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VI. *On the Nature of the Coccospheres and Rhabdospheres.*

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[Plates 15, 16.]

The origin of the present investigation was an attempt to gain information as to the character of the coccospheres and rhabdospheres by employing the pumping method, first used by Sir John Murray at sea in place of tow-netting. It was considered that the difficulty and great expense of obtaining tow-nettings remote from land, involving the charter of a vessel, might be overcome by inducing the commander of a steamship to pump water through fine silk nets and to prepare and preserve in a suitable manner the proceeds obtained in this way. We have described in 'Nature' (April 1, 1897) the success of this method in the hands of Captain W. Haultain Milner, then of R.M.S. "Para," one of the Royal Mail Steam Packet Company's ships. He obtained for our study not only specimens of coccospheres, but of both kinds of rhabdospheres, of *Pyrocystis noctiluca* and other organisms considered by many to be of uncertain position. While he was engaged on the second voyage during which he carried out these operations, we were enabled, by a grant from the Government Grant Fund and by special leave of absence from the Trustees of the British Museum, to prepare to accompany him on his third voyage, in order to make observations on living material at sea. We made this voyage from Southampton to Barbados, Hayti, Jamaica and Colon (Panama) and back. The unwearying services and numerous valuable suggestions of Captain Milner, Mr. Jolliffe, the chief officer of the "Para," and Mr. Hindmarch, the chief engineer, while we were aboard, contributed greatly to such success as we may have attained.

Our knowledge of the phyto-plankton of the high seas has been derived almost exclusively from the observations and collections made by zoologists, who have advanced their part of the study of plankton with far greater zeal than has been shown by botanists. The "Challenger" Expedition left many problems unsettled, and the Hensen Expedition, accompanied by a botanist (Dr. SCHÜTT) skilled in the minute examination of such organisms, though it accomplished great things, still left a legacy of doubts on many points, and in fact proclaimed more loudly than ever the richness of this field of investigation.

The method of collection was to pump a steady stream of sea-water through fine silk nets. We employed No. 20 miller's silk by three different makers, and though there were at first differences in capacity of these silks for stopping organisms, they soon became fairly equal with use. It has been assumed in making estimates of the amount of plankton that No. 20 silk practically stops all organisms, or at least with a degree of error that may be calculated. Our experience is so decidedly opposed to this, that we are led to doubt the value of estimates based on such an assumption. A new No. 20 miller's silk tow-net stops probably all the larger organisms, Copepoda, large diatoms and the like, but permits a very large proportion of the smaller diatoms, Peridiniaceæ, &c., to pass. When such silk has been used until it begins to be discoloured and for some time afterwards, its efficiency steadily increases, and if it be carefully washed at intervals of a few days, depending on the amount of use, it will remain at its optimum efficiency, always declining a little after each washing, and then recovering again: after some weeks, however, it will begin to decline with great rapidity and soon become riddled with minute holes. The increased efficiency is doubtless attained by the swelling of the fibres and the partial plugging of the meshes. A tow-net, whether towed or used as a filter in the pumping method, is therefore a very variable factor, and we have refrained from making estimates based on its performances. A net even at its highest state of efficiency permits many organisms to pass, as we frequently discovered by pumping into double and even triple nets. Similarly we have tested new nets against seasoned nets by towing them together at the same depths, with the unvarying results on which this criticism is based.

The nets were suspended from boat davitts, the end of the hose-pipe directed into them, and in order to diminish the pressure, the body of each net was immersed in a barrel of water with an overflow into the scuppers. When a net was taken in, its contents were emptied into a funnel of the shape of an inverted and steep cone with a stop-cock at the base. The organisms were allowed to settle in the funnels, and soon drawn off into tubes with fixing and preservative fluids. Most of the organisms settled fairly rapidly. *Pyrocystis noctiluca*, on the other hand, remained sometimes for days afloat in the clear water and capable of emitting brilliant luminosity. We kept the funnels, and indeed all the apparatus in use, securely clamped to working benches throughout the voyage.

Owing to the calcareous nature of the skeleton of the coccospheres and rhabdospheres, the use of fixing fluids of an acid nature (which are usually the best) is completely prohibited. Experiments were made with osmic acid, formic aldehyde, and mercuric chloride. Osmic acid gave the best results (it has no action, at least in dilute solution, upon the skeleton), but it always caused a certain amount of contraction of the contents. Material fixed in this fluid was, after washing, put up in camphor water or in 10 per cent. glycerin with camphor. Formic aldehyde in dilute solution was also found to give fairly satisfactory results. Mercuric chloride, owing to the difficulty of exact neutralisation, was found to be practically useless.

We would recommend for future work of this kind the employment of india-rubber hose-pipes. Canvas hose frequently gives off fine fibres, and leather hose discharges oily matter which clogs the nets and spoils the captures.

Coccospheres and Rhabdospheres.

It is unnecessary to recapitulate the various speculations that have been associated with the coccoliths first described by the late Mr. Huxley from Captain Dayman's deep sea soundings in the North Atlantic, from H.M.S. "Cyclops," in the summer of 1857. About the same time Dr. G. C. Wallich, on board H.M.S. "Bulldog," engaged on a telegraph-cable survey, observed the spherical aggregation of these bodies and named them coccospheres. Dr. Wallich went farther and pointed out the identity of the coccoliths with bodies observed in chalk by Mr. Sorby. Professor Haeckel, studying ooze dredged by Wyville Thomson and Carpenter from the "Porcupine," published a detailed account of his observations in the "Jenaische Zeitschrift," vol. 5, 1870.* The settlement of the matter was, however, in no way materially advanced until the "Challenger" Expedition rediscovered coccospheres and rhabdospheres on the surface, living free in the water, and entangled in the protoplasmic matter of Radiolaria and Foraminifera, and in the stomachs of Crustacea and Salpæ. The rhabdospheres were stated to be tropical, and the coccospheres, though tropical as well, yet more characteristically inhabitants of temperate seas. "There is considerable variety both in the form and size of coccospheres and rhabdospheres, some of the varieties having the component parts (coccoliths and rhabdoliths) much more compactly united into a sphere than others. The interior of the spheres is perfectly clear when examined fresh from the surface, and becomes coloured brown with iodine solution, but with iodine and sulphuric acid no blue colour was observed. They were never observed to colour with carmine solution. When the calcareous parts are removed by dilute acids, a small gelatinous sphere remains, in the outer layer of which the coccoliths and rhabdoliths were embedded" ("Challenger" Reports, Narrative, vol. 1, p. 939). In the "Challenger" Report on the Deep Sea Deposits, Sir John Murray divines the coccospheres and rhabdospheres to be minute pelagic calcareous algæ (p. 257), and, if our observations be worth anything, correctly. The Hensen-Plankton Expedition failed to discover either coccospheres or rhabdospheres, and Dr. Schütt, the botanist of the expedition,

