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Article XIX.—FURTHER NOTES ON OZARKIAN SEAWEEDS AND OÖLITES.[1]

By G. R. Wieland.

Plates XIV–XIX.

In July, 1825, there appeared in the 'American Journal of Science' an excellent article by J. H. Steele on the Oölites and certain remarkable concretions observed to accompany them in the limestones about Greenfield, Saratoga County, New York. In fact this short paper was a really notable contribution. For its clear record of the occurrence of the oölites and cherts in the mid-Ozarkian formation now called the Saratogan is not only the first definite notice of American oölites but one of the earliest of all references to the oölitic horizons of the Paleozoic; while the large "concretions" of which there is given a very good figure showing both outer form and mode of occurrence, are but little different from the long problematic fossils described without reference to Steele's earlier notice nearly sixty years later by James Hall as *Cryptozoön proliferum* (2). Still more recently similar isolated bulky turbinate types from the St. Peter sandstone of Minnesota have been named *Cryptozoön minnesotense* by Winchell (3), and a somewhat more lenticular form of the Shakopie limestone is called *Cryptozoön giganteum* by Chaney (18). Yet other species are those of Dawson (16) and Seely (23), amongst them being *Cryptozoön steeli*.

Although the lapse of eighty-eight years has added much to our knowledge of the two subjects of Steele's paper, *Cryptozoön* still remains a little known form, while the origin of the oölites is a subject of keen controversy, a problem as difficult as it is interesting. We have, therefore, not passed by the time when these seemingly remote subjects need necessarily be dissociated. *Cryptozoön* and the cherts, calcareous and siliceous oölites are notable features of the Ozarkian, ever recurring together in the field as objects of widening geologic interest. And it may yet prove that aside from mere historic perspective Cambrian and later shore conditions justify a sequel to the contribution of Steele. Accordingly, in the present paper we briefly consider the evidence now going to show that *Cryptozoön* belongs to a group of Algæ which formed vast reefs in the Ozarkian oceans, and also

[1] See list of authors cited in chronologic order at the end of this article and referred to in the text by parenthetic numbers, or by dates.

describe from the Conococheague of Pennsylvania a new species, likewise of the reef-making type, going to prove that the hypothetical "age of seaweeds" preceding the coal plants was a reality. Following which there are subjoined remarks on the origin of the more closely associated oölites.

I. Silicified Seaweeds of the Conococheague.[1]

Text Figs. 1 and 2 and Plates XIV–XVIII showing a huge new silicified type.

Fully as interesting as the oölites of the Cambrian and Ordovician, and quite as problematic until now, are the huge fossils from Centre County, Pennsylvania, of the type shown in text Figs. 1 and 2 and Plates XIV–XVIII. These new forms occur closely associated with fine grained oölites of the lowermost Conococheague, Stose (28), and would in any case be well worthy of record because belonging to a series in part collected over forty years ago near locality A in Ziegler's map (31). At this point these silicified seaweeds, together with some siliceous oölite and numerous flinty boulders not distinctly granular or cherty, weather out from the underlying limestones which although markedly siliceous are yet soluble enough to be subject to cavern honeycombing on an extensive scale. Drainage, as numerous sinkholes and ponds plainly show, has in the course of time become subterranean, and it is here that trident-like three considerable swales unite to form the main branch of the old cavern-robbed stream course known as the "Big Hollow."

The seaweeds of the new type before us are not as yet known to be abundant,— doubtless because the Centre County Conococheague mainly traverses the borders of the wooded "Chestnut Ridge" country and a systematic search along the outcrop has never been made. Such will doubtless reveal points where these striking fossils are more numerous. So far about a dozen specimens weighing from one to three hundred pounds are all that have been collected. But these are mostly from one point, and from their great size and the fair inference of abundance it is quite certain that they are, like the other Cryptozoöns, a reef-forming type. Other specimens have been seen one mile southwesterly.

It is curious to find that despite the wide occurrence and great abundance of the problematic fossils of the *Cryptozoön* group such large silicified forms as these before us have not often been reported. Yet there appears to be but

[1] A brief *résumé* of the facts and conclusions here presented concerning ancient algal life was given at the December, 1912, meeting of the Paleontological Society of America at New Haven in conjunction with an exhibit of representative specimens and sections.

little doubt that these specimens represent a distinct and unnamed species. Accordingly without raising larger questions of classification and generic relationship which I leave to those more familiar with hydrozoan, coral and seaweed structure than myself, I shall take the liberty of naming this new form after Professor R. S. Bassler of the U. S. Geological Survey, giving the brief analysis here appended.

Cryptozoön *Hall,* 1883.

This genus as established by Hall contained the single species *C. proliferum,* nearly identical as already remarked with the concretionary masses figured by Steele. But later studies render it certain that *Cryptozoön* is well represented by species, and belongs to a family of mostly calcareous seaweeds widely distributed in the Paleozoic.[1] Winchell (3) and Chaney (8) have reported huge Cryptozoöns from Minnesota. Dawson (16) added several species of lesser size, and others were named by Seely (23) and by Walcott.

Further, the studies of Rothpletz (25) show *Girvanella* of Nicholson (7) to be a calcareous seaweed, and it is now obvious that this genus is closely related to *Cryptozoön.* While but very recently the allied Asiatic genera *Metasolenopora* and *Petrophyton* have been established by Yabe (29). Although only critical study as yet difficult to make can finally serve to separate these several genera from the Stromatoporoids they clearly constitute an important and homogeneous assemblage passing from minute pseudolitic species like *Girvanella sinensis* Yabe up to the most gigantic of seaweeds fully characterizing their age.[2]

Cryptozoön bassleri sp. nov.

Text Figs. 1 and 2 and Plates XIV–XVIII.

Material.— A series of immense crescentiform segments weathering from the Upper Conococheague of Centre County, Pennsylvania, two and a quarter miles N. N. W. of the Pennsylvania State College. The type series aggregating a ton or over in weight is entirely from the W. F. Wieland farm.

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[1] The possibility that some of these species had their tissues impregnated with silica more as in the case of the brown seaweeds has never been suggested, but should not be excluded, especially in the case of the forms before us.

[2] Only after the present study was prepared for publication did the presidential address of Garwood come to the writer's knowledge. (See Nature, Sept. 25, 1913). In developing his investigations Professor Garwood has followed lines nearly parallel to those here followed, and reaches essentially the same conclusions here set forth as to the important rôle played by the sea weeds in geologic time.

The specimens were first collected by the writer's father, W. F. Wieland, about 1870, later by the writer and his brothers, and were mistakenly figured as inorganic in the American Journal of Science, Vol. IV, 1897, p. 263. The larger forms indicate fossils that if found complete would weigh a ton, or much more.

