1 ALGAL BARRIER REEFS IN THE LOWER OZARKIAN OF NEW YORK with a Chapter on the Importance of Coralline Algae as Reef Builders through the Ages

By

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THE REEFS

In Lower Ozarkian times (uppermost Cambrian of authors) a notable succession of barrier reefs, composed entirely of species of the calcareous alga *Cryptozoön,* bordered the oldland of the Adirondacks, stretching from the east around the southern end of the oldland through the Mohawk Valley area and westward for an unknown distance beyond the present site of Utica.

Following the deposition of the Grenville sediments in the Adirondack region and their invasion from beneath by great masses of igneous rock, there ensued a very long period of erosion of the region during which it was above sea level. According to Cushing (1916, p. 55), "there is no evidence to controvert the statement that the Adirondack region was a land area throughout all the great lapse of Precambrian time following Grenville deposition . . ." This long erosion period continued throughout the Cambrian in this area. A great thickness of rock was removed from the surface, resulting finally in the reduction of the entire region to one of low altitude and small relief. The Adirondack region then developed a tendency to doming upward centrally with sagging at the margins. Depression occurred on all four sides of this region permitting invasions of the sea and the formation of deposits on the old erosion surface. Deposition began in the northeast (Clinton county) in Lower Ozarkian time with coarse conglomerates followed by sands, constituting the initial deposits of the Potsdam sandstone. Sagging was extended progressively and slowly to the southward up the Champlain trough and westward up the St Lawrence trough, only the upper part of the Potsdam formation being found in the Saratoga region. As shown by the marine fossils, the upper portion of the formation must have been laid down in shallow marine waters. Succeeding the sands of the Potsdam is the series of alternating sands and dolomites constituting the Theresa formation. Through lowering of the bordering lands by erosion the sand supply was lessened, calcareous matter was increased and dolomite began to be deposited. The trough or bay along the St Lawrence line was landlocked on the north, south and west. As with the underlying sandstone, thickness increases eastward and diminishes westward in the St Lawrence trough and southward in the Champlain trough. As the sands steadily diminished in frequency and thickness the Theresa formation graded up into the thick Little Falls dolomite, also marine, (locally the Hoyt limestone) in the Mohawk and Champlain valleys.

Uplift following Theresa sedimentation raised the northern part of the State above sea level, so that no representation of the Little Falls is found in the northern part of the Champlain valley and there is nothing in the St Lawrence region which can be directly correlated with the Little Falls unless the heavy sandstone (Heuvelton beds) at the top of the Theresa represents the upper cherty beds seen at Little Falls and elsewhere (Cushing, 1916, p. 34).

Great reefs of *Cryptozoön* species have been found at several horizons in exposures of Little Falls throughout its extent. The profusion of growth of these calcareous algae indicates a congenial climate and conditions supporting abundant life. The Hoyt limestone is a more calcareous and more fossiliferous phase of the lower portion of the Little Falls dolomite, and is preëminently a reef formation, carrying three horizons of reefs, each built up by a different species. (See Cushing and Ruedemann, 1914; Cushing, 1916.)

Following the deposition of the Little Falls dolomite mild uplift brought the troughs above sea level and they existed as land for a time. Eventually depression was renewed, apparently beginning simultaneously on the west, south and east sides of the Adirondacks and the Tribes Hill formation (calcareous sandstones, sandy limestones and dolomites), constituting basal Canadian (Lower Ordovician of authors) was laid down on the south, west and north of the Adirondacks in the Mohawk valley and the St Lawrence region. Uplift following brought the south and west sides of the district above sea level, and subsidence continued only in the Champlain valley and the deposition of the great thickness of the later Beekmantown beds (Canadian) began (divisions B [in part] and C). As Beekmantown time continued the St Lawrence trough became involved, the depression extending westerly up that trough to the Ogdensburg region, and the deposition of the Ogdensburg limestone (age of division D) went on as Beekmantown deposition continued in the Champlain trough. At the close of the Beekmantown the whole region was raised above sea level (Cushing and Ruedemann, 1914; Cushing, 1916). Species of Cryptozoön have been found in the basal Cassin formation (Beekmantown, upper D) of the Champlain valley (Ruedemann, 1906) and in the Bald Mountain limestone (correlated with Cassin beds; Beekmantown D, E) at Middle Falls and Bald mountain, Schuylerville area (Ruedemann, 1914). Two horizons of different species are reported from the Ogdensburg limestone (Cushing, 1916).

Evidently reef conditions continued into Beekmantown (Canadian) time but the reefs were not as frequent or as well developed. The

Ozarkian reefs stretched from the east side of the Adirondack region southward and westward through the Mohawk Valley region, while the Canadian reefs were formed in the submerged areas to the east, northeast and northwest of the Adirondack region and stretched northward (figure 1).

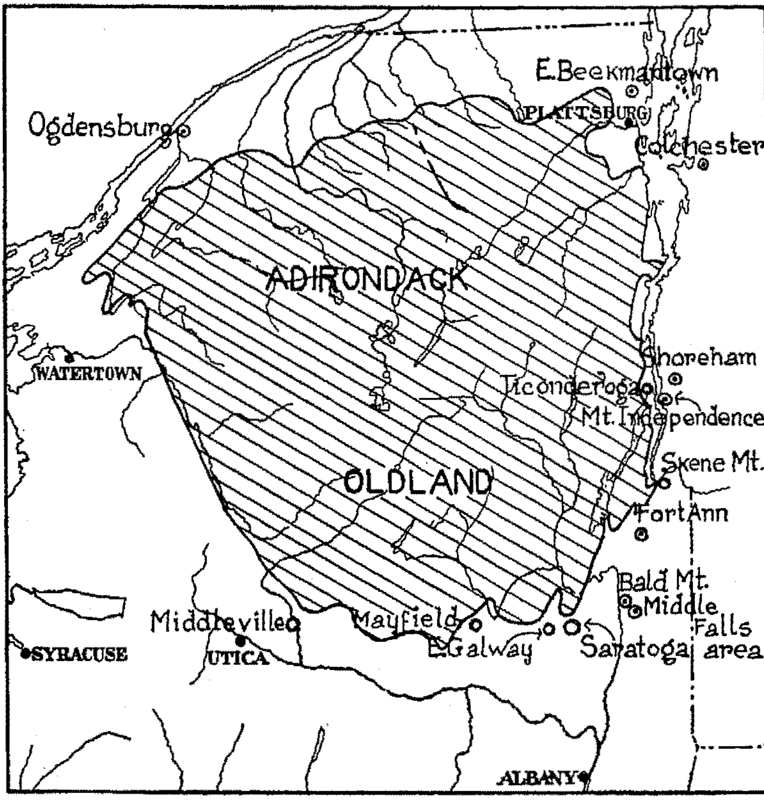


FIGURE 1 Outline map of northern New York and western Vermont showing the distribution of reported occurrences of Cryptozoön. ○ = Ozarkian (uppermost Cambrian of authors); ⊙ = Canadian: Beekmantown or its equivalent (Lower Ordovician of authors).