* The *rhabdoliths* were first observed by Oscar Schmidt ('Sitz. der k. k. Akad. der Wissenschaften in Wien,' vol. 62, Part 1, 1870) in the deep sea mud of the Adriatic.

in his "Pflanzenleben der Hochsee" (p. 44), casts doubt on their very existence as organisms, and in any case will have none of them in the vegetable kingdom. Meanwhile, Sir JOHN MURRAY, while crossing the North Atlantic, again obtained coccospheres by the pumping method, and, in private conversation, stated he felt confirmed in his opinion. Matters were in this position when, through Captain MILNER'S enterprise, we obtained the specimens described in 'Nature,' April 1, 1897. Briefly, these enabled us to determine that the calcareous scales (coccoliths) of a coccosphere overlap each other in definite order, providing a defensive armour which yet admits of growth or other alteration of volume. In the diatoms, for example, the siliceous shell admits of only trifling alterations of volume in the individual by sliding at the girdle, and it imposes successive diminutions of size on successive generations, by the peculiar mode of division and the periodical restoration of the maximum size by auxospores. By the overlapping arrangement of its scales, the coccosphere secures the protection of an encrusted wall without such disadvantages as those described in diatoms. We were also enabled to point out, as regards the rhabdosphere with clavate projections, that there was no geometrical arrangement of accurately fitting hexagonal plates such as the "Challenger" figures conveyed, but that the bed-plates in which the rods are inserted are separate from each other. In various other minor points we described the structure of these organisms.

The coccospheres and rhabdospheres were never found in abundance in our collections, though, on a few occasions, they occurred in considerable numbers; of those obtained, however, many were mere shells without contents. The very small size of both coccospheres and rhabdospheres in comparison with the size of the meshes of the finest silk to be obtained for this work, will account for their comparatively rare appearance in our gatherings. Their abundance and wide distribution in pelagic waters is amply proved by the nature of the deep sea deposits.

COCCOSPHERES.

It seems to have been generally overlooked that WALLICH ('Ann. Mag. Nat. Hist.,' 1877) has founded the genus *Coccosphæra* for the reception of two species, viz., *C. pelagica* and *C. Carterii*. The form which we found floating free in the Atlantic agrees with neither of his species even when allowance is made for imperfection of description.

We propose for this species the name *Coccosphæra leptopora*. As obtained from the surface waters, except when undergoing division, it is always spherical in form, its average diameter being about 17μ. When the coccosphere is observed in water, little more can be made out, even with the best objectives, than that the skeleton consists of a number of minute circular plates with an apparent central boss, the plates overlapping one another at their edges: we have previously figured a coccosphere showing these characters ('Nature,' April 1, 1897).

If, however, a drop of water containing the coccospheres is carefully dried on the slide and the residue mounted in Canada balsam, considerably more light can be obtained on the structure of the skeleton. A preliminary treatment with gentian violet is also of advantage, as by its means the calcareous plates themselves become slightly coloured, and their outlines are rendered more distinct. In such a preparation each plate, or coccolith, as it is called, is seen to possess a central clear area from the edge of which radiate a number of beautiful striæ which run to the edge of the plate (Plate 15, figs. 1 and 2). This central clear area has at its middle a small but distinct perforation (figs. 1 and 2) passing through the substance of the plate. The central clear area, as is discovered in a profile view of the plate, is really a slight depression, and in some coccospheres the striæ which run from the edge of the plate can be traced down into the depression, giving to the plate the appearance shown in figs. 4 and 5. In by far the larger number of coccospheres, however, the striæ either do not run down the walls of the depression, or are too close together to be visible, and the depression appears in surface view merely as a clear area.

The exact form of the coccolith can be best made out in a profile view after separation from its surrounding plates. Plate 15, fig. 5*a*, shows a sectional view of a free plate; for such a minute object, it has a somewhat elaborate structure. The coccolith is seen to possess two distinct limbs joined together by a central thick-walled collar. The outer limb is a round plate, convexo-concave in section, very like an inverted shallow watch-glass; the inner limb is a small circular flat plate; the two plates are joined together by the central collar. On the convex free surface of the outer plate there is a minute circular depression appearing in surface view as a clear area. The bottom of this depression is perforated by a canal which leads through the collar and opens out on the free surface of the lower limb. This canal is so very minute that if it had not been possible to fill it with staining material, its existence could only have been suspected from analogy with the larger plates of *Coccosphæra pelagica*, shortly to be described. The two limbs are free at their edges (fig. 5*a*) being connected only in their central parts by the collar.

Although the exact relation of the coccoliths to one another in the skeleton of the organism is difficult to make out, owing to their transparency and close arrangement, a study of coccospheres in optical section leads to the conviction that the plates overlap one another by their outer limbs alone, the edge of the outer limb of one plate being wedged between the edges of the outer and inner limbs of a neighbouring plate. We have given in Plate 15, fig. 3, a diagrammatic representation of a coccosphere as seen in optical section. Such a system of interlocking plates must prove a very effective protection to the organism.

The number of plates in a single coccosphere varies very considerably (*cf.* figs. 2 and 5). A computation of the total number of plates from the appearance of different specimens in surface view, gives a number which varies with the individuals from 20 to 50.

Within the skeleton lies a central protoplasmic body, round which however no distinct cell-wall could be observed. (The protoplasmic body is shown contracted in Plate 15, fig. 2.)

When the organism is observed living the centre of the cell is seen to be occupied by a single more or less round chromatophore of a distinct green colour though with a slight yellow tint (Plate 15, fig. 6). Imbedded in the chromatophore there may be observed a few small refractive granules, presumably oil globules (Plate 15, fig. 7).

Owing to the small size of the objects, and the somewhat contracted condition of most of the fixed material, it has not hitherto been found possible to bring to view a nucleus in the cell. Considering the size of the cell, the nucleus, if it exists, must be excessively minute. We have hopes, however, that we may later, by the aid of other material, be able to distinguish such a structure. All that we can establish at present is that the interior is filled with a protoplasmic body, in the centre of which lies a single yellow-green chromatophore.