Description.— The free thalli of *C. bassleri* grew in large open circles or crescents, or the recovered portions may have been more or less tangential to radiate outgrowths from a central mass, the separate individuals often crowding each other. Since only outer segments of thalli lacking a proximal

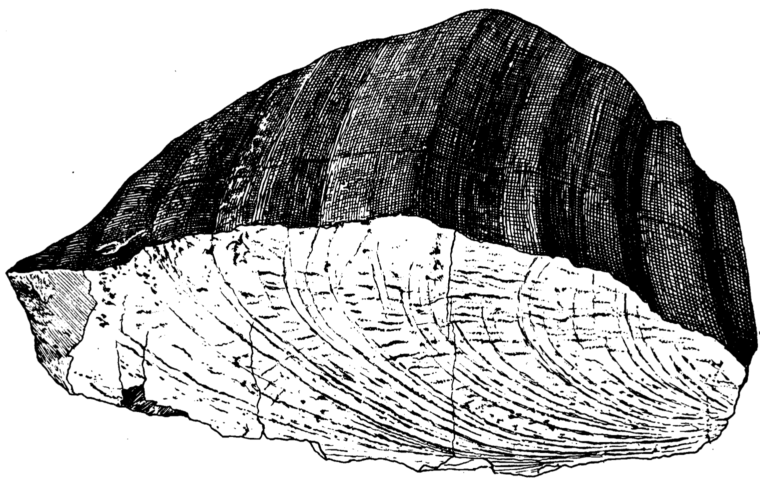

Fig. 1. *Cryptozoön bassleri.* Drawing which shows the laminar markings of the vertical transverse section but fails to bring out the secondary furrowing and the pitting of the superior surface. × ½. Lower Ozarkian near Pennsylvania State College, Centre County, Pennsylvania.

insertion have been seen the form of the entire fossil is unknown. But as transverse sections are always much alike, it is at least evident that the plant was of distinctly squamous habit with more or less linear sessile attachment of the primary leaf and subsequent increase in size by a more or less irregular false dichotomy of the new laminæ due to nether suppression of growth. The finer features of our fossil are not conserved, it being a siliceous cast, with only rare instances of indistinct traces of cells traversing the leaves.[1] But it cannot be doubted that the cell structure was of essen-

[1] Of course it is improbable that these Cryptozoöns were gigantic silica secreting types instead of calcareous. Whence in suggesting that they were primarily silicified the replacement of organic lime (arragonite) is still involved. The question is as to the time of mineralization, whether *early* as I believe or late. That the fine structure fails is not in itself evidence

tially the same highly palisaded *Lithothamnion* type Rothpletz (6, 25) and Yabe (29) have figured and described in various well conserved species of *Girvanella,* etc. Along with this structure probably goes the partial preservation of a finer lineation which as well shown by Yabe in *Petrophyton* may be formed by the very regularly palisaded cells with thickened ends. In

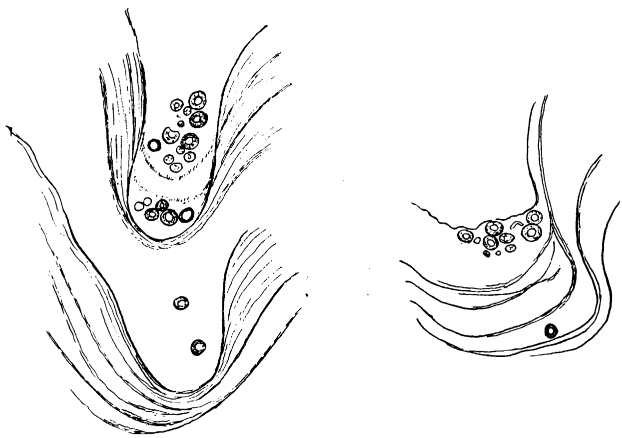

Fig. 2. *Cryptozoön proliferum* of the Beekmantown. Collected by Ziegler near Scotia, Centre Co., Pennsylvania. Transverse section through conceptacles (?) containing supposed spore cases, some of which are more or less imbedded by growth as in certain *Lithothamnium* species. Camera lucida drawing. × 10.

consequence the limits of the individual and evidently freely perforate leaves are rather difficult to make out, the borders or surfaces often having an appearance as of solid textures; so that it is more convenient to speak of laminæ than of the actual leaves or congeries of branches. For the fuller

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of later replacement, since the allied calcified forms show precisely the same structureless type of fossilization.

The occurrence of structureless siliceous casts of lime bearing organisms ordinarily found calcareous with all structures conserved does of course show that siliceous casts are often secondary. Thus Etheridge describes considerable portions of the skeleton of a Sauropterygian (*Cimiliosaurus*) as converted into precious opal (Records of Australian Museum, Vol. III, No. 2, 1897). But contrariwise specimens of chalcedonized wood vary all the way from perfect preservation to forms retaining but the faintest traces of growth rings and medullary rays. One such containing imbedded crystals of selenite varying from small up to several centimeters long I collected on Crystal Mountain in the Yellowstone Park and find hard to explain, but think was initially silicified in the absence of sufficient iron to stain the cell walls, and at too rapid a rate to favor structure conservation. It may at least be concluded from these general facts that caution is required in adjudging many structureless siliceous casts as simply replacements of earlier calcareous casts with their histologic structure conserved.

Furthermore down to the present hour insufficient attention has been given the silica series in its relation to lime as an organic and skeletal constituent. I find little information anywhere on the important question as to whether invertebrates habitually use all silica, or all lime, or as in higher organisms to some extent employ both these elements to build up the body.

conception of other than macroscopic details therefore, the reader must, in conjunction with a review of the structure of the simpler seaweed types, consult the papers of Rothpletz (6, 25), Ruedemann (27, 29a), and Yabe (29).

This lack of the finer structures does not however prevent a fairly satisfactory comparison with other species. The American fossils thus far referred to the genus *Cryptozoön,* omitting reference to *Stromatocerium Solenopora* and the various Stromatoporoids — those more debatable forms with the tubule systems — are the following: —

1883.	*Cryptozoön*	*proliferum* Hall.
1891.	"	*giganteum* Chaney.
1892.	"	*minnesotense* Winchell.
1897.	"	*boreale* Dawson.
1897.	"	*lachutense* Dawson.
1897.	"	*occidentale* Dawson.
1906.	"	*steeli* Seely.
1906.	"	*saxiroseum* Seely.
1906.	"	*wingi* Seely.
1906.	"	*frequens* Wallcott.

As already mentioned all the known types differ from our form in having a far more distinctly circular to turbinate habit of growth. Doubtless the species primarily to be compared is *C. proliferum.* But this type is according to Hall often turbinate, strikingly so in a specimen from Saratoga County recently acquired by the writer. So also the *C. minnesotense* where isolated or weathering free from the matrix; while the Steele specimens have the same character somewhat accentuated. It follows that our own specimens, the terminal thalli of which are of decidedly open habit of growth, or were at times nearly linear in form and have a flat basal surface, differ too broadly from either of the foregoing to be explained away as a growth variation due merely to local shore conditions or to situation.[1]

It appears too that compared with older specimens of *Cryptozoön proliferum* there is less crenulation of the laminæ, at least as they emerge on the upper thallial surface, so that the emergent congeries of laminæ produce a more regular ridging. That the lesser bud-like and probably young forms evident in Hall's figures and strikingly present in the *Cryptozoön* ledge

[1] The remarkable freedom of these huge fossil seaweeds from either crushing or recemented fractures is one of their most striking features, and suggests original silicification rather than siliceous replacement of an imbedded calcareous fossil. In the latter case there should be occasional evidences of the infiltration of silica into previously fractured structures but none are found, although the laminæ were rarely faulted with some recementing after silicification.

shown by Professor Bassler's photographs (Plate XIX) also accompany the silicified forms is however likely. A cavity on the lower surface of the largest segment recovered may have been occupied by just such a lesser form. But further than this, comparisons cannot be carried until specimens with structure conserved are found, and a series of large polished surfaces of *Cryptozoön proliferum* comparable to that made from the Pennsylvania Cryptozoöns for these studies is available to show in addition to general form if the same false dichotomy of the laminæ rules. That the fine structure of the Pennsylvania specimens must agree very nearly with that of *C. proliferum* is however certain.

On turning to secondary features one notes a very interesting habitus variation from the next most closely allied species, the *Cryptozoön giganteum* of Chaney (8). This plant also reaches enormous size, and from the short but excellent paper of Chaney it appears that the laminæ in rising from the main prostrate branch took on a distinctly overthrust growth so that the free edges formed a nearly vertical instead of flat outer surface, while the mass was far more hemispherical or lens-like than in our specimens. At least this is the interpretation of form and structure one may reach if a slight modification of Chaney's figures be permitted, these not showing or not accounting for the false dichotomy of the laminæ.