The Little Falls dolomite and its calcareous basal phase the Hoyt limestone, as pointed out above, carry reefs built by three species of calcareous algae, *Cryptozoön proliferum* Hall, *C. ruedemanni* Rothpletz and *C. undulatum* Bassler (see p. 32). The first two species, so far as known, only occur in the Hoyt limestone; *C. undulatum* in both the Hoyt and the Little Falls. In the Mohawk valley Cryptozoön reef conditions have been found nearly as far west as Utica. About a quarter of a mile south of Middleville along the Herkimer-Middleville state highway is a 500-foot exposure of Little Falls dolomite showing a reef of *C. undulatum.* This species has also been found along the Saratoga-East Galway state road (route 29), two and a quarter miles directly east of East Galway and about one-half mile beyond (west of) the bridge across Kayaderosseras creek. Here *undulatum* is found in what the writer has interpreted as basal Little Falls, at least the occurrence is close to the boundary between the Theresa beds and the Little Falls dolomite. *C. undulatum* is found, associated with oölite, in the Hoyt limestone of the Saratoga Springs area in the Greenfield railroad cut just east of the junction with the Greenfield-South Greenfield road and east of this in the Corinth state road cut at the underpass; three-eighths of a mile south of South Greenfield four corners on the east side of the road; just southeast of the above locality in the brook on the north side of the road following the Milton-Greenfield town line and in Ritchie park, forming the ledge upon which the house stands. In the Little Falls dolomite of this area *undulatum* occurs in the bank above (south of) Disappearing brook, about half a mile east of the Ritchie place. This species has also been found two miles north of Mayfield along the Sacandaga state road in Walker's quarry, which is in the Little Falls dolomite near the base of the formation, and Cushing and Ruedemann (1914, p. 45) have reported the species from the summit of the Little Falls at Ticonderoga.

C. proliferum, so far as is known, is found only in the Hoyt limestone. In the Saratoga Springs region (figure 2) it is found in Ritchie and Lester parks, whence it continues northward, and in the railroad quarry one mile north of the city. In the same area *proliferum* occurs near the summit of a hill about three-quarters of a mile somewhat northeast of North Milton. The rock in this area was originally mapped by Cushing as Little Falls dolomite (Cushing and Ruedemann, 1914) but later as Hoyt limestone (Colony, 1930). Both the reef occurrences and the character of the rock indicate that the Hoyt continues into this area. *Proliferum* has also been found (Ruedemann) at the top of Skene mountain north of Whitehall.

C. ruedemanni has the same distribution as *proliferum* in the Saratoga Springs region and has not been found elsewhere. It occurs as a reef several feet above the *proliferum* reef in the Hoyt limestone.

The three algal reefs and their relations are best studied in the Saratoga Springs area (figure 2) and particularly in Ritchie park, which comprises over 20 acres. Ritchie and Lester parks are located respectively two and a quarter and two and a half miles west of Saratoga

Springs on the east side of a road running north from the State highway (route 29) to Greenfield Center. Ritchie park ("Petrified Gardens") is three-quarters of a mile north of the state road; Lester park a little over a mile and a quarter. The same reefs continue through both parks and northward. The Ritchie house stands on a

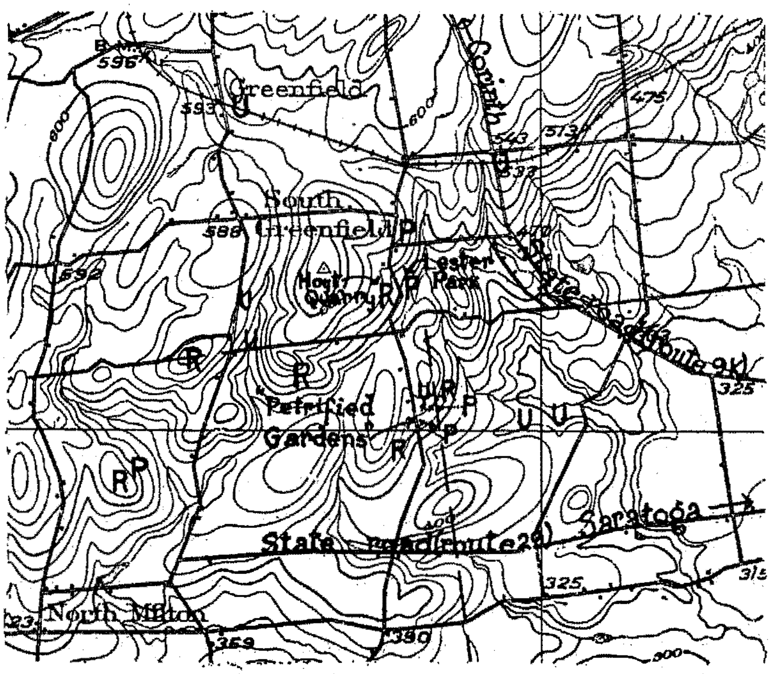


FIGURE 2 Section of topographic map showing the distribution of species of Cryptozoön in the Saratoga Springs area. **P**, *proliferum;* **R**, *ruedemanni;* **U**, *undulatum*.

ledge composed of beds dipping S. 28° W. at an angle of 7°. The top of the ledge is formed by a four-foot reef of *C. undulatum*, beneath which are 40 inches of gray, sandy dolomite and below again to the base of the ledge 34 inches of coarse sandstone with little if any lime. The *ruedemanni* reef is exposed in the field east of the house (150 feet) and slightly northeast (200 feet), the top being eight feet below the base of the *undulatum* reef. The *proliferum* reef outcrops about 400 feet east of the house and the top of the reef is 16 feet below the base of the *undulatum* reef. The *ruedemanni* reef as shown in the ledge east of the house has a thickness of about 28 inches below which is exposed about one foot of coarse sandy dolomite and above three feet of sandy dolomite. The *proliferum* beds here have a dip of 7°

to 8° in a direction S. 33° W. Between 500 and 600 feet southeast of the Ritchie house in Ritchie park is a ledge of *ruedemanni,* 40 feet below the top of the *undulatum* ledge on which the house rests. About 150 feet northeast in the woods is a quarry showing well the *ruedemanni* reef at practically the same elevation as the occurrence at the ledge above. At the base of the old quarry wall are shown 5 inches of coarse sandstone with little lime, followed by 31 inches of thin-bedded sandy dolomite, 40 inches of *ruedemanni* reef (the lower 22 inches most typical), 37 inches of thin-bedded dolomite without Cryptozoön, but with sandy layers and lenses; 20 inches of coarse heavily bedded sandstone, with little if any lime; something over 5 feet of sandy dolomite, more thin-bedded in the basal foot. The top of the ledge here as in the locality just mentioned shows specimens of *ruedemanni* smaller and more scattered than in the exposures near the house. Some of the individuals are drawn out in stringers as though they grew in rill channels. These stringers run roughly N. 10° E. The shore line must have been at right angles to these rill channels, that is, running roughly close to an east-west direction.