The central channels in each plate naturally suggest protoplasmic protrusions from the cell, though no trace of them was observed in any of the specimens. That the protoplasm passes at least into the canal of the plate is suggested by analogy with *Rhabdosphæra Tubifer* (to be described later); and further, the fact that the external depression and canal within the plate sometimes become filled with colour under the action of gentian violet, also points in the same direction. The stain, however, may have been held in the minute cavity only by capillarity.

The only evidence we can bring forward as to the method of reproduction of *Coccosphæra leptopora* is an isolated observation of an individual which was obviously undergoing fission into two (Plate 15, fig. 7).* The body was large and oval in form, and had become slightly but distinctly pinched in on one side, the chromatophore had already divided into two, and the plates were considerably increased in number, as one would expect. The organism must obviously increase in size by the intercalation of new plates between the old ones, but no trace of small or immature plates was observed in any of the specimens examined.

The coccosphere which we have described as *C. leptopora* differs considerably from the coccospheres described by WALLICH and HAECKEL, since it is not only a much smaller structure, but its constituent plates (coccoliths) are round, and much smaller and more delicate than the usually oval coccoliths described from the deep sea deposits by HUXLEY, WALLICH, and HAECKEL. Sir JOHN MURRAY in the "Challenger" Report states that the coccospheres were found in quantities free on the surface, but unfortunately the only figure given represents an imperfect specimen from the sea bottom, and a glance at it shows clearly that it is not our form, *C. leptopora*. It is a form with coccoliths of the type described by HUXLEY and WALLICH, &c. There seemed at first sight to be no evidence that the *Coccospheres*, which we had found

* See note with reference to the reproduction of *C. pelagica* on page 435.

floating free in the surface waters, played any part in the formation of deep sea deposits.

An examination, however, of Plate 11 in the "Challenger" volume on Deep Sea Deposits throws more light on the subject. In fig. 4 of that plate the finer particles of a Globigerina ooze from the Atlantic are figured; among the numerous coccoliths represented, quite a number are obviously the constituent plates of *C. leptopora*. They are not only round with a small central perforation, and of corresponding size, but the characteristic radial striation is also indicated. An examination of fig. 3 of the same plate of the "Challenger" Report gives a still more interesting result; there is there figured a portion of the finer particles of a very pure Globigerina ooze from the Pacific. A number of whole coccospheres are shown, but the interesting point is that these are of two kinds, though it is not noted in the text. The one form has oval coccoliths of the well-known type so often described with a large oval or two smaller apertures; the other form, consisting of circular coccoliths each with a small central pore, is obviously the species *C. leptopora*, which we found floating free upon the surface. The *Coccosphæra*, with large oval plates each of which has a single central or two D-shaped apertures, described in deep sea deposits by HUXLEY (Cyatholiths), HAECKEL and WALLICH, doubtless corresponds with *Coccosphæra pelagica* WALL., and will in future be referred to by that name.

By the kindness of Sir JOHN MURRAY, who provided us with material obtained at various stations by the "Challenger" Expedition, we were enabled to fully confirm the existence of two species of coccospheres in the Atlantic and Pacific ooze, the one, *C. pelagica* WALL., the other, *C. leptopora;* also of two kinds of coccoliths, the constituent plates of the two species.

Plate 15, fig. 12, is a representation of the finer particles of the same deposit, as shown in Plate 11, fig. 4 of the "Challenger" Report. It shows these particles as they appear under an apochromatic objective and under the same magnification as the coccospheres on our plate. The constituent plates of *C. leptopora* are very clearly seen; in some of the plates the striæ show a tendency to run in a somewhat curved manner. Very numerous club-shaped rhabdoliths are present, and also a single specimen of the trumpet form, at the top of the figure.

An examination also of material from Station 166B (as figured in Plate 11, fig. 3 of the "Challenger" 'Report on Deep Sea Deposits') shows a large number of both forms of coccospheres, besides very numerous coccoliths from both species.

In spite of the fact that the shell of *Coccosphæra pelagica* WALL., has been known for more than a quarter of a century, and its constituent plates for a longer period, it has not hitherto been at all satisfactorily described. WALLICH'S figure has undoubtedly the *plates* of the organism to which we have applied his name, *C. pelagica*, but it hardly seems to represent the complete shell as we find it at the sea bottom. The figures given by HAECKEL and by Sir JOHN MURRAY refer either to imperfect specimens, or show very little detail of structure.

Plate 16, fig. 6 shows, under the same magnification as that of *C. leptopora*, a specimen of *C. pelagica* obtained from a Pacific Globigerina ooze ("Challenger," Station 166B). It is seen at a glance to be much larger than the largest of the species just described. The specimen was about 27μ in diameter; they vary down to 20μ, but it is unusual to find them smaller. The individual plates themselves (coccoliths) are also much larger, those figured reaching 14μ in diameter. It is interesting to note that the range of variation in size of the coccoliths themselves is much less than that of the coccospheres; the small size of some coccospheres being due more to a reduction in number of the plates than to a reduction in size of the individual plates.

The plates of *C. pelagica* are oval in form, and in the middle of the upper surface each has a large oval cup-shaped depression (some 8μ in long diameter) very clear in surface view (Plate 16, fig. 6). Running from the edge of the depression to the edge of the plate itself are a number of fine radial striæ; somewhat finer striæ also run down on the inside of the central depression. At the bottom of the depression there is a fairly large oval aperture, in some cases cut into two **D**-shaped apertures by a cross-bar of calcareous material. The plates vary a little in the extent to which they overlap, some overlapping one another nearly up to the central depression, others to a much less extent (see fig. 6). A study of the surface view alone would lead one to believe that the coccoliths of *C. pelagica* have a simple plate-like structure with a single central hollow, but an examination of separate coccoliths from various aspects proves that they have a complicated structure built up on the same type as that of the coccolith of *C. leptopora*.

HUXLEY, WALLICH, HAECKEL, &c., have all studied in detail from the deep sea deposits objects which they called coccoliths; these are, in point of fact, the constituent plates of *C. pelagica*. HUXLEY, as is well known, compared the form of the plates, to which he gave the special name of cyatholiths,* to two shallow watch-glasses, placed one inside the other, with a pad of some substance, such as paraffin, between. WALLICH also compared them to a shirt-stud, but the first satisfactory explanation of the structure of the plates (of *C. pelagica*) is that given by Messrs. DIXON and JOLLY ('Nature,' September 10, 1897) in their description of the coccoliths obtained by them in the waters of Dublin Bay, specimens of which they have been good enough to give us for examination. We determine them to be the coccoliths of *C. pelagica*. It is their interpretation, with some modifications, that we believe to be the correct one. As they point out, owing to its small size, its transparency and its complexity of structure, the coccolith (of *C. pelagica*) is a very difficult object (though, of course, it is very much larger and more distinct than that of *C. leptopora*). We found that the best way of studying these structures was

* There seems little doubt that the "discolithi" described by HUXLEY and HAECKEL are really the constituent plates of *C. leptopora*, in which the double structure was overlooked. OSCAR SCHMIDT (*loc. cit.*) as long ago as 1870 suggested that there was really only one form of coccolith, the cyatholith.

to mount them in strong glycerine, and by means of gentle movements of the cover-glass to roll them slowly over and over while keeping them under close observation under an oil immersion objective. Partially broken specimens are also a great help to the proper understanding of the plate structure.