Regarding the interpretation of the very large convex lens-like or dome-shaped Shakopee aggregates observed to reach as much as ten feet in diameter by four in height, I am quite in accord with Chaney (8). He noted that it was difficult to observe how far from the center the *Cryptozoön*-like structure extended, and thought a large portion of the outer mass might be a continuation of the laminæ of the fossil as an inorganic foliation, or exfoliation of the surrounding matrix due to the course of imbedding and fossilization. This we consider the explanation nearest at hand, and in a slightly different manner well illustrated by the remarkable wheel-like burr-stone concretionary masses enveloping either the cycads or especially the rooted stumps of the coniferous trees which form such a striking sight as they weather out of the highly inclined strata of the "Portland dirt bed" outcrop on the coast of the Isle of Purbeck to the east of Lulworth Cove.

A searching generic definition is doubtless uncalled for because difficult to give; although if the forms figured herewith are not yet found to fall within *Stromatocerium* and are to be finally included in the genus *Cryptozoön* (instead of being called by what would be a far more appropriate generic term [*Cryptophycus*] to which I ask the attention of paleontologists) some extension of characters is necessary. For, while all the larger types described by successive authors from Steele to the present day are characteristically hemispheric to turbinate, the seaweeds before us must as already noted have been of slightly curved to strongly crescentric form, with a flat rather than convex base, and a far more regularly furrowed upper surface than is seen in other *Cryptozoön* species. But it should be specially recalled that as the thallial insertion has not been seen, it is quite possible that instead of a distinctly linear attachment to the sea-bottom the entire organism was initially turbinate. If so free peripheral or tangential outgrowth of the thalli from a central holdfast or turbinate mass resulted in gigantic subasteriate forms of magnificent appearance and size (*cf.* legend of Plate XVIII.)

Fruit Conceptacles of Cryptozoön proliferum.

Text Fig. 2.

In the preceding description of the silicified specimens of *Cryptozoön bassleri*, an algal nature has been assumed because there is unquestioned specific relationship to *Cryptozoön proliferum*, the fruiting of which is probably determined. At least in a calcified specimen collected by Ziegler in the Beekmantown north of Scotia (*cf.* Map in ref. 31) and kindly given to me for study, I find numerous oögonia-like spherules in regularly aligned pockets formed by the lamellæ in a manner strongly resembling systems of fertile conceptacles, as shown in Fig. 2, page 241. Others of the spherules or pseudolites, it is true, are found outside the pockets, and are sometimes imbedded as in old pockets, but the entire appearance suggests growth of the spherules in the pockets with a later pouring out of the matured fruits from between branches or through the lamellar perforations into the interlamellar spaces.[1] Moreover these spherules have exactly the size of certain algal oögonia of the Devonian and while not showing a structure conclusively organic, do not present the wide variation in the concentric zones seen in most older oölites. Moreover various of the grains show very distinct traces of radial cell walls in the outer test, as it may be called, and there is a uniform absence of nuclear grains of variant size and shape generally characteristic of oölites, the large central space appearing on the contrary to be in all cases secondarily filled. I therefore expect to see the view that we here have

[1] With respect to these features it may be noted that excellent descriptions of the luxuriant arctic species of *Lithothamnium* are to be found in Kjellman's *Algae of the Arctic Sea* (Köngl. Sv. vet. Ak. Handl., Band 20, No. 5). And it is of direct interest that on page 94 of this work the interesting fact is recorded that on the fractured surfaces of *Lithothamnium glaciale*, the large hemispherical to spherical species reaching 15 to 20 centimeters in diameter; old conceptacles of sporangia are found grown over, a condition which appears to be repeated in our fossil.

fruit-containing conceptacles confirmed by other and better conserved specimens, or at least by frequency of observation.

It is of some weight to recall that higher types of algæ were already developed in the Devonian. The genus *Chara* certainly goes back to the Corniferous as determined by Knowlton from specimens of distinctly sphericiform oögonia collected at the Falls of the Ohio and since figured in paleobotanic texts (20). And that such *Chara* forms are of wide Upper Devonian range is conclusively proven by a further group of beautifully sculptured oögonia gathered from the Hamilton shales on Snyder Creek, Calloway County, Missouri and about a dozen years ago placed in my hands by Professor C. E. Beecher. These spore-cases only differ from the Corniferous specimens in their lesser size, a length of five millimeters being taken up by eight oögonia placed side by side. Taken along with the Knowlton oögonia which were simply ascribed to the genus *Chara,* they constitute a valid unnamed species differing in size and sculpturing from other fossil forms (*cf.* ref. 20, fig. 46) and most conveniently recorded as **Chara devonica.**

It is perhaps a mere coincidence that the oblong oögonia of the existing *Chara fœtida,* the rounded Devonian forms, and the supposed spore-bodies of *Cryptozoön proliferum* figured herewith, are all of the same size. But it helps call attention to the fact that by suppression of the spiral grooves of the *Chara devonica* oögonia the rounded pseudolitic form would result. Again *Chara* antheridia are spherical, and the possibility that the *Cryptozoön proliferum* conceptacles were bisporangiate is by no means excluded.

That grains of oölite might often be found accompanying such specimens is to be sure not only possible, but probable. Every circumstance in the life of these plants, bearing in mind the great range of temperature the algæ endure and the possible variations in growth processes in a remote geologic period easily conceived of as chemically active far beyond later ages, suggests the conditions theoretically favoring oölite formation, even did we not know how frequently the oölites recur in ever varying forms in the *Cryptozoön* horizons. Nevertheless a mere outer resemblance to oölite in the grains found between the laminæ is not conclusive evidence. And the more must be questioned the view of James Hall, who also observed these grains, that they are oölite derived from or formed on the outside of the organism because greater in quantity towards the edges of the outer laminæ. Not only must the conceptacles be more abundant there, but the opposite interpretation at once comes to mind. For as the conceptacles matured their fruits it may be assumed as certain that some accelerative force, whether of water or gravity, combined with laminar movement tended to carry the swarms of oögonia out continually. While any weighting down due to incipient mineralization might hold the oögonia in great numbers near the outer laminar fringes. A study of thin sections taken from examples *in situ* will doubtless later yield the desired confirmatory evidence. Certainly typical *Chara* oögonia are frequent fossils in the later rocks. Thus Mantell in his Geology of the Isle of Wight (p. 78) mentions limestone blocks on the shores of Whitecliff Bay in which the *Chara* fruits are "so numerous as to constitute a large proportion of the mass." Moreover it is entirely possible that certain strata of the Paleozoic rocks described as oölitic are in reality great banks of oögonia comparable to the accumulations of coal plant spores which as first proven by Jeffrey make up cannel coal strata reaching as much as two meters in thickness. Indeed Van Ingen has called my attention to one of these supposed oögonia banks in the Devonian of Kelly's Island, Lake Erie, and it is undoubtedly true of all oölites ancient and modern that an organic origin whether direct or indirect is the first presumption in the absence of positive proof to the contrary.

Obviously the point of greater interest in the foregoing description is as to the true nature of the silicified and other gigantic reef-forming fossils of the Ozarkian, which, with *Cryptozoön proliferum* Hall, *Girvanella* and a long list of associated or closely allied *problematica* were an ever present feature of the early Paleozoic shallow waters and shore lines. For it is now believed that at least all those forms once included amongst the Stromatoporoids, which lack a tubule system with corresponding surface pustulations and are in great part of characteristically laminate, linear, or much branched *Lithothamnium* form, are all primitive algæ which form the abundant record of a far more luxuriant seaweed growth than has hitherto been understood to have characterized the Paleozoic.[1] In fact the data accumulated by various workers during the past fifteen years go far to indicate that preceding early terrestrial plant life there was an "*age of algæ*" in every respect characteristic.