Between 200 and 300 feet southeast of the quarry in Ritchie park is found the finest exposure of *C. proliferum* known (figure 3). Between this spot and the outcrop east of the house, this reef is gradually being uncovered through the efforts of Robert Ritchie, the owner, so that soon there will be a continuous exposure. There are between five and eight feet from the base of the *ruedemanni* reef in the quarry to the top of this *proliferum* reef. The beds here dip S. 30° W. at an angle of 5°. The *proliferum* reef is 12 to 15+ inches thick in this locality. Under the reef in the crevices (figure 7) are exposed something over six feet of sandy dolomite, and then below this again is calcareous sandstone. Oölitic structure is shown in the rock beneath the *proliferum* specimens, which is also an indication of reef conditions (figure 12, 13 A). The *proliferum* heads or stocks are concentric growths, somewhat resembling a cabbage in structure, which in general have had their tops sheared off by the glacier that passed over the region. The stocks are very large in this most southern exposure in Ritchie park. They are usually composed of a number of budded individuals (figure 12 A) growing together into specimens reaching two to three feet and over in diameter (figure 11). Sometimes one individual may attain this size (figure 4). Evidently in this part of the reef the conditions were most favorable to growth, because individuals and stocks are also very closely crowded together. There is a coarse sand filling between the separate heads or stocks of *proliferum,* which through weathering stands out in places as conspicuous ridges

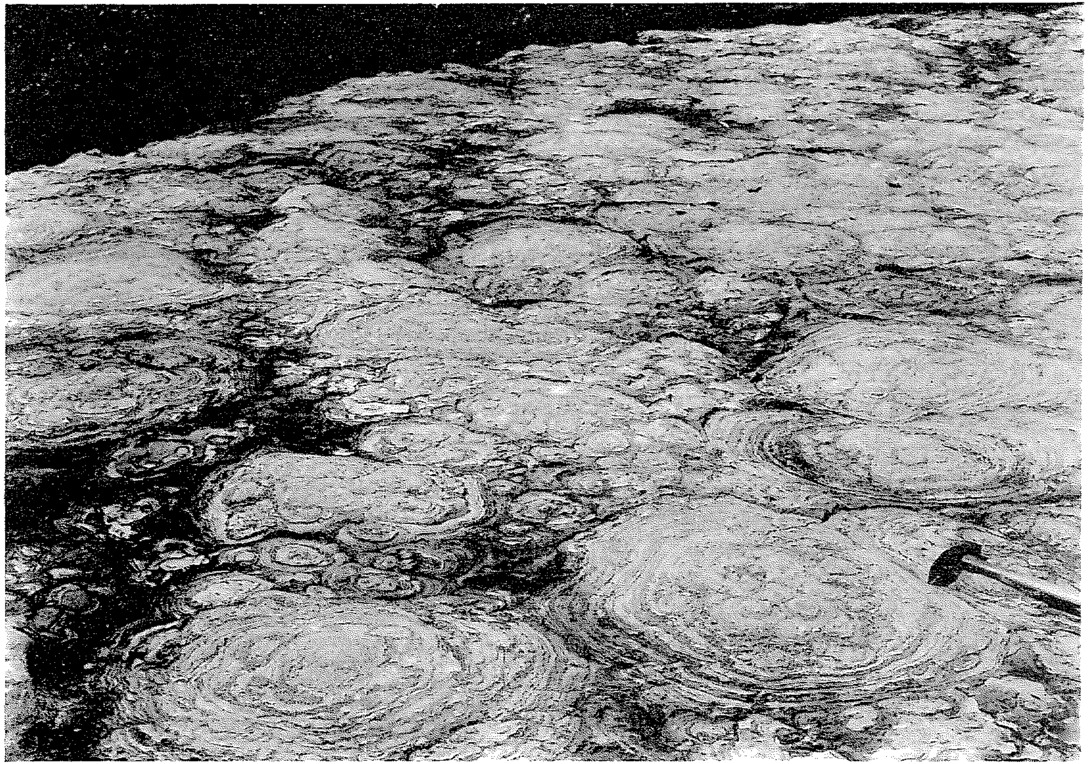


FIGURE 3 *Cryptozoön proliferum* reef at its finest exposure in the southern part of the "Petrified Gardens" (Ritchie park). Stocks here reach a size of two and a half feet and over. (Photograph by E. J. Stein).

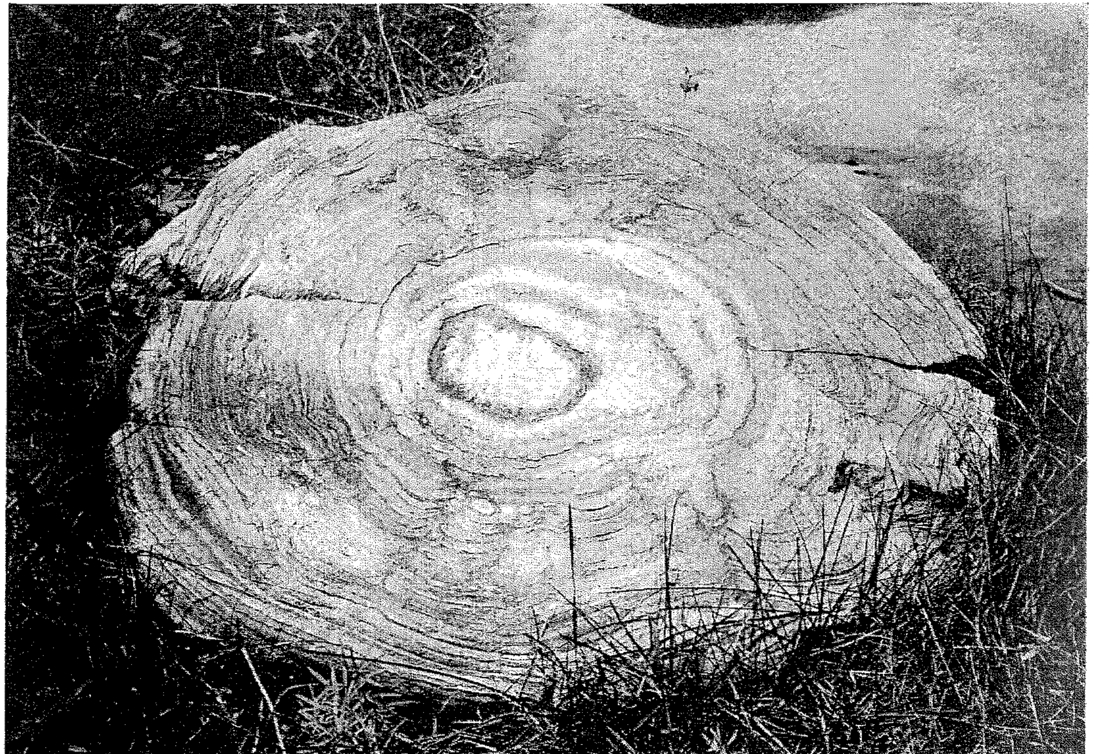


Figure 4. One of the largest stocks taken from the *Cryptozoön proliferum* reef, "Petrified Gardens" (Ritchie park). Approximately three feet in greatest diameter. (Photograph by E. J. Stein).