The plates and coccoliths of *C. pelagica* are then found to consist each of two thin limbs, elliptical in surface view and convexo-concave in section. These two limbs are connected together by a thick walled collar.* The outer limb has its convex surface turned outward and is somewhat larger than the inner limb (Plate 16, fig. 8, where a coccolith is shown in optical section). The outer limb shows in its centre the wide-mouthed hollow which is so clearly seen in surface view (Plate 16, figs. 6, 7). This hollow rapidly narrows as it continues downwards, and at about the middle of the collar it is reduced to a small oval opening by the bulging in of the walls. The oval opening is also very clear in surface view (Plate 16, fig. 6); in many coccoliths it is divided into two D-shaped apertures by a cross-bar which runs across the short diameter of the opening (fig. 7*a*, *b*). The small oval opening soon widens out again below (Plate 16, fig. 8), and opens as a funnel-shaped cavity on the free side of the inner limb. It is clear from this description that the coccolith of *C. pelagica* is perforate through its whole thickness like that of *C. leptopora*, and that it is built up on exactly the same type. A study of optical sections of *C. pelagica* shows also that the plates are interlocked with one another in exactly the same way as is described for *C. leptopora*.

A study of the deep sea deposits of the Atlantic and Pacific Oceans shows then clearly that the coccoliths to be found there are of two distinct kinds, one large and oval with a very clear perforation, the constituent plates of *C. pelagica* WALL., the other small and round with a minute perforation, the constituent plate of *C. leptopora*. The latter organism we have found living and floating free on the surface waters of the Atlantic; that it exists also in the waters of the Pacific there is no shadow of doubt, as its skeleton is found in numbers in the deposits of that Ocean. The former organism, *C. pelagica*, is found in both Pacific and Atlantic Oceans, as its skeleton bears witness, and it was no doubt the form found by WALLICH and the "Challenger" naturalists in the surface waters.† It is from these two organisms, and as far as we know from these two organisms alone, that the coccoliths of the deep sea deposits are derived.

* We have refrained from the use of the term valves, employed by Messrs. DIXON and JOLLY to describe the two portions of the plate, since it bears with it the suggestion that the coccolith is an independent organism.

† In material, lately obtained for us by the kindness of Captain COWIE, R.N.R., of the Peninsular and Oriental Steam Navigation Company, from the surface waters of the Arabian Sea, we have found not only *C. pelagica*, but have also observed it connected together in chains of four or fewer individuals: this seems to suggest that the daughter cells remain together after successive fissions. We have inserted a figure of this in Plate 15.—(August 18, 1898.)

The Coccoliths and Rhabdoliths of Cretaceous and other Deposits.

Since Wallich in 1861 pointed out the identity of the coccoliths observed by Huxley and himself, with the structures described by Ehrenberg and Sorby in chalk, it has been a generally accepted view that the coccoliths are to be found in abundance in cretaceous rocks. Owing, however, to the want of a clearly-defined standard of structure, the name coccolith is now given by geologists to a number of very diverse objects; in fact, it has come to be applied to any small, perforated, plate-like body, either consisting of calcium carbonate or of some presumable replacement of that substance. Geologists have in this matter departed from the view of Huxley, derived from his interpretation of the structure of coccoliths in the deep sea deposits.

We have shown that these coccoliths are the constituent plates of *C. pelagica* and *C. leptopora*, and that they possess a very well marked type of structure, viz., two limbs joined together by a central collar. The real test of a coccolith is thus its double structure. Judged by this standard, by far the larger number of bodies described by geologists as coccoliths, have no claim to be so considered. There is, in fact, no evidence that they are derived from even allied organisms.

In order to place this matter beyond doubt by an examination of authentic geological coccoliths, we were supplied by Professor Judd and Mr. Chapman with material for comparison with that obtained from the surface organisms and the deep sea deposits.

Huxley has figured a true coccolith with double structure from the Sussex chalk ('Quart. Journ. Micr. Sci.,' 1868), and he states further that he has observed coccospheres in the chalk. Sollas ('Geol. Mag.,' 1876) has figured what he describes as a coccosphere from glauconitic granules in the Cambridge greensand, but the record of true coccoliths is exceedingly scanty—partly, no doubt, owing to geologists having paid no attention to the profile view of these bodies. Sollas, for example (*loc. cit.*), has figured a number of very diverse and dubious bodies as coccoliths.

For the purpose of comparison with the true coccoliths we have figured on Plate 16 a number of spurious geological coccoliths from various beds. These bodies are shown under the same magnification as our figures of the coccospheres and coccoliths of *C. pelagica* and *C. leptopora*. Fig. 1*a*–*g*, shows so-called coccoliths from the gault of Folkestone. All three types of them are given in side as well as in surface view. Of these three, only that in figs. 1*a*, *b* exhibits the characteristic double structure, and it occurs comparatively rarely. It has an oval form, with a distinct oval perforation, and seems to be of the *C. pelagica* type, though considerably smaller than the plates of this species. Figs. 1*c*, *d*, *e* are three views of one plate, possessing a very odd structure which excludes it from the category of coccoliths, as does the structure of the form represented in figs. 1*f*, *g*, which is simply a flat plate with a single perforation and various markings on one surface. Fig. 2 shows a number of similar bodies from chalk marl. Fig. 2*a* is the well-known cross-barred type of so-called coccolith, but when viewed from the edge it is seen to be a simple plate of slight thickness. It may conceivably be the remaining portion of a coccolith like that of *C. pelagica*, with the projecting limbs eroded, but there is no evidence in support of this view. Fig. 2*c* is a simple oval plate with a single perforation, and figs. 2*d*, *e* have no traceable resemblance to true coccoliths. Figs. 2*f*, *g* represent two rhabdoliths from the same bed; the latter differs from the rhabdoliths of our own seas in its crenate margin, its large size, and in the width of the tube of the trumpet. In figs. 3*a*, *b*, *c* are shown so-called coccoliths from a hollow chalk-flint from Guildford. The calcium carbonate in their case is supposed to have been replaced by chalcedony. They have no structural claim to be included among coccoliths. Figs. 4*a*–*d* represent so-called coccoliths from the chalk of Meudon, near Paris. Figs. 4*a* and *b* are surface and side views respectively of a simple hollow plate of calcium carbonate. Figs. 4*c* and *d* are similar views of another type of spurious coccolith. It is radially striate, and in surface view resembles a true coccolith, but a side view shows that it is a simple thick plate with a central boss, but with no trace of double structure.