If on the one hand the time-honored custom of calling all older *problematica* and unusual rock markings seaweeds has been abandoned, on the other, Rothpletz, White, Ruedemann and others are very correct in pointing out that from the small number of ancient forms actually demonstrated to be of algal nature we thus far get no criterion of the real abundance of seaweeds in the Paleozoic.

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[1] That many of the Stromatoporoids like *Labechia* and certainly *Solenopora* may also eventually be found to fall within an older seaweed series of far more varied aspect than has as yet been conceived to have existed, is a highly interesting suggestion recently made to me by Professor Parks. Frankly stated, it is a fact that neither zoologists nor botanists are as yet able to define in even the broadest terms the boundary between the primitive seaweeds and the older hydroids or coralloids. [But see Professor Garwood's address, ref. 34.]

But the evidence of this varied algal life in the early Paleozoic is no longer scant. Ruedemann (29a), whose studies have especially qualified him for the recognition of the older fossil seaweeds, has within the past year found a great quantity of finely preserved algal forms in the new fossil localities of the Schnectady shales. And the Lower Silurian seaweeds have seldom been so well figured as are these forms in part referred to a new genus *Sphenophycus*.

Chapman and Mawson (24) have shown the importance of the coralline alga *Halimeda* as a reef maker in their description of the *Halimeda* limestones of the New Hebrides proving how effective a rock builder this form may become. And Brown (33) has recorded the principal facts concerning certain pebble beds of peculiar occurrence and wide distribution in the Paleozoic rocks of Centre County, Pennsylvania, reaching the conclusion that the pebbles which show traces of a laminiform structure and are often siliceous are the fossil remains of some gigantic *Halimeda*-like form. These hypothetic fossil algæ extend from the Cambrian into the Ordovician and are said to make up a large proportion of the first few hundred feet of the Beekmantown, *Cryptozoön* being frequently associated. The latter, as I have been told by C. J. Sarle, furthermore, occurs in some new specific, if not generic variation, distributed throughout fifteen hundred feet of the Carboniferous rocks of southwestern Texas in noteworthy abundance, often forming huge reefs that must have extended mile-wide. Also, Blackwelder reports that in the Ordovician of the Northwest, limestones some thousands of feet in thickness are mainly made up of peculiar structureless masses producing odd erosion forms and best explained as due to vast aggregations of coralline algæ. Whilst the presence of the bulky algoid form called *Cryptozoön frequens* by Walcott throughout full ten or twelve thousand feet of the great development of Algonkian in Northwestern Montana is doubtless the most striking and best attested example of the mode of occurrence and vast extent of the *Cryptozoön* reefs in the older rocks (24a). So striking indeed are these occurrences that it is necessary to infer the absence of *Cryptozoön* in many Cambrian and Ordovician terranes of the Rocky Mountains as quite probably due to lack of conditions favorable to preservation.

Taking these facts into account there appears to be sufficient ground for modifying the outline of plant development in geologic time long since given by Brongniart as follows:[1]

[1] In giving this new outline I avail myself of yet other studies, which indicate that so far nearly all the general outlines of ancient plant life have not taken into full account the extreme antiquity of gymnospermous seeds and woods of high organization and cosmopolitan distribution. While all recent study has given us a greatly changed conception of the alignment of Mesozoic plants.

I Reign of Primitive Life (Hypothetic)	Oldest Precambrian
II Reign of Algæ	Precambrian Cambrian Ordovician
III Reign of Gymnosperms	Silurian (?) Devonian
IV Reign of Acrogens	Carboniferous Permian
V Reign of Proangiosperms	Triassic Jurassic
VI Reign of Angiosperms	Cretaceous Tertiary

In short, then, without going on into the inevitable reconsideration of *Eozoön* as a presumably algal form which Dawson long since *figured and described as a large turbiniform type,* or taking up any other fossils than those quite certainly algal, it becomes clear enough that so long as the older seaweeds remained wholly undifferentiated from the Stromatoporoids their true abundance largely escaped attention. The records of *problematica* are assembled but slowly. And as such the Paleozoic seaweeds find little mention from which might be inferred the extraordinary rôle they surely played. Nevertheless it becomes obvious that the further study of the older Paleozoic terranes will bring to light not only an abundance but a variety of algal life such as could not be inferred from the meager and occasional references in geologic literature to forms merely recorded as *problematica,* or without proof described as algæ. Nor does it even seem too much to say that no dominant organisms of later ages whether plant or animal ever exceeded the Paleozoic seaweeds as rock-forming agents or left a bulkier record. We now pass on to a brief discussion of the siliceous oölites so closely associated with the seaweeds and forming like them a most distinctive feature of the Cambrian and Ordovician rocks.

II. Conococheague Oölites. (Plate XVIII, fig. 2.)

The siliceous oölites of principal record are mainly from the American Paleozoic of Pennsylvania, Tennessee, Kentucky, Missouri and Canada. But contrary to the impression prevailing nearly to the present time this rock is rather common in older Paleozoic horizons the world over and occurs in a great variety of forms ranging through granular cherts hardly distinguishable from sandstone to rarely beautiful concretionary quartzites.

In fact it is precisely this marked gradation which has led some writers to speak only of cherts, and others only of oölites, thus easily leading to the impression of a somewhat restricted occurrence — an impression added to by the fact that the Jurassic oölites are so largely algal or pseudolitic and European, while conversely the main bodies of siliceous oölite are Paleozoic and American.

The first definite reference to these American oölites is clearly that of Steele as already mentioned; while ten years later in Featherstonhaugh's report of 1835, (p. 27) certain oölites "of the Carboniferous of the State of Missouri" are spoken of *as entirely converted into silica* like the Bristol, England, oölites. The occurrence of calcareous, but not siliceous oölites or cherts in Tennessee is also noted. And one year later, as quoted H. D. Rogers called attention to the oölitic cherts of Centre County, Pennsylvania as an unusual loose rock type; though on rapidly scanning his first Pennsylvania Report and also his two later bulky volumes I fail to verify any clear reference to concretionary structures.

The American oölites of the Paleozoic received but scant notice in the geologic literature of the subsequent fifty years. In the reports of Sir William Logan from 1860 on there are however occasional references to the cherts which grade over into the siliceous oölites of markedly concentric structure, and it is strongly inferred that such rocks may result from direct chemical deposition.[1]

Still later, various notes on the occurrence of the Missouri "siliceous oölites" and oölitic cherts are found in Broadhead's 1873–4 Report; though in Safford's Geology of Tennessee (1869) the only oölites mentioned are calcareous.

In fact, it is quite fair to say that the later and adequate study of the older oölites was not fairly begun until about 1890 or a few years earlier when the present writer brought the attention of petrographers to the handsome siliceous oölites of Centre County, Pennsylvania, locating at about the same time the occurrence of an Ordovician outcrop of siliceo-calcareous oölites on the Pennsylvania State College grounds, and later noting the interesting types of siliceous oölites occurring in the Knox terranes near Rockwood, Tennessee, both as imbedded boulders and stratified.

A siliceous "oölyte float" had been noted in 1884 by A. L. Ewing in

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[1] Logan also briefly mentions a partly silicified *Stromatopora* (Rep. Geol. Sur. of Canada for 1863, p. 630) and seems scarcely to question either its original silicification or the direct deposition of cherts, citing the then new experiments of Church (Proc. Chem. Soc. of London, Feb., 1862, also Phil. Mag. (4) XXIII, p. 95). Church showed that when a solution of silica in about 100 parts of water containing at the same time carbonic acid is filtered through fragments of coral, the whole of the silica is taken up by the coral while a large part of the carbonate of lime is dissolved. Shells behave in a somewhat similar manner.