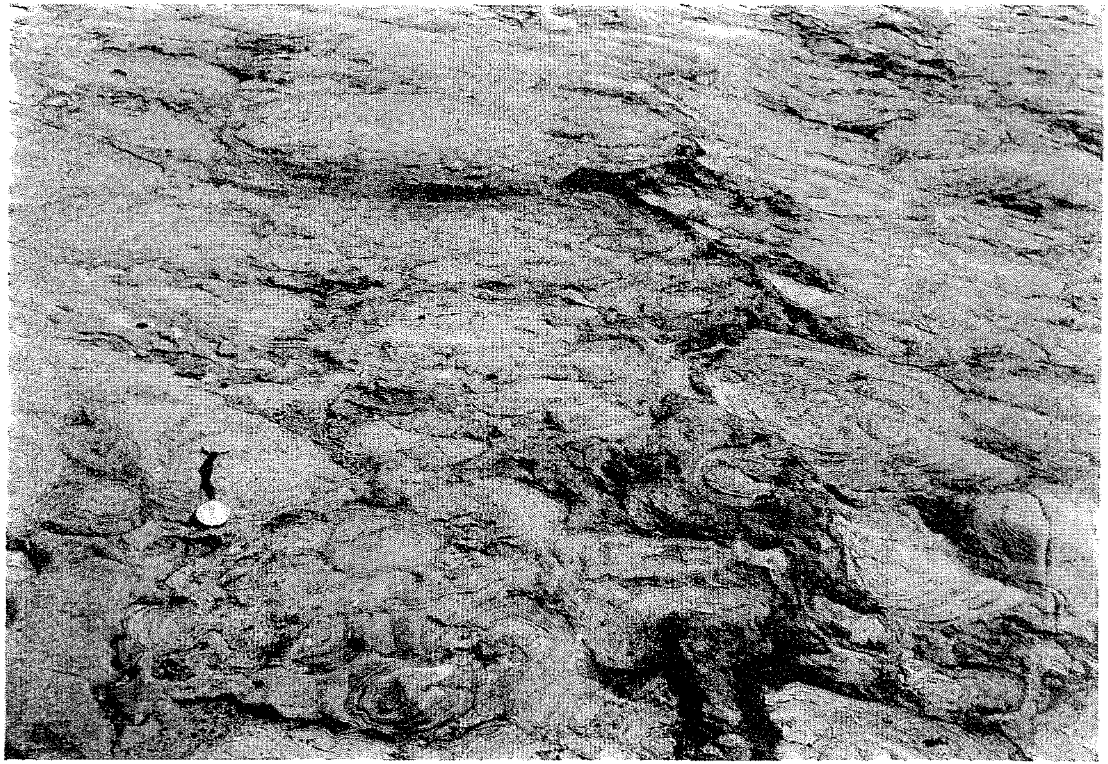


FIGURE 5 Section of the *Cryptozoön proliferum* reef showing the coarse sand filling between individual heads or stocks. "Petrified Gardens" (Ritchie park). (Photograph E. J. Stein).

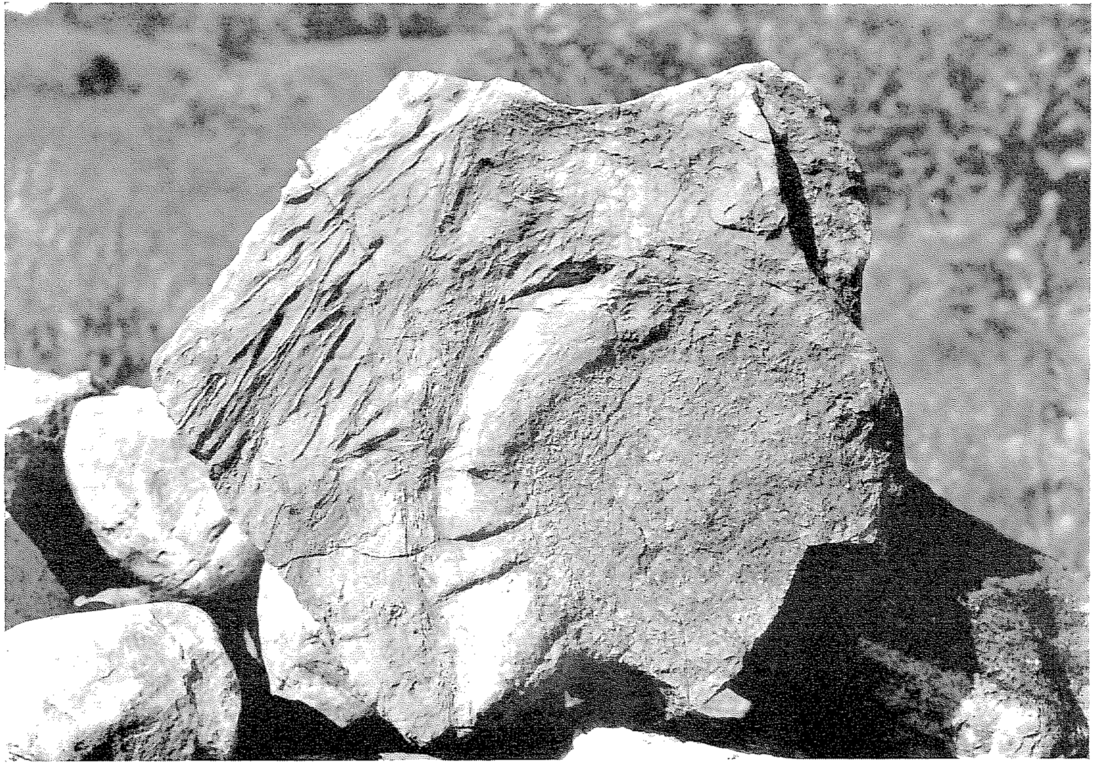


FIGURE 6 Slab of Hoyt limestone showing the macerated remains of *Cryptozoön proliferum*, giving the appearance of an edgewise conglomerate. "Petrified Gardens" (Ritchie park). (Photograph by E. J. Stein).

(figure 5). This condition would seem to favor organic rather than inorganic origin for these structures. In the sand filling have been found fragments of trilobite remains and in places macerated pieces of Cryptozoöns, usually long strips. In the area in process of being cleared there are spots where the macerated remains of these algae constitute a filling of considerable mass, giving the appearance of an edgewise conglomerate (figure 6). Many individuals show well the dichotomous budding which is characteristic of plants, another fact in favor not only of organic but of plant origin.

In Lester park a little over half a mile to the north and along the same road is an exposure of the same reef. Here, although there are some fair-sized specimens, the preponderance of the stocks and individual heads are fairly small and considerably less crowded together (figure 9). The coarse sand filling is well shown here, too, but no macerated Cryptozoön material was seen. Just north of Lester park a road comes in from the east (right). In the field on the north side of this road, near the junction, this reef again outcrops but the habit of the individuals is quite different. The specimens of *proliferum* apparently grew in rill channels and instead of forming the cabbage-like growths so characteristic are drawn out in long stringers (figure 10). These rill channels with the stringers run N. 35°–37° W. There are some heads and stocks in addition to the stringers, but they are fairly small and more scattered in distribution.

The character of the *proliferum* reef as shown in the outcrops discussed above indicates to the writer that the specimens exposed in the southern end of Ritchie park are on the outer side of the reef toward the open ocean where the waters were purer and conditions more favorable to growth. The abundance of macerated Cryptozoön material here would also indicate the same thing, since specimens would be broken up by storm waves. Lester park then would be on the shore side, as would be expected from the more sandy character of the rock, the smaller more scattered specimens, and the stringers of *proliferum* found in the rill channels just to the north. These rill channels must have run roughly at right angles to the shore line which therefore extended in a northeast-southwest direction.

The *ruedemanni* reef followed the *proliferum* reef after the deposition of five to eight feet or more of coarse limy sand and sandy dolomite. One of the best exposures of the reef is found in the face of the Hoyt quarry across the road (west) from Lester park (figure 16). Here the reef is five feet thick. At the summit of the hill about three quarters of a mile northeast of North Milton is a reef of *ruedemanni* with individuals between two and three feet in diameter and some even reaching a diameter of around four feet. In spots the *ruedemanni* is found growing in stringers with the direction N. 18° E. About five feet under this reef *proliferum* and *ruedemanni* are found together and below again *proliferum* alone. It would seem that the *proliferum* requires more favorable conditions, particularly purer waters, in which to have its best development. In the locality just discussed *ruedemanni* apparently came in with a scattered distribution as more sand appeared and the *proliferum* grew less profusely. Another fine exposure of *ruedemanni* occurs south of South Greenfield corners and four miles west of Saratoga Springs (Cushing and Ruedemann, 1916, p. 45, pls. 9, 10). In each locality where the *ruedemanni* reef has been studied it has been seen to follow sandy dolomite and coarse limy sand or thin-bedded limestone and sandstone. So far as present records go, the *proliferum* does not appear anywhere above the Hoyt limestone and there only in the purer limestone phase. During the growth of the *ruedemanni* reef in the Saratoga Springs area the shoreline was somewhat changed from the northeast-southwest direction it held while the *proliferum* reef flourished. In both Ritchie park and the hill northeast of North Milton the stringers of *ruedemanni* in rill channels have a northeast-southwest direction (N. 10° –18° E.), which would indicate a nearly east-west shore line.