We have found coccoliths which agree most closely with those of *C. pelagica* and *C. leptopora* in the calcareous earths of the Barbados rocks. Messrs. JUKES BROWN and HARRISON ('Quart. Journ. Geol. Soc.,' vol. 48, 1892) state that the coccoliths of this deposit possess the double structure described by HUXLEY. We show at fig. 5 a number of these bodies. Figs. 5*c* and *d* compare very well with plates of *C. pelagica* and *C. leptopora*. In figs. 5*e* and *f* we show a three-quarter side view of two of these coccoliths in which the double structure is clearly displayed. The central perforation of these two forms is large in proportion to the size of the plate, probably due to erosion. In figs. 5*a* and *b* there are shown two somewhat aberrant forms. Fig. 5*g* no doubt represents a kind of rhabdolith.

Mr. SCHWARZ has described ('Ann. and Mag. Nat. Hist.,' 1894) coccoliths as separate independent organisms,* which he puts "provisionally among the Phycochromaceæ, near to *Glœocapsa*, *Chroococcus*, &c., to which they seem to be allied by their reproduction." He establishes the name *Coccolithus Oceanicus* to include all forms, fossil and recent. It is apparent that our observations in no respect agree with those of Mr. SCHWARZ.

We may conclude our remarks on this part of the subject with the general statement, that though true coccoliths are to be found in cretaceous deposits, they are usually far from numerous, and the majority of the bodies described as such have no claim to be so considered. Presumably the latter are derived from some calcareous organisms, for the present unknown.

* In this he has followed GÜMBEL, "Vorläufige Mittheilung über Tiefseeschlamm;" 'N. Jahrb. für Mineral.,' vol. 6, 1870.

Rhabdospheres.

The rhabdospheres were much more rarely met with than the coccospheres. Their distribution is said to be more distinctly tropical, but an individual was found as far north as Lat. 41° 30′ N. To the rhabdosphere with trumpet-shaped projections we have given the name *Rhabdosphæra Tubifer*, and to the form with club-shaped projections, the name *Rhabdosphæra Claviger*.

The body of *Rhabdosphæra Tubifer* is usually spherical, but sometimes oval in shape, and when seen in optical section is apparently composed of closely-apposed plates, though the exact limits of the individual plates are not clearly visible. The trumpet-shaped projections arise regularly over the surface (Plate 15, fig. 8), one presumably from the centre of each plate. The trumpets are extremely attenuate at their point of insertion on the plates (fig. 9); they broaden out rapidly, however, at their free end, where the edge is sharply recurved (figs. 10*a* and 10*b*).

The trumpets are hollow throughout, and in stained specimens granular protoplasm can be seen extending up the trumpet for nearly two-thirds of their length. The actual substance of the trumpets takes up gentian violet slightly. The central portion of the body contains a protoplasmic substance which may be readily stained. No nucleus was discovered. We can present no evidence as to the existence of chromatophores, though we have little doubt that these will yet be observed under favourable conditions.

The central portion of *Rhabdosphæra Claviger* (fig. 13) is spherical and composed of numerous plates. These seem either to be closely apposed or to be separated by a short distance from one another (fig. 14). From the centre of each plate rises a single club-shaped projection, perforated by a central canal (fig. 15), which passes through the plate and connects the central body with the exterior. The rhabdoliths in deep sea deposits are sometimes found split, along the line of the canal, into two halves (Plate 15, fig. 15). There is a minute central protoplasmic body (fig. 13). No nucleus was discovered, and, as in the other species, we can present no evidence as to the existence of chromatophores. This species was of exceedingly scanty occurrence. Considering the great abundance of rhabdoliths at the bottom, we should have expected to find more of it at the surface.

We observed only one case in which the plates were separate from each other (Plate 15, fig. 14). They would seem usually to be in close apposition, like those of *R. Tubifer*. In the specimen figured there were also indications of five small elongated perforations in each plate.

Classification.

Haeckel ('Systematische Phylogenie der Protisten und Pflanzen,' 1894, p. 110) places the coccospheres and rhabdospheres in a family by themselves which he calls

"Calcocyteæ (= Coccosphærales)". The Calcocyteæ, with the Palmellaceæ, Xanthellaceæ, and Murracyteæ, form the class Paulotomeæ of the algæ. He also makes two genera for the coccospheres, *Coccosphæra* and *Cyathosphæra;* and two genera for the rhabdospheres, *Rhabdosphæra* and *Discosphæra.* HAECKEL knew nothing of their mode of division, of details of their skeleton, or of the chromatophore; his reason for placing them among the algæ seems to be due to the belief that a yellow sphere of protoplasm is left on dissolving the skeleton with acid.

The resemblance to the Palmellaceæ (Pleurococcaceæ), on which HAECKEL relies, is however, a purely superficial one. The Coccosphæraceæ cannot be considered as related to any of the Protococcoideæ, but must, at present, be placed alone as an isolated group of doubtful affinities.

As we have shown, the coccospheres belong to one genus only; the rhabdospheres also we have included under one genus.

CONSPECTUS OF COCCOSPHÆRACEÆ.

Free unicellular Algæ, provided with an outer covering of calcareous plates free from, over-lapping, or readily separable from, each other; the plates characterised by symmetrical excrescences or markings.

Coccosphæra WALL., in 'Ann. and Mag. Nat. Hist.,' Ser. IV., Vol. 19, 1877, p. 348.—Spherical; plates consisting each of an outer and an inner expanded limb joined by a central collar, numerous, circular or oval, and over-lapping, perforate, striate radially on the outer face; with a single central green chromatophore. Reproduction by fission. *Cyathosphæra* HAECK.

C. pelagica WALL., *loc. cit.*—Plates oval, with a large central depression and oval perforation, inner limb concave inwardly (Plate 16, figs. 6–10). *C. Carterii* WALL., *loc. cit.*

C. leptopora n. sp.—Plates circular, with a very small central depression and minute perforation, inner limb flat (Plate 15, figs. 1–7).