D'Invilliers' report of the 2nd Pennsylvania Geological Survey (Centre County, Appendix B, p. 406). But no further facts were given, and the Centre County oölites did not become a subject of definite record in Geologic literature until in 1889 when I found a previously unobserved series of large surface boulders near the edge of the wooded Cambrian terranes locally termed the "Barrens" to the north of the Pennsylvania State College. These boulders weighing up to 400 pounds, were found approximately *in situ* at the locality where this rock was much later located in place in railroad cuts by Anderson and Ziegler (31), and undoubtedly furnished the first clear and unweathered specimens ever obtained of this handsomest of known oölites.

Study of this new material resulted in descriptive papers by Barbour and Torrey (4), Hovey (11, 13), Bergt (9), and myself (5). In 1890 Barbour and Torrey gave figures of two of the oölites with analyses, reaching the conclusion that the siliceous oölites must be pseudomorphic [because transition oölites I found outcropping in the Ordovician of the Campus of the Pennsylvania State College included a lime-silica and silica-lime form].

This was really a return to the early replacement idea that seems to have had little more basis than that inasmuch as the better known oölites of the Mesozoic were calcareous, siliceous oölites of the Paleozoic must be secondary, just as the siliceous casts of organisms once containing lime were readily regarded as always pseudomorphic, an idea known to be untenable ever since the actual silicification of corals by Church in 1860. (*Cf.* footnote, page 249.)

Bergt in 1892, however, added an extended description of the siliceous forms with more accurate analyses than those of Barbour and Torrey, studying the rock in polarized light and giving a number of figures. His work gives the German records on oölites, in particular the siliceous pisolite of Egypt, brought to notice in 1851, by Kengott and a siliceous oölite with 1.50% of titanium oxide studied by Knop. Bergt for the first time argued clearly that the siliceous oölite was formed by direct deposition, in a manner analogous to the calcareous oölites, and supposed it probable that geyser-like springs or other thermal waters may have afforded the silica.

Hovey in 1893 gave a figure of a far more recent siliceous oölite from the Tertiary of New Jersey, and in studying the Pennsylvania types independently of Bergt, also reached the conclusion that the rock was due to direct chemical deposition, a view with which I concurred in a paper published in the American Journal of Science for 1897, giving a further chemical analysis of the finest of the Pennsylvania forms and the only recorded analyses of the Tennessee oölites. But the most important early contribution to the general subject of the oölites and cherts is unquestionably a second paper by Hovey in the same Journal on the Cherts of Missouri. Supplementary to Bergt, in this contribution, references to the work of Prestwich and other English writers are found, the facts adduced all going to show direct deposition of the oölites.

The next stage in the investigation of these oölites begins with the recent papers of Moore, Ziegler (31), and Brown (33). In a paper read before the British Association at the Portsmouth meeting in 1911 Moore (30) recorded the locating of numerous thin bands of oölite at the old "Barrens" locality similar to those I had earlier noted in Tennessee, and very briefly discussed their origin returning to the view or surmise of Barbour and Torrey that the siliceous oölites all originated by replacement of calcareous forms.[1]

The contribution of Ziegler (31) in the 'American Journal of Science' gives the first adequate field notes for the occurrence of the Centre County oölites. Following the best field work so far done on the oölites, he returns to the syngenetic view of direct deposition, giving a discussion of the possible effect of alternating alkalinity and acidity on lime and silica deposition, and rendering a solid contribution to the subject in hand. This work again carries us back to the views of chert and flint deposition held by Bergt and Hovey and found in the writings of Logan and Prestwich following the fundamental experiments of Church in silicification of corals, as well as in the work of Hinde and Van Hise.

In the still more recent paper of Brown (33) the siliceous oölites once more come up for mention and an interesting review of the observations and studies of the theory of oölite origin by Rothpletz and Linck is given,

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[1] These latter authors had observed two varieties in the Ordovician oölites I sent them from the Pennsylvania State College grounds, a lime-silica oölite with a radial, and a silica-lime oölite of a more markedly concentric structure. From which it was argued that while there are "indications of a different mode of formation it seems probable that the siliceous oölite (of lower horizons) is derived from the calcareous by the replacement of lime particles by silica." This is all Barbour and Torrey say in defense of their explanation, but Moore in subscribing to it adds that he finds some calcite about sand grains when present, and in other grains (of Cambrian oölites) outer rings of calcite. To these observations may of course be added my own determination that the Knox oölite stratum twenty feet in thickness near Rockwood Landing, Tennessee, consists in siliceous spherules imbedded in a gangue of dolomite. But a little higher up clear siliceous oölite boulders of large size lay imbedded in the dolomite just as might any siliceous nodule directly deposited as such.

Assuredly there are two ways to arbitrarily interpret such evidence. And similarly, the "*field method*" may fail when the attempt is made to explain sources and movements of silica available for the needs of those who believe in invariable replacement. Thus Moore observes that:— "In the (Cambrian) sandstone there are numerous examples of a partial solution of sand grains and the movement of the silica along cracks in the rocks, where grains are found partially dissolved and the material *redeposited* in a granular condition." The italics are mine. Observe that there is simply a deposition of silica in a granular condition, just as there might be direct deposition in an amorphous, botryoidal, lamellar or crystaline condition. And so far as evidence to the contrary goes have we not equal reason to believe that silica can also be directly deposited as a true oölite, and was more generally so deposited in the Cambrian and Ordovician than in later periods?

this author nevertheless fully convincing himself "that the material in his possession" will finally go to show that all the siliceous oölites are pseudomorphic.

From examination of the literature and study of the oölites it becomes evident that neither at the present time, nor at any time during the fifty years which have elapsed since the laboratory work of Church, nor yet in the case of the students of any country, has there been unanimity of view on the origin of oölites. And in the main one readily reaches the conclusion that the advocates of a general pseudomorphic origin have not displaced by evidence rather than contention the opposed syngenetic view according to which oölite origins are complex, and involve the direct accretion of both lime and silica, the subsequent replacements being occasional rather than universal phenomena.

Also Hovey's paper on the cherts of Missouri (13) has been somewhat neglected by the students of the past few years; to say nothing of the clear statement of Clarke in his discussion of these cherts and oölites (Geochemistry, pp. 518–520) that "no one process can account for all the occurrences of cryptocrystalline silica." Though if the cherts of Missouri and the oölites of Pennsylvania afford a criterion we have not yet reached the point where "local study" will necessarily result in similarity of view.

It would seem that the very fundamental experimentation of Church in showing sixty years ago that corals could be silicified indirectly suggests some of the conditions requisite to the artificial production of oölites. At least there are no recent observations which by themselves need compel us to disbelieve the possibility of direct deposition of many of the cherty and oölitic quartzites of the older formations, certainly not in the absence of laboratory studies going to prove that silica has no cryptocrystalline properties analogous to those of calcite,[1] and that hyalite, for instance, has no semblance to oölite.

That only definite chemico-physical studies and new discoveries can suffice to fully solve the oölite problem now seems clear. But some real advance along these lines has been made. Vaughan (32) in his study of the muds of the Dry Tortugas and the Marquesas Lagoon, has recently confirmed the observation of Linck that a peripheral deposition of lime on

[1] The oldest siliceous oölite of which I have been able to learn occurs stratified in the "Animike" shales of Port Arthur at the west end of Lake Superior. These shales are of Upper Pre-Cambrian age. As described by Coleman (Geol. Surv. of Canada) the spherules vary from small forms up to large pisolites.

