has been removed by grinding, so as to bring into view the inner layer of the wall, on which the foramina are seen to be deficient along the projecting ribs, but to be more closely set together in the portions surrounded by these (see fig. 16): 30 diam.

13.—Portion of a section taken in the same direction as Fig. 11, but represented on a larger scale, showing the annulations of the foramina that are seen obliquely traversing the shell, and the two layers of which not only the principal septa *a*, *a*, but also the incomplete septum *b*, are formed, with the canals included between them; at *c* is seen a large dilatation of one of the canals: 75 diam.

14.—Portion of the group of *Carpenteria* growing on the surface of *Porites*, of the natural size.

15.—An unusually large specimen, of the actual size.

16.—Portion of the external wall of a specimen which has been thinned away by the action of acid, showing the reticulated arrangement of the incomplete septa; the spaces included in the reticulations are in some instances covered in by a thin layer of the shelly wall which has not been removed; but in most other cases this wall has been eaten away by the acid in the central portion of the reticulation, so as to display the dark, spiculiferous substance within: 30 diam.

17.—Siliceous spicules (resembling those of *Halichondria*) from the spongeous tissue occupying the chambers of *Carpenteria*: 75 diam.

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

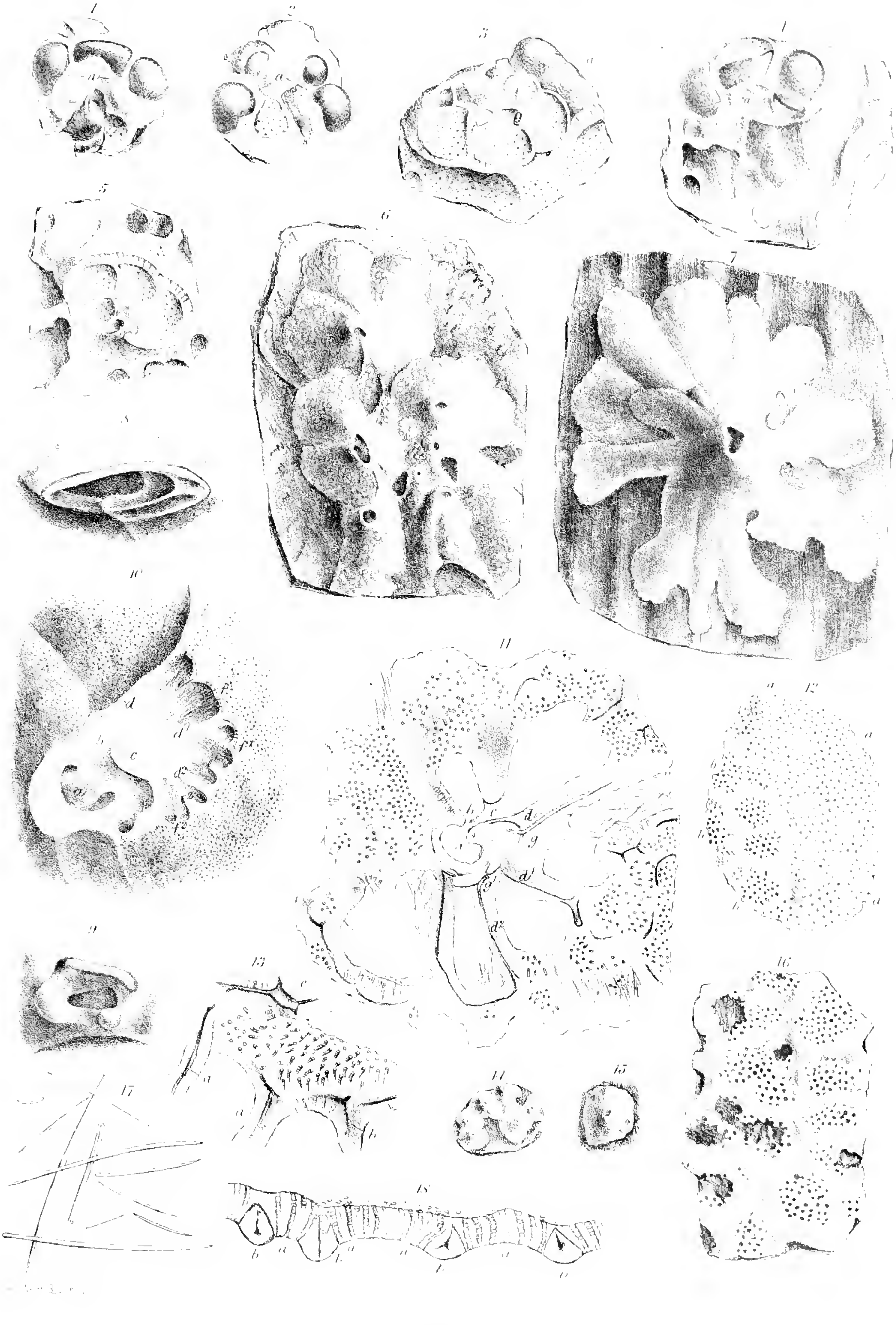


PLATE XXII.

All the figures in this Plate represent casts of the interior of Foraminifera of different types, described and figured by Prof. Ehrenberg in his Memoir 'Ueber den Grünsand und seine Erläuterung des organischen Lebens.'

FIG.