Though there is a great variation in the size of these organisms, *C. pelagica* is generally larger than *C. leptopora*, and its plates are invariably so.

Rhabdosphæra HAECK., 'Syst. Phyl.,' p. 111.—Globular to oval, plates round or angular perforate, free from or apposed to each other, bearing projections from the centre of the outer surface.

R. Tubifer n. sp.—Plates bearing hollow, straight trumpet-shaped projections from the centre of the outer surface (Plate 15, figs. 8, 9, and 10). *Discosphæra* HAECK.

R. Claviger n. sp.—Plates bearing straight perforate club-shaped projections at the centre of the outer surface (Plate 15, figs. 13, 14, and 15).

Description of the Plates.

PLATE 15.

Figs. 1–7. *Coccosphæra leptopora* Murr. and Blackm.

Fig. 1. External view of skeleton. × 2450.

Fig. 2. Specimen showing central protoplasmic body. × 2450.

Fig. 3. Diagram showing arrangement of plates.

Fig. 4. Specimen with central protoplasmic body, showing the striation running down the sides of the external depression.

Fig. 5. A similar specimen with a small number of plates. × 2450. *a*. Optical section of a single coccolith.

Fig. 6. Specimen when seen in the living condition, showing central chromatophore. × 900.

Fig. 7. Individual undergoing fission; the chromatophore already divided. × 900.

Fig. 7a. *Coccosphæra pelagica* Wall. A chain of four individuals.

Fig. 8. *Rhabdosphæra Tubifer* Murr. and Blackm., in surface view. × 1900.

Fig. 9. The same in optical section. × 2450.

Fig. 10. *a* and *b*. Sketches of the free ends of the trumpets of *R. Tubifer*.

Fig. 11. A Protozoon devouring rhabdospheres; the trumpets have been dissolved away from the upper rhabdosphere. × 400.

Fig. 12. Deep sea deposit ("Challenger," station 338, Lat. 21° 15′ S, Long. 14° 2′ W. 1990 fathoms), showing coccoliths of *C. leptopora* and numerous rhabdoliths. × 2450.

Fig. 13. *Rhabdosphæra Claviger* Murr. and Blackm. × 900.

Fig. 14. The same in surface view showing separate plates and apparent apertures in the plates. × 1300.

Fig. 15. Rhabdoliths from the deep sea deposit before figured, one of them split along the line of the central canal. × 2450.

PLATE 16.

(*All figures* × 2450.)

Fig. 1. From the gault of Folkestone; *a* and *b*, surface and side views of true coccolith; *c*, *d*, *e*, three views of spurious coccolith; *f* and *g*, two views of another spurious coccolith.

Fig. 2. From chalk marl; *a*, *b*, *c*, *d*, *e*, various types of spurious coccoliths; *f* and *g*, true rhabdoliths.

Fig. 3. From hollow chalk flint of Guildford; *a*, *b*, *c*, spurious coccoliths.

Fig. 4. From chalk of Meudon; *a*, *b*, surface and side view of a form of spurious coccolith; *c*, *d*, similar views of another such form.

Fig. 5. From the calcareous earths of Barbados; *a* and *b*, aberrant forms of coccoliths; *c* and *d*, coccoliths of the *C. leptopora* and *C. pelagica* type respectively, in surface view; *e* and *f*, three-quarter side views of similar coccoliths; *g*, rhabdolith.

Figs. 6–10. *Coccosphæra pelagica* WALL.

Fig. 6. Coccosphere from the sea-bottom in surface view ("Challenger," station 166B., Lat. 39° 8′ S, Long. 170° 43′ E, 400 fathoms).

Fig. 7. *a*, Coccolith seen from outside; *b*, coccolith seen from inside.

Fig. 8. Diagrammatic optical section of a coccolith.

Fig. 9. Broken coccolith which has lost inner limb.

Fig. 10. Coccolith from Dublin Bay.