One of the most curious of oölite structures is the pisolitic limonite of Tern, New Zealand. The spherules vary from small sizes up to 2 centimeters in diameter, 1 centimeter being an average size. This is strictly a form of direct deposition analogous to a somewhat similar siliceous pisolite from the Yellowstone Park, where arragonitic pisolites likewise recently formed also occur.

embedded gas bubbles with or without solid nuclei, may explain the origin of some oölites, it being found that the gas can escape without rupture of the initial layer. While still later (35) this observer ascribes the origin of the Floridian and Bahama plateau oölites to the direct precipitation of arragonite by devitrifying bacteria. Accretion of spherules continues to go on in the sample alkaline solutions from the waters where oölite is today in process of formation. And very obviously if in recent seas with abundance of calcareous slimes such processes readily go on in the case of calcium carbonate, the question at once presents itself whether siliceous oölites may not form by analogous processes. For certainly the cryptocrystalline forms of silica include as distinctly sphericiform types of accretion as do calcite and arragonite. While in the course of geologic time it is permissible to hypothesize abundant silica resulting from widespread submarine volcanic action or derived from thermal springs or from organic sources, under conditions favoring either siliceous bubble coatings, or direct accretion, dependent on varying alkalinity or acidity, along shore lines or in the ocean depths where occur the most of the organisms containing notable quantities of silica, especially in the early Paleozoic or age of seaweeds.

Bubbles coated by either lime or silica appear to offer the more difficult explanation of oölite origin; but the remarkable regularity with which in the oölitic quartzites radially cryptocrystalline masses of quartz are found to project inwards from the outer rind of concentric layers would be simply explained, if the grains were at any time hollow. In the grains lacking nuclei the central portions have a quartz filling which very well suggests a tiny geode. But on the other hand this cryptocrystalline quartz which continually tends to assume true hexagonal structure is doubtless comparable to that of the spheno- and sphærocrysts observed actually traversing the cell structure of fossil woods, where, though some lime may have been present and played a part in chemical change, the process of petrifaction consisted in the direct deposition of silica, the fair assumption being that the siliceous cast of the original woody structures and the sphærocrysts traversing them were both formed simultaneously or virtually so. And by analogy it seems certain that the sphenocrysts of the oölite grains, if formed during replacement of a calcareous by an opalaceous groundmass, would often be observed to traverse concentric lineations.

Nor is it yet proven that lime and silica could not be alternately deposited on a single spherulite by chemical reactions strictly "reversible" for these substances. One needs but to recall that both animals and plants even within the same group use both lime and silica in building up their skeletal structures, a strong proof of the delicate balance between lime and silica deposition. Indeed there is good evidence distinctly pointing to the possibility of alternant deposition of lime and silica, or silica and hematite whether or not the grains are formed by direct accretion. At any rate I have found in the siliceous oölite boulders pockets filled with loose quartz crystals and fine grains of oölite either solid or the thinnest of shells, which latter possibly are the zone of the grain first segregated and most resistant to solvent action. And similarly when the oölitic hematite of the Clinton formation is subjected to acid action as was observed by Smyth (10) thin siliceous tests, scarcely noticeable in the thin sections are left behind. That these were directly deposited on the grains (as they increased in size) was the original view which I fully accept, as do also Newland and Hartnagel (26) in their study of the Clinton ores, it being very clear that the burden of proof rests on any other explanation. While just as the consensus of opinion now is that the advocates of the pseudomorphic origin of the Clinton iron ore deposits have utterly failed to sustain their views so the universal siliceous replacement theory of oölite origin is too restricted to fit all the known facts.

Another fact bearing on this question is the uncrushed condition of the great silicified seaweed rims accompanying the oölites. That these fossils are not secondary replacements of calcite after some great interval of time is the strong presumption already noted; and that what is true of their origin is also true of that of the oölites is a probability worthy of record.

Finally the rarity of siliceous oölites in later geologic facies has little bearing on the question of siliceous *versus* calcareous deposition. The absence of lime oölites in many formations is as good a kind of scientific *tu quoque* argument. Besides, it may yet be found that there have been some very fundamental changes in lime and silica distribution in the course of geologic time, if not exactly in the period marked by the siliceous oölites. Indeed it is a facile supposition that the Ozarkian may be included in the older time of thinner and even warmer crusts favoring thermal solution of silica along shore lines or over wide areas of the sea bottoms; and it is a very fundamental if not a related fact that not until the Ozarkian did animal secretion of lime become a marked geologic factor.[1]

It will have been noted that in these studies of Paleozoic seaweeds and oölites one does not find additional support for the view of Wethered gained

[1] "During the Ozarkic period, for the first time in the history of the earth, the animals living in the sea, especially the mollusks, began a general secretion of calcareous skeletons. Of course the sponge-like corals of the Georgic had the lime habit much earlier, but until the Ozarkic in none of the earliest faunas did the secretion of lime become a factor among many types of invertebrate animals. That this mode of protection was of great benefit to the creatures possessing it is seen not only in the rapid rise of genera and species in the Ozarkic, but also in the marked increase in the size of individuals. This evolution is particularly noticeable in the middle and upper beds of this period."

Schuchert,— Paleogeography of North America, p. 524.

from his interesting and valuable studies mainly based on the oölites of mid-geologic time but also including ancient calcareous oölites, that all the oölites are accretions of filiform algæ (Ref. 12 and other papers in Quart. Journ. Geol. Soc.). On the contrary it seems that the grains of siliceous oölites are quite free from traces of algæ, and apparently due to direct deposition, though the chemical changes involved in their formation may well have depended on algal growth or decay. Also there is the strong presumption that both lime and silica often entered into the initial building up of the grains, with but little subsequent replacement. Moreover, in connection with the oölite problem it will unquestionably be found instructive to more carefully consider the sphæro- and sphenocrysts already briefly commented on. I have figured remarkable examples of the latter in my American Fossil Cycads (Plate XXVIII, Fig. 1, and Plate XXIII, Fig. 6), while Seward shows a most pronounced instance of sphærocrystic structure traversing the tissues of a silicified *Lepidodendron* stem in his Fossil Plants, Vol. I, figs. 14 and 15 (20). In addition I may mention that both these structures of pronounced type and striking form are present on a large scale in the silicified stems of conifers which occur so abundantly in the strata of the Black Hills rim yielding the fossil cycads. These structures apparently traverse the trunks of the largest forest trees of the "Rim," and in some weathered specimens the appearance would even suggest an oölite to the unpracticed eye. (*Cf.* lower Fig., Plate XVIII, showing oölitic sphenocrysts.

Evidently such structures appear capable of several explanations. It might be suggested that the spherulitic structure resulted from calcification as the very first step in the mineralization of these trunks, and that secondarily silicification of tissues set in with replacement finally of the calcite in the spherulites. But on the other hand the sphenocrysts have the characteristic hexagonal forms of quartz, and moreover, they seem to graduate by almost insensible degrees into forms with concentric banding. Also it is interesting to observe that in some of the stems there is a decidedly lenticular form of the sphærocrysts which may be due to pressure in the opaline state before the final stages of induration.

From all the evidence at hand, we may conclude that in the presence of abundant silica in the colloidal to partially soluble state there is a strong tendency of the molecules to aggregate concentrically, and that consequently the direct formation of oölitic quartzite is a possibility. But that all of the conditions requisite for the formation of siliceous oölite were mainly confined to the early Paleozoic is likewise apparent. Similarly one cannot fail to note that actual observations of oölites in process of formation have been thus far exceedingly limited and restricted to relatively shallow lime laden waters. Very different must be the processes which go on in the ocean depths where mainly occur the forms which segregate organic silica.

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EXPLANATION OF PLATES.

Plate XIV.

Fig. 1. *Cryptozoön bassleri.* × ¼. In vertical transverse section (same specimen as figure in text) showing that scorpioid dichotomy of the laminar aggregates results from procumbency.