C. undulatum like *ruedemanni* apparently thrived in less pure, more sandy waters. The beds in which the *undulatum* reefs occur weather very sandy, as also the beds of sandy dolomite and coarse limy sandstone found just beneath the reef. In the Ritchie park area the *undulatum* reef follows about eight feet above the top of the *ruedemanni* reef in the upper part of the Hoyt formation. Reefs of this species have been found in the lowest Little Falls dolomite (or uppermost Theresa), in the basal part of the formation, toward the middle and in the uppermost beds. Conditions must have been very congenial throughout Little Falls time to permit the development of such a succession of reefs.

The three species of Cryptozoön are discussed in detail below. They are so very distinct in their habit of growth that they may be readily recognized in the field. *C. proliferum* grows in heads or budded stocks up to considerable size (figure 11), three feet and over in the case of the largest stocks and sometimes individuals, which roughly resemble cabbage heads and also have a very striking irregularly concentric structure. The concentric structure is brought out beautifully by the planing off of the upper parts of the heads during the continental glaciation. In *ruedemanni* the concentric layers are more regularly distributed and one finds instead of the compound, budded stocks as

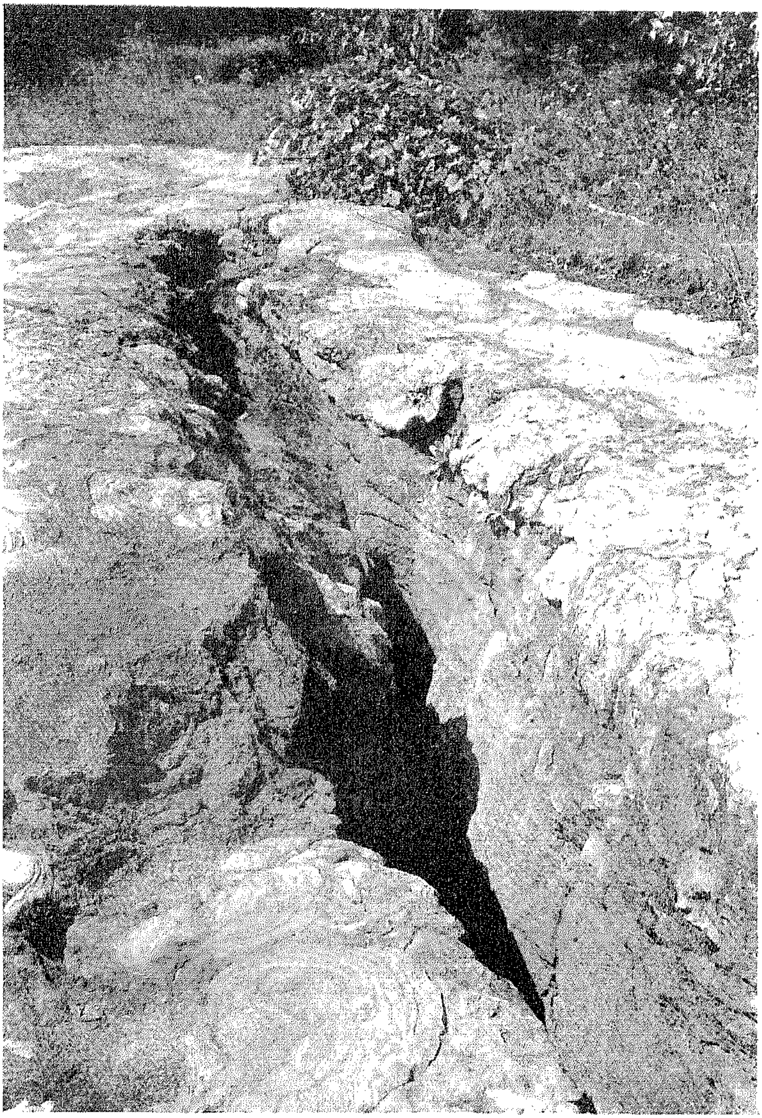


FIGURE 7 One of the solution crevices in the *Cryptozoön proliferum* reef, southern part of the "Petrified Gardens" (Ritchie park). Vertical sections and the attachment of the heads are shown. (Photograph by E. J. Stein).

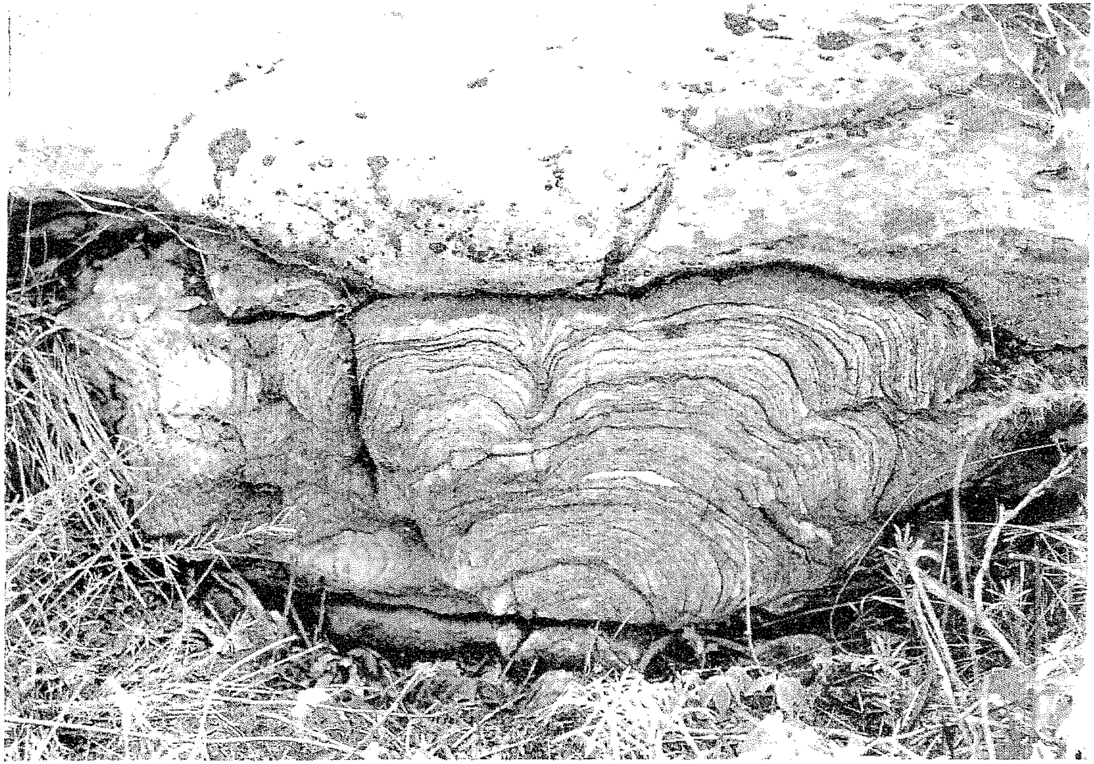


FIGURE 8 Vertical section of a single head of *Cryptozoön proliferum* along a crevice, showing mode of attachment and slightly rounded (unglaciated) upper surface. (Photograph by E. J. Stein).

in *proliferum* simple individuals up to about four feet in diameter (figure 17). *C. undulatum* differs strikingly from the other two species (figures 19–21). This form is composed of thin laminae, the basal ones practically horizontal to the bedding plane. Soon a strong wavy character is developed with frequent narrow or broad undulations with narrower or sharper down-bending of the laminae. On the bedding planes the wavy outlines seen in cross section appear as concentrically lined areas of varying diameter, corresponding to the width of the undulation seen in transverse section.