1.—Cast of the interior of a Nummuline shell from the Nummulitic Limestone of Traunstein, and considered by Ehrenberg as representing a new genus, to which he gives the name *Mesopora*.

2.—Cast of the interior of *Orbitoides Fortisii* (*Prattii*), from the Nummulitic Limestone of Traunstein.

3.—Cast of a portion of the median layer of a similar specimen, showing the connections of its chambers and its annular canals.

4.—Cast of the central chambers of an organism designated by Ehrenberg *Orbitoides javanicus*.

5.—Cast of two of the peripheral chambers of the same, showing their connections and the interseptal system of canals.

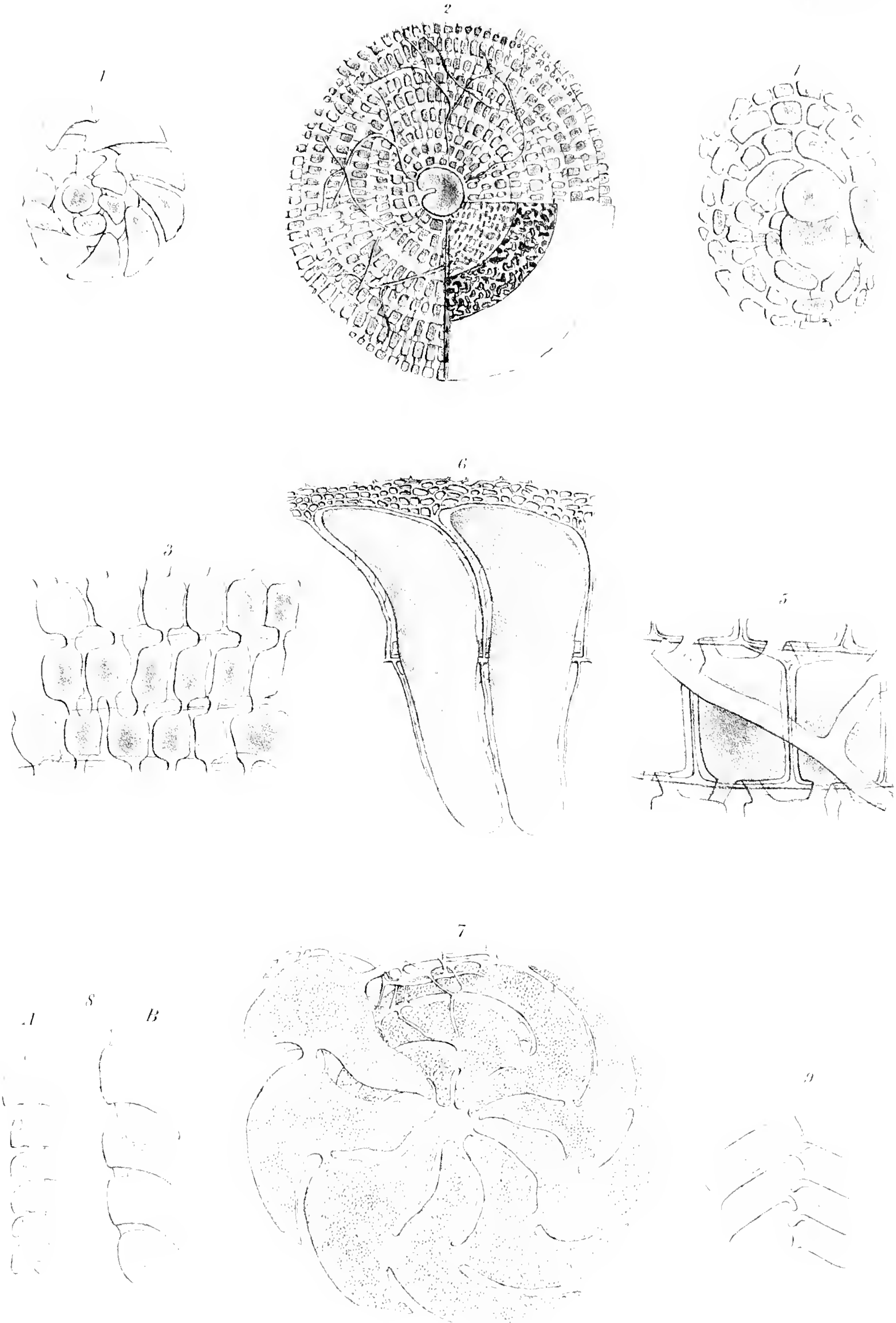
N.B. The broad bifurcating band by which this figure is crossed pretty certainly represents the excavation of some parasitic plant or animal, such as has made the irregular canals in fig. 2.

6.—Cast of two chambers of *Nummulina striata*, showing the forms of their segments and the communication between the canal-system of the interseptal spaces and that of the marginal cord.

7.—Cast of the interior of a Nummuline shell, designated by Ehrenberg *Nonionina* (?) *bavarica*, from the Nummulitic Limestone, showing the forms and connections of the chambers, and a portion of the canal-system.

8.—Casts of (A) *Nodosaria*, and (B) *Vaginulina*, the latter from the Zeuglodon (Nummulitic) Limestone of Alabama.

9.—Cast of the interior of a *Textularia* (*Grammostomum*, Ehr.) from the same.



Internal Casts of Foraminifera