Fig. 2. *Cryptozoön bassleri.* × ¼. Superior view of a segment from the left terminus of one of these huge crescentiform thalli. Observe to the left the heavily rounded end, which is but little broken near the inner margin, and is in nearly radial position. In Plate XVIII occur the only suggestions of proximal portions of thalli. The straight right border is the edge of the polished section shown in Plate XV. The ordinary process of photographic reproduction yields in this and succeeding figures very nearly the natural colors of the original specimens.

Plate XV.

Cryptozoön bassleri. × ⅜. Same segment as in preceding Fig. 3, showing to better advantage the furrowing of the upper surface, and also the polished radial vertical section. Note unequal scorpioid dichotomy of the laminæ which appear in more or less regular series corresponding to furrowing of the superior surface.— The absolute freedom from either crushing or fracture of this and other of these specimens, except solely the specimen of Plates XVI and XVII is a striking feature indicating early silicification of these gigantic fossils.

Plate XVI.

Cryptozoön bassleri. × ⅕, nearly. Segment from mid region of largest form recovered, showing to advantage the uneroded superior surface with sharp furrows and small crenulations.— Observe with a reading glass how small but regular is the crenulation of the laminæ in these specimens. They vary markedly from *Cryptozoön proliferum* and all other types in this respect.

Plate XVII.

Cryptozoön bassleri. × ⅓, nearly. Same specimen as preceding in polished radial vertical section. External border somewhat broken away. This specimen shows a vertical cleavage which is entirely secondary and was developed during erosion long after the opalaceous condition of initial silicification had been passed. The presence and character of a slight secondary faulting on the cleavage lines shows this. Even from this figure these facts and features will be apparent after a little attentive study with a reading glass. Weight 140 kgs.

Plate XVIII.

Fig. 1. *Cryptozoön bassleri.* × ⅓. Polished radial section showing inferior, and perhaps also superiorly, appressed individuals. The appearance seen here is not fully understood, since no other specimens so far recovered suggest such a com-

plexity of the individual plant as existed if these branches all belonged to one individual. If they did so belong it follows that after growth of the two main normally shaped thalli had progressed to the point of ventral appression the two triangular spaces left over above and below were then closely occupied by a third or perhaps a third and a fourth thallial branch or outgrowth with some intergrowth due to appression. This section would then pass very near to the insertion of the free thalli on the central mass or holdfast. So that the suggestion of an asteriate form made in the text has in its favor two observed features; 1stly the condition seen here, and 2ndly the turbinate forms of the young or simpler types of Saratogan Cryptozoons. Such features would at the same time afford the broadest of specific differences from any of the Cryptozoons so far reported.

a, b, c, d, are the four separate thallial axes, and *f* a line of fracture corresponding in position to f^1 along which latter node the appearance suggests continuous growth or else complete fusion.

Fig. 2. Two grains of oölitic quartzite from near the Pennsylvania State College, Centre Co., Pennsylvania (locality A in map, reference 31). Enlarged 60 times and photographed in reflected light passed through a blue screen to bring out details of the *sphenocryst zone.*

Following the primary deposition of a clear opaline *nucleus* with or without a *nucleolus* and envelopment by the finely concentric indurated outer *test*, the radially arranged sphenocrysts were formed during final dehydration. Initial radial structure of the quartz may also occur. The process may be considered as directly chemical, the silica being inorganic, or organic and segregated just as is the silica of the siliceous nodules of the deep ocean floor.

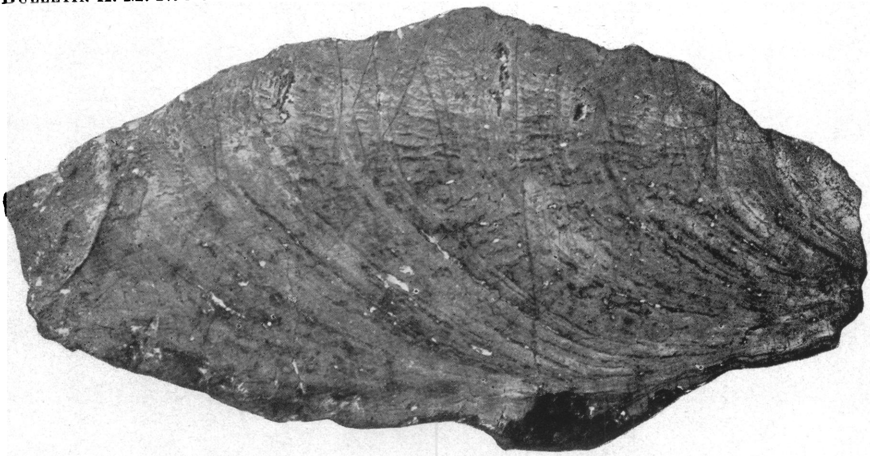
[Hand specimens I collected over twenty-five years ago show how reversible chemical reactions account for deposition of these grains. Either the initial or terminal step consisted in the formation of characteristic siliceous chert which passed directly into the oölitic quartzite with simultaneous formation of rhombic calcite as proven by the presence of rhombohedral cavities which are sometimes *penetrated* by the oölitic spheres or again *shear* these like a knife edge. At times very small and perfectly formed rhombohedral cavities *cut* into the tests of individual grains. When siliceous deposition was completed crystalline calcite still remained imbedded just as in the Crystal Mountain silicified wood mentioned in the footnote, p. 241, the selenite crystals so occur. But while the calcite in the oölite was finally dissolved out, the selenite in the silicified wood, once protected from the action of water, proved very permanent.

Deposition of (1) chert, (2) arragonitic oölite, (3) rhombic calcite, (4) arragonitic oölite with calcite, (5) siliceous replacement of oölite $CaCO_3$, and (6) solution of the crystalline calcite would be only one of the various other alternative and in reality difficult explanations of these specimens.]

Plate XIX.

Fig. 1. *Cryptozoön proliferum* (Hall) forming a reef outcrop in the Saratogan limestone (Conococheague) in the battlefield of Antietam, Maryland. The details appear in about one-sixth the natural size, and one readily notes the heavy striate mass above with the lesser crescentic to sub-circular outlines in considerable abundance below. From a photograph by R. S. Bassler.

Fig. 2. *Cryptozoön proliferum* (Hall). Reef on Antietam battlefield. Portion of preceding figure somewhat enlarged with continuation to right,— both figures thus representing a length on the reef of a meter or more. The upper seemingly denser portion of the reef shows the characteristic cleavage running nearly vertical to and obscuring the lineations formed by the emergence of laminæ.