In these calcareous algae, the remains are not those of the plant itself, simply secretions of calcium carbonate upon the tissue of the plant, the form of the plant, however, being well preserved in the limestone secretions.

THE NATURE OF CRYPTOZOÖN

Steele (1825) in his paper on the limestones about Greenfield, Saratoga county, describes an oölitic formation, the first definite notice of American oölites and one of the earliest of all references to the oölitic horizons of the Paleozoic (Wieland, 1914). Steele calls attention to the presence in this formation of a bed two feet in thickness which "has imbedded, throughout its substance, great quantities of calcareous concretions of a most singular structure; they are mostly hemispheral but many of them are globular and vary in size from half an inch to that of two feet in diameter; they are obviously composed of a series of successive layers, nearly parallel and perfectly concentric; these layers have a compact texture, are of a dark blue or nearly black colour, and are united by intervening layers of a lighter-coloured calcareous substance, either stalactical or granular, they are very thin and I have counted more than a hundred in one series" (*ref. cit.* p. 17). This was the first mention of the Cryptozoön.

Hall in 1847 in a descripition of the "Calciferous sandstone" of the Saratoga region mentions "a great number of what appear to be the remains of sea plants" (p. 5); and points out that "it is impossible in these, as in nearly all the remains of marine plants of the Paleozoic rocks, to detect any structure which can be reliable in making distinctions" (*ref. cit.*). In 1883 he described these bodies as plants belonging to a new genus, *Cryptozoön*, with one species, *Cryptozoön proliferum*. Here also Hall discusses the Hoyt farm exposure and the continuation of this outcrop (our reef) for two miles southward. The fossil is also cited as found at Little Falls, Herkimer county. Dana in his Manual of Geology, 1896 (p. 500) places *Cryptozoön proliferum* with the hydrozoans, "if really organic." Walcott (1912, p. 257, 258) repeats Hall's description and figures, with sections, specimens from "the Upper Cambrian [Ozarkian] shaly calcareous sandstone resting on massive layers of Potsdam sandstone east side of the town of Whitehall, Washington county, New York." *Cryptozoön* has also been found in Dutchess county in the lower Wappinger limestone of Hoyt Age (*see* Knopf, 1927, p. 438).

Since the first description of *Cryptozoön* from the Cambrian (Ozarkian) limestone at Saratoga, species have been described from Ozarkian and Ordovician (Canadian) rocks in various places in this country and others, as in the Cambrian rocks of Norway and Lower Paleozoic strata of Ellesmere Land and elsewhere (Holtedahl, 1917, 1919) and the Ordovician of Eastern Asia (Kobayashi, 1931*a*, p. 134; 1931*b*, p. 6, 8, 10, 12; 1933*a*, p. 62–64, 77; 1933*b*, p. 251–52). Kobayashi writes (March 6, 1934) that this Ordovician Cryptozoön reef constitutes a great display in South Manchuria and North Korea and marks the base of the Ordovician; that only the stratigraphical horizon has been studied and no special study has yet been carried out on the structure of this Cryptozoön. Cryptozoönlike forms have been reported from Precambrian rocks and from more recent formations (Permian, Triassic, Cretaceous), some of which, at least, are undoubtedly of inorganic origin; and doubt has been thrown on the organic nature of all such forms (Seward, 1931, p. 86; see discussion below).

Seely (1906, p. 160–68) describes, besides *C. proliferum* Hall, three new species of Cryptozoön from the Beekmantown (Canadian) of the Champlain valley: *steeli, wingi* and *saxiroseum.* The new species are not accurately delineated or figured. Both the figures and descriptions of *steeli* and *wingi* indicate that they are probably *proliferum. C. steeli* is recorded from the original locality of Steele along the Greenfield-Ballston Spa, N. Y. road; from the Beekmantown of Shoreham, Vt., where as in the original locality the Cryptozoöns rest upon oölitic rock; and the Beekmantown of Phillipsburg, Canada. *C. wingi* is also from the Beekmantown. Its primary station is Mount Independence, Orwell, Vt., 100 rods southeast of Fort Ticonderoga; Fort Ann, Washington county, N. Y. and Colchester, Vt. *C. saxiroseum* was found in the Beekmantown at East Beekmantown, Clinton county. He also cites from the Beekmantown formation, Lachute, P. Q., *C. lachutense* Dawson (1897, p. 203). Seely calls attention to the fact that these fossils especially should be looked for wherever the oölitic strata of the Beekmantown are exposed. He describes the sea in which these organisms grew "as sweeping in an irregular crescent from Atlantic back to Atlantic through the depression of the St Lawrence, broadening at Lake Champlain. . . In these waters sea plants; and animals of every known type but one, found here their home. . . Among the lowly forms of animals growing in the shallower waters was one increasing by concentric laminae producing a rounded calcareous mass . . . *Cryptozoön*" (*ref. cit.* p. 173). Seely places this organism with the stromatoporoids (p. 171). Dawson (*ref. cit.* p. 205–211) in his discussion of *C. proliferum* and the new species described by himself from Canada and Winchell (1885) and Chaney (1889) from the Upper Cambrian of Minnesota says "fossils of the type of *Cryptozoön* constitute a type differing from that of the ordinary *Stromatopora*, and probably inferior to them in organization."

Grabau in his Index Fossils (1909, v. I, p. 46) places *Cryptozoön* with the stromatoporoids, diagnosing it as follows: "Coenosteum of irregular concentric laminae, transversed by minute canals which branch and anastomose irregularly." In his paper Further Notes on Ozarkian Seaweeds and Oölites, Wieland (1914) discusses *Cryptozoön*. After a survey of various described species he writes, "*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. . . In the present paper we briefly consider the evidence now going to show that Cryptozoön belongs to a group of Algae which formed vast reefs in the Ozarkian oceans, and also describe from the Conococheague of Pennsylvania a new species, likewise of the reef-making type" (p. 237). This new species from the lowermost Conococheague (*Cryptozoön bassleri* Wieland) occurs closely associated with fine-grained oölites. Wieland points out that the algal nature of *Girvanella* (Rothpletz, 1908), closely related to *Cryptozoön*, and allied Asiatic genera *Metasolenopora* and *Petrophyton* (Yabe, 1912) has been established, "although only critical study as yet difficult to make can finally serve to separate these several genera from the Stromatoporoids" (*ref. cit.* p. 239). In the description of *C. bassleri* he calls attention to the cell structure as essentially the same as the highly palisaded *Lithothamnium* type. *C. bassleri* is assumed to be of an algal nature because of unquestioned relationship to *C. proliferum* (*ref. cit.* p. 244). In concluding his discussion Wieland remarks: "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 greater part of characteristically laminate, linear, or much branched *Lithothamnium* form, are all primative algae which form the abundant record of a far more luxuriant seaweed growth than has hitherto been understood to have characterized the Paleozoic (*ref. cit.* p. 246).