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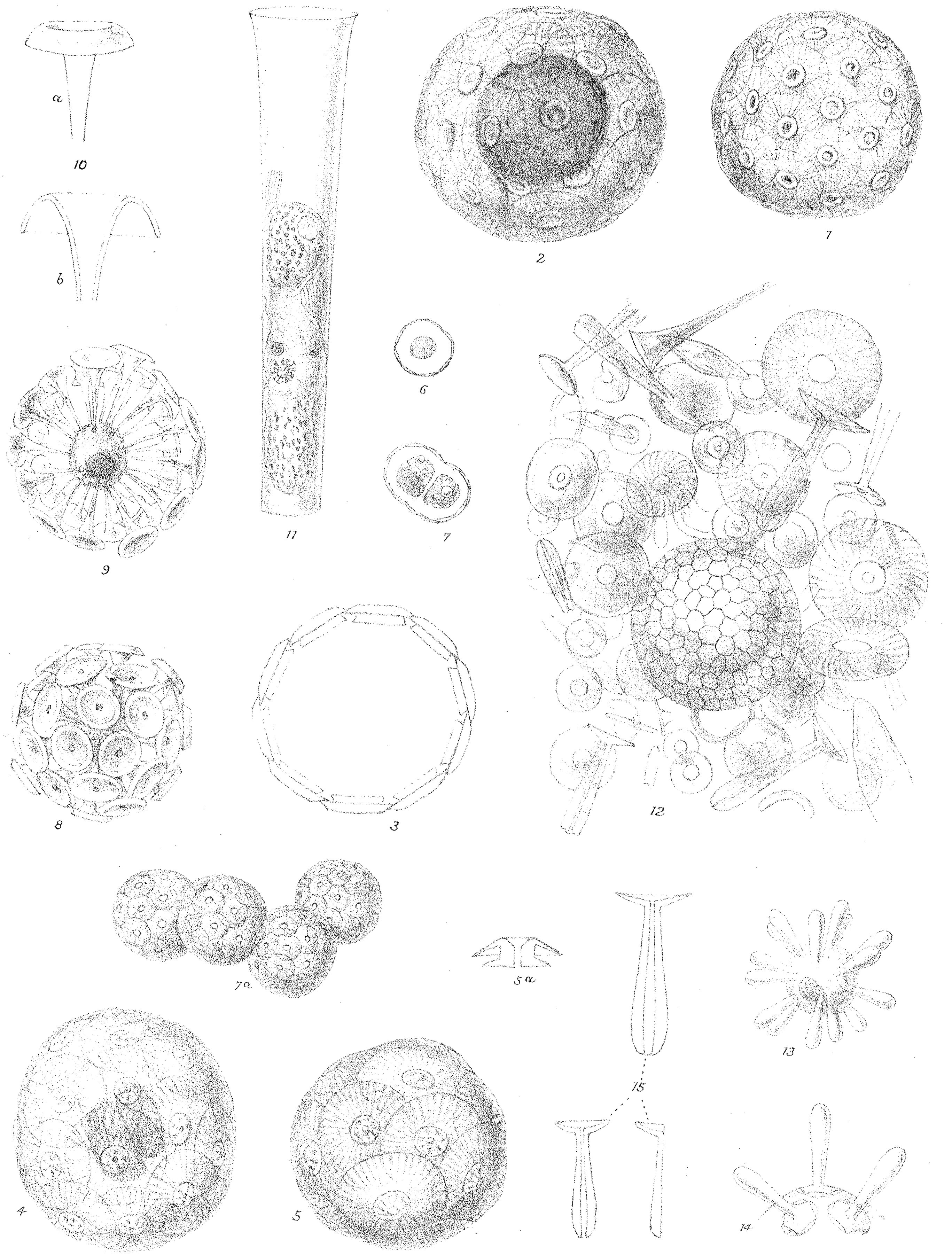
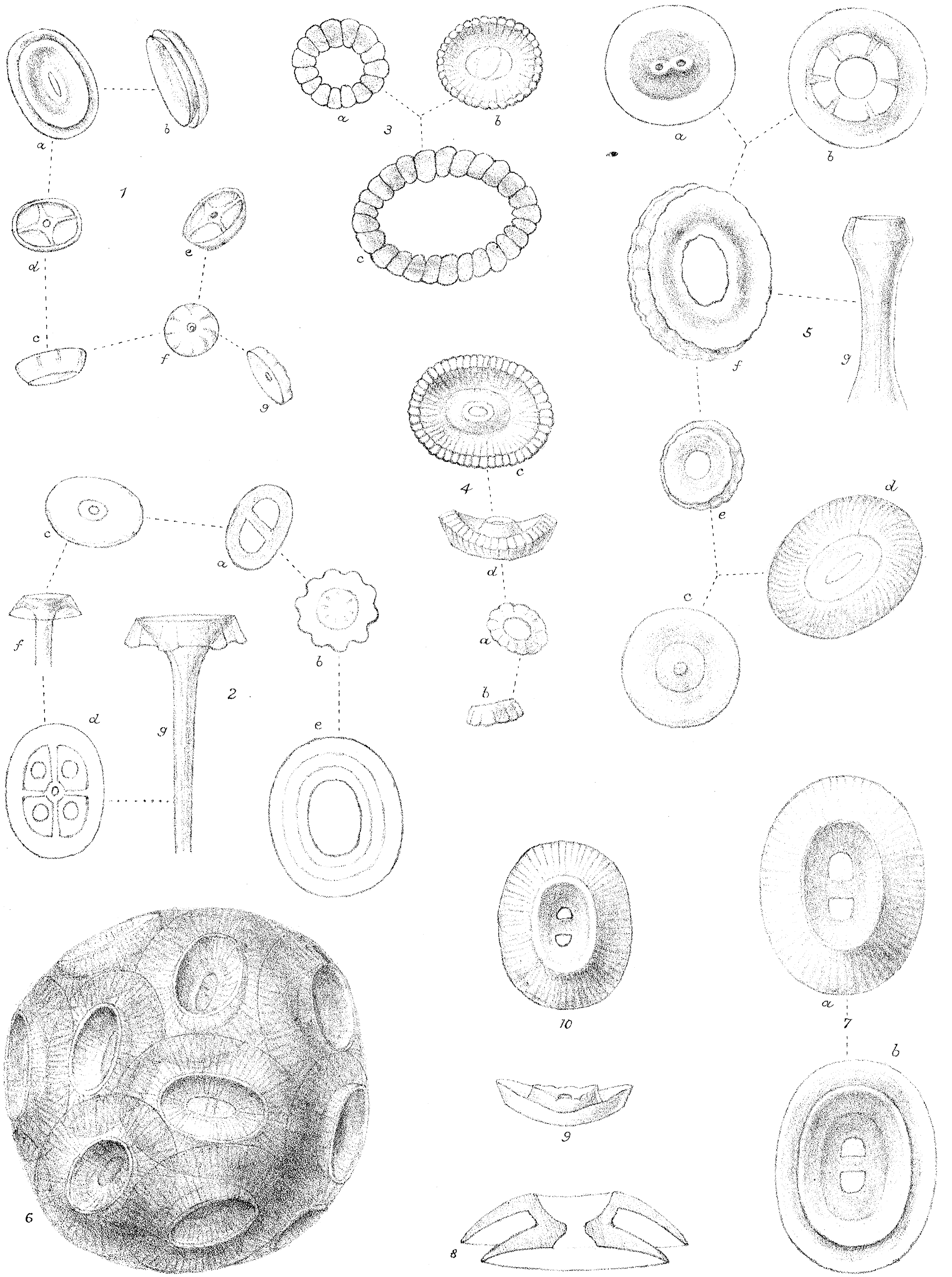


R. Highley del. et lith.

COCCOSPHERES & RHABDOSPHERES.