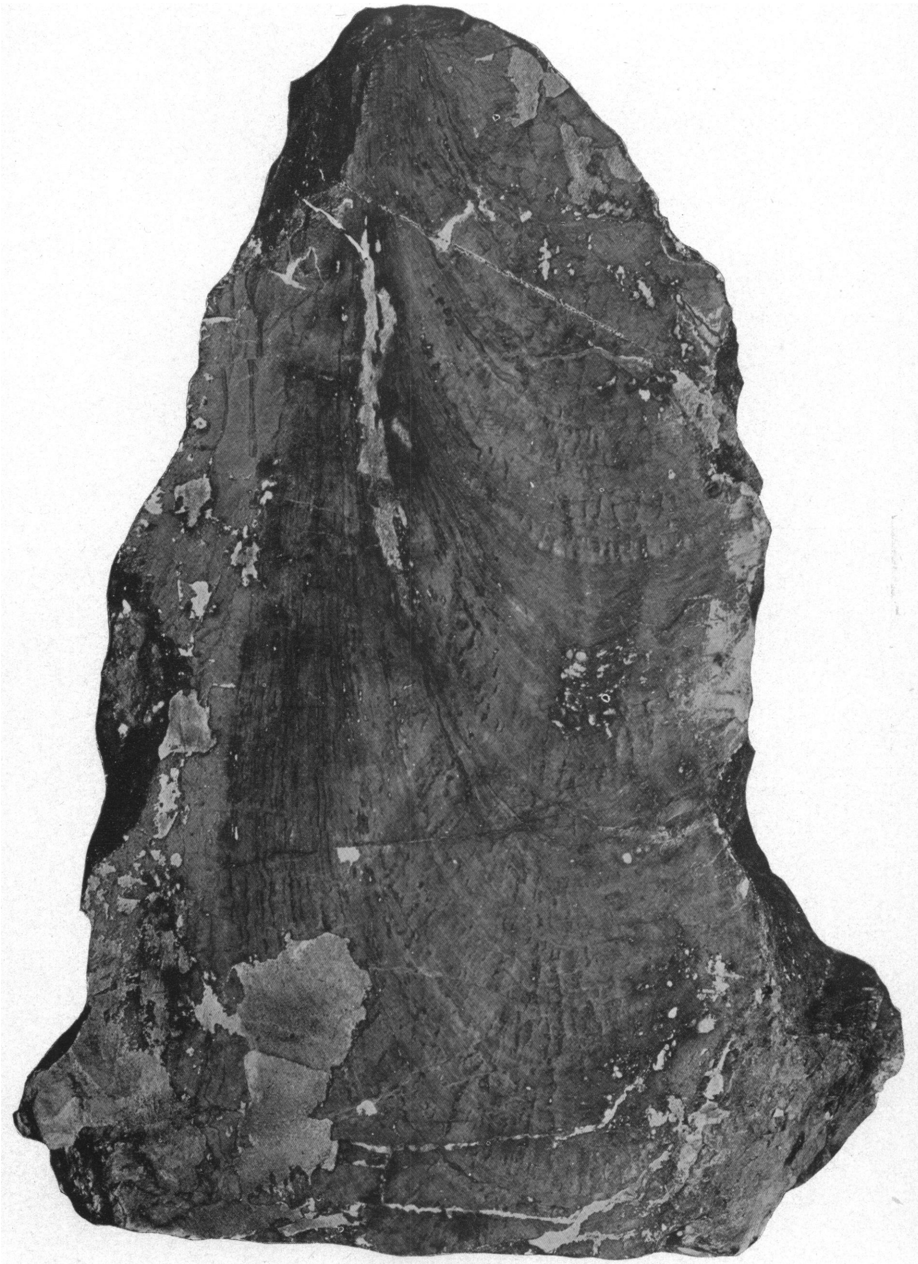
1

2

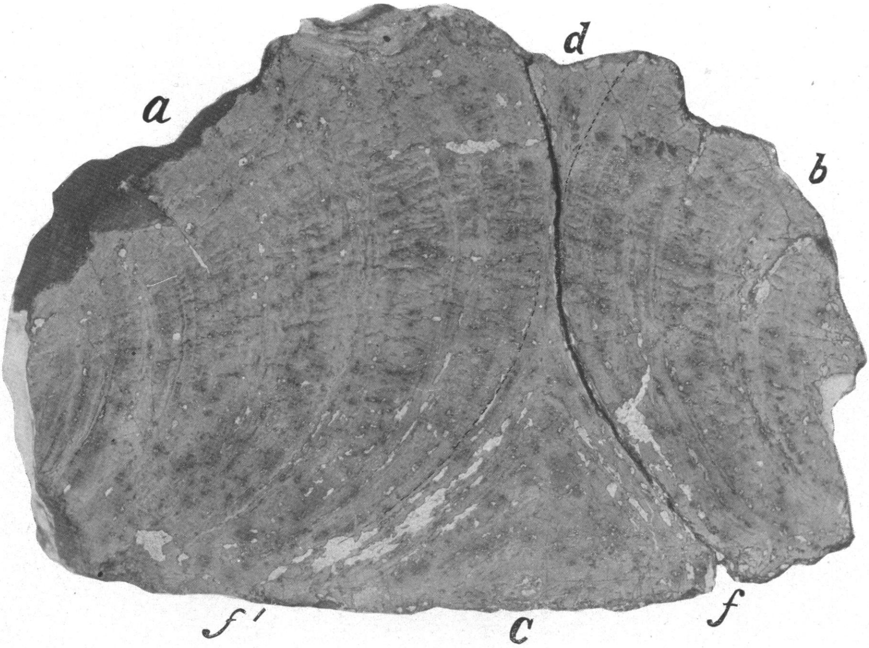
Cryptozoön bassleri. × ¼.

CRYPTOZOÖN BASSLERI. × $\frac{3}{8}$.

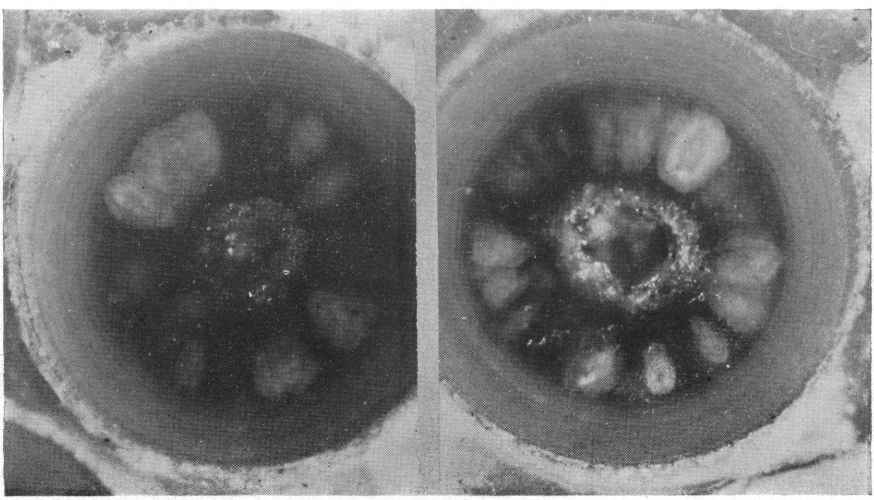
Cryptozoön bassleri. × $\frac{1}{5}$, nearly.



CRYPTOZOÖN BASSLERI. × 1/3, nearly.

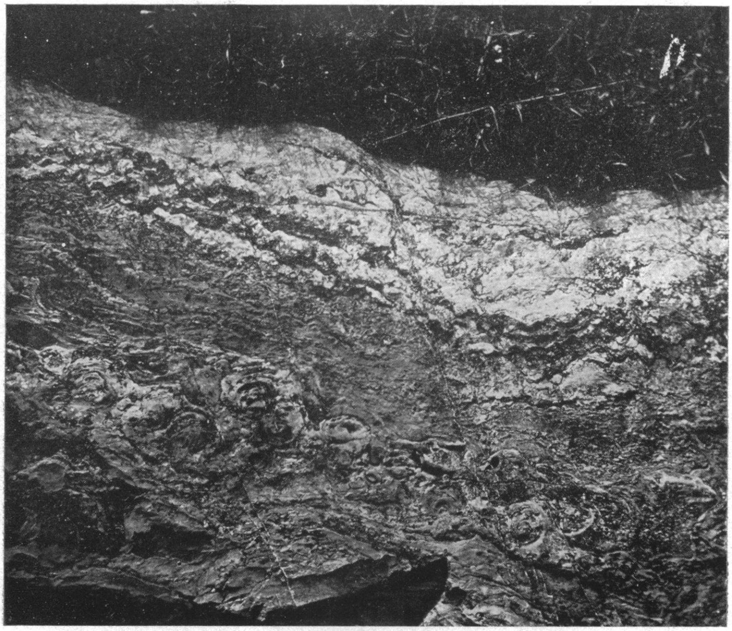


1



2

Fig. 1, Cryptozoön bassleri. × 3.
Fig. 2, Sphenocrystic oölite. × 60.



1

2

CRYPTOZOÖN PROLIFERUM (*Hall*), in situ.