In an article on The Cambrian and Ordovician Deposits of Maryland Bassler (1919) discusses two species of calcareous algae (*Cryptozoön proliferum* and *C. undulatum*, a new species with laminae of equal undulations) which have an important bearing on the age determinations of certain formations in the Appalachian valley. These two species occur in the Conococheague limestone (Ozarkian) of Maryland and beds of the same age in Pennsylvania and New Jersey. Southward in the Appalachian valley through Virginia, Tennessee and Alabama and farther west in Oklahoma and Texas the same Cryptozoön forms are also known in the Ozarkian (Dake and Bridge 1932, p. 727). In describing the Conococheague of the section in Hagerstown valley, Md., Bassler notes "a basal division of 250 feet of oölite, edgewise conglomerate and Cryptozoön reefs, the latter in a massive dark blue to light coloured rather pure limestone constituting the lower 50 feet. . . The edgewise conglomerates and the oölites are shallow water deposits and the rounded quartz grains occuring with them indicate nearby land (p. 78). . . The two calcareous algae (*Cryptozoön proliferum* Hall and *C. undulatum* new species) at the base of the formation are found in abundance wherever these beds are exposed" (p. 82).

Farther on in his discussion (p. 84) Bassler calls attention to the quite similar laminated structures in the Proterozoic rocks of the West, described by Walcott and shown to represent the secretions of calcareous algae, and continues: "The Proterozoic forms of calcareous algae have been described under six genera, but all of the Cambrian and Early Ordovician forms have been referred to the single genus Cryptozoön" (p. 85). He describes a strongly laminated type of *Cryptozoön* found near the top of the Conococheague limestone in both the eastern and western areas of outcrop in Maryland. "Natural sections in the rock show that the undulations are 18 or more inches in width and that the zone of strong undulations rises in the stratum to a height of two feet or more. This *Cryptozoön* sometimes consists of a single mass of strongly marked undulating layers one-half inch apart rising in the rock like a column. . . This particular *Cryptozoön* is of special interest in having oölites one-eighth of an inch in diameter abundantly developed in the areas between the downfolds of the laminations. The formation of these oölites appears

FIGURE 9 *Cryptozoön proliferum* reef in Lester park, where the stocks are smaller and less crowded and the budding is well shown. (Photograph by H. P. Cushing; plate 3, N. Y. State Mus. Bul. 169).

Figure 10. Long stringers of *Cryptozoön proliferum* which grew in rill channels, near road junction north of Lester park. (Photograph by E. J. Stein).

to have been connected with the life activities of the plant" (p. 85, 86). Bassler also notes the occurrence in the Beekmantown (just above the Stonehenge limestone member) in southern Pennsylvania and Maryland, of a Cryptozoön zone (referred by him to *Cryptozoön steeli* Seely) in which these organisms are associated with an oölitic, cherty blue and gray limestone (p. 93, 101). "This fossil occupies a similar position in the Beekmantown throughout the Appalachian Valley and is so abundant and characteristic that the division is termed the *Cryptozoön steeli* zone" (p. 101).

Rothpletz, while visiting in this country in 1913, made a one-day trip to the Saratoga area and studied the Cryptozoön exposures there. He describes (1916) three species, *C. proliferum* Hall, *C. ruedemanni* Rothpletz and *Cryptozoön* sp. nov., which now is *C. undulatum* Bassler. A fourth form described by him as a type showing cauliflower stocks, apparently is *C. proliferum* developing large heads. Rothpletz calls attention to the association of *Cryptozoön* here with a sandy oölitic limestone. His description of the Saratoga species is referred to below under the description of species. *Cryptozoön* is placed by him with the Hydrozoans (stromatoporoids).

Seward (1931, p. 83–89) in Plant Life Through the Ages discusses the various views on the nature of *Cryptozoön* and states:

> The general belief among American geologists and several European authors in the organic origin of *Cryptozoön* is, I venture to think, not justified by the facts. The *Cryptozoön* structure differs essentially from Calcareous Algae, such as *Lithothamnium* and other genera . . . in the absence of any characters suggesting a cellular frame work. They are precisely the same in their series of concentric shells as many concretions which are universally assigned to purely inorganic agencies. . . It has been asserted that cells and chains of cells comparable in size and shape to those of existing Blue-Green Algae have been found in some sections of *Cryptozoön*-like structures. The term cell may be correctly used, but one would like to have evidence more convincing than the photographs and drawings which have so far been published (p. 86, 87).

Liesegang's rings, referred to by Seward (p. 87, 88) are quite different in structure from the true Cryptozoön as exemplified by our Saratoga specimens. It is from a study of these rings (developed in a coagulated colloidal material, a gel, containing a substance in solution by reaction of a second solvent with the former) that Seward concludes: "A deposit of a colloidal calcareous mud on the floor of a sea might provide conditions favorable to the formation of concentric shells of carbonate of lime and the ultimate development of masses constructed on the plan of Cryptozoön" (p. 87).

In 1926 in his Pflanzen als Gesteinsbildner (p. 51, 52) Pia in his discussion of calcareous algae regards *Cryptozoön* and *Collenia* as undoubtedly algal masses, probably built up by several species. The latest reference to the algal nature of *Cryptozoön* that I have found is that by Hadding (1933) in a discussion of algae as limestone formers:

On the formations termed *Collenia* and *Cryptozoön* we may be brief, as to our knowledge they do not play any rôle in the sedimentary series of strata in Sweden. Their organic or inorganic formation has been disputed and so has their position in the organic world after they have been definitely counted in this. After having long been numbered with the Stromatoporoids (Nicholson 1878; Rothpletz, 1916), these calcareous formations have more and more been regarded as belonging to the vegetable kingdom and there as a rule counted among lime producing algae (Walcott, 1914, Wieland, 1914, Pia, 1926). Pia thinks that they show a structure mostly reminding us of the blue-green algae (p. 16). . .

A closer estimation of the systematic position and mutual relations of the different algae forms is often very uncertain, as the structural features desirable for the estimations have not, or only imperfectly, been preserved by the incrustation of calcium carbonate (p. 14). . .

Precipitation of calcium carbonate by the activities of certain algae results from their extraction of carbon dioxide from the water. The decrease of carbon dioxide in the water also diminishes its power of dissolving calcium carbonate, and an excess of this salt must therefore be precipitated from a previously saturated solution. The rôle of the algae as limestone formers consequently is that they provide the conditions favourable for an inorganic precipitation. . . As in the case of bacteria, the precipitation of calcium carbonate through algae can take place outside and quite independent of these organisms' own structure. In certain algae, however, it can also take place inside or on the surface of the cellular structure. In such cases certain structural features of the organism can of course be preserved (p. 12).