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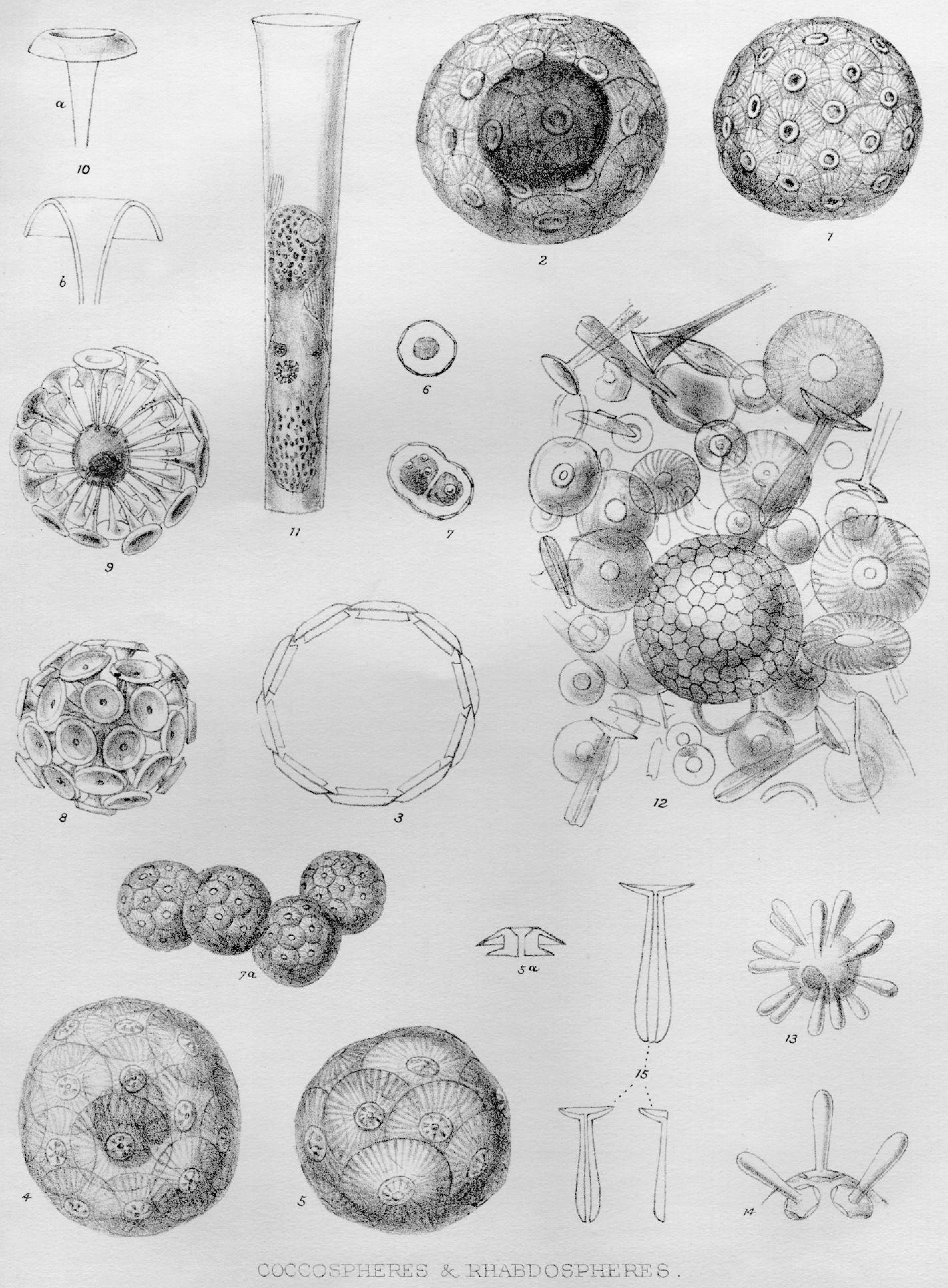

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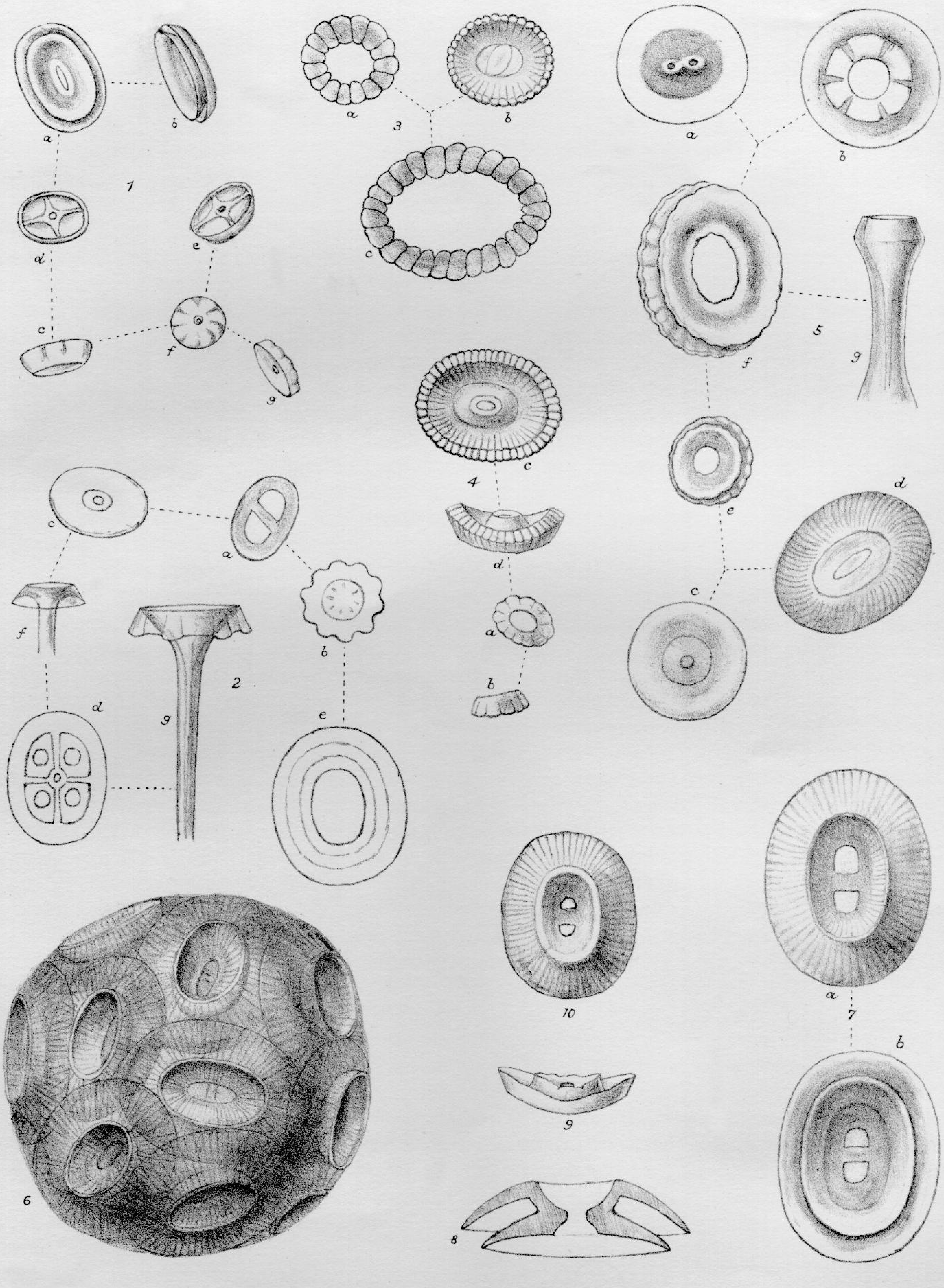

COCCOSPHERES & RHABDOSPHERES

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