The structure of the three New York species of *Cryptozoön* will be discussed below. As pointed out above, there are several facts that seem to indicate organic origin for these forms at least. The dichotomous budding (figure 11) is characteristic of plants. The *proliferum* exposures show particularly well a coarse sand filling between the separate stocks, which would seem to favor organic origin; and in the sand filling are found fragments of trilobite remains and in places macerated pieces of specimens of Cryptozoön, usually long strips. In Ritchie park, near the quarry, where the finest specimens are exposed on what has been interpreted to be the shore side of the reef are areas where the macerated remains of *Cryptozoön*, broken by storm waves, constitute a filling of considerable mass, giving the

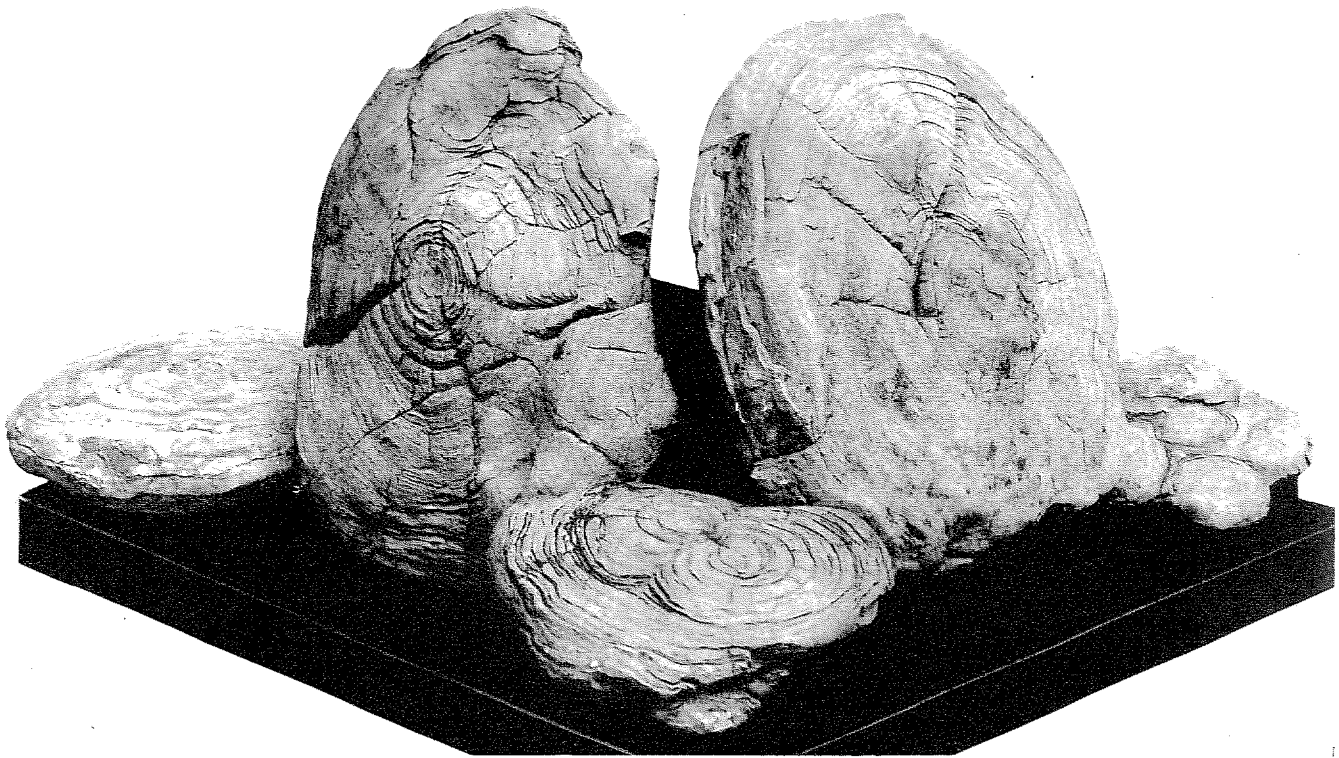


FIGURE 11 Group of entire specimens of *Cryptozöon proliferum* from the "Petrified Gardens" (Ritchie park) on exhibition in the New York State Museum. The large examples measure two and a half feet in diameter; the specimen in the foreground shows well the dichotomous budding. (Photograph by J. E. Glenn).

appearance of an edgewise conglomerate. In the exposure north of Lester park specimens of *proliferum* apparently grew in rill channels and are drawn out in long stringers. The same is true of *ruedemanni* in the vicinity of the quarry. This would indicate not only organic, but plant origin for these forms, an indication strengthened by the association with oölites (*see* p. 21–24).

Supplementary Note

Dr Oskar Baudisch, director of the New York State Research Institute for Hydrotherapy, Saratoga Springs, N. Y., has recently written a paper on "The Isotopes of Potassium and Lithium in Saratoga Mineral Water and Cryptozoön" (1937), which sets forth evidence that confirms the view that the Cryptozoön reefs are of plant origin. The abundance ratio of the two principal isotopes of potassium (K^{39}, K^{41}) has been found to vary in plant and animal tissue from the ocean water ratio (14.20), in the case of kelp showing an abnormally high concentration of K^{41} (heavy postassium). Consequently it was decided to make a study of a formation presumed to be of marine plant origin, such as the Cryptozoön beds of the Saratoga area. The results show "an appreciable concentration for K^{41} in the mineral water and a small concentration for the Cryptozoön formations. The overlying shale, however, does not differ appreciably from that normally present in rocks of this type" (*ref. cit.*, p. 1579). In discussing his results not only for the isotopes of potassium but also for those of lithium and rubidium, for which the ratio in Saratoga water does not differ appreciably from normal, Doctor Baudisch states:

The results just described are of interest in that they represent the only inorganic source so far discovered in which the K^{41} [heavy potassium] content is appreciably higher than normal. It is significant that the lithium isotope ratio does not deviate correspondingly. It would appear, in consequence, that the process which concentrated K^{41} does not concentrate Li^7 [heavy lithium]; this precludes most physical mechanisms for the isotope effect since they would be expected to result in larger deviations for lithium than for potassium. The simplest interpretatons for these results is, therefore, that the salt deposits from which the water arises are of marine plant origin rather than that any isotope effect is occurring at the present time, which would result in an abnormal abundance ratio for potassium (*ibid*). [*See* Baudisch, Science, 86:531, 532. 1937.]

THE THREE SPECIES OF CRYPTOZOÖN

Cryptozoön proliferum Hall

Figures 3-15A

Hall (1883) described the genus *Cryptozoön*, based on specimens of *Cryptozoön proliferum*, as follows:

> In the town of Greenfield, Saratoga county, there occurs a bed of limestone which presents a very remarkable appearance, the surface being nearly covered by closely-arranged circular or subcircular discs which are made up of concentric laminae, closely resembling in general aspect the structure of Stromatopora. It very often happens that within these larger discs there occur two or more smaller ones, each with its own concentric structure and exterior limitation, and appearing as if budding from the parent mass. A farther examination shows that the entire form of these masses is hemispheric or turbinate, with the broadest face exposed upon the upper surface of the limestone layer; that their growth has begun from a point below and, rapidly expanding upwards, has often extended one or two feet in diameter, as now shown upon the exposed surface of the limestone bed. . .
>
> These bodies have long been known under the name of Stromatopora, from their general resemblance in form and structure to that fossil; but their position in reference to the bedding of the rock is uniformly the reverse of that of Stromatoporae, which occur in the higher limestones, growing from a broad base which is covered by an epitheca, while these bodies under consideration grow upward and expand from a point below, while the convex surface is on the lower side. A careful examination of the nature of these bodies proves that while having the concentric structure common to Stromatopora they have not the regular succession of layers of tubuli characteristic of the species of that genus and cannot properly be included under that term (description with plate 6).

Rothpletz (1916) describes this species from the section at the Hoyt farm (Lester park), where the *Cryptozoön proliferum* bed rests upon oölitic limestone and then is followed by an oölitic limestone. In Ritchie park, where there is by far the finest display, the *proliferum* bed has a thickness of 12 to 15+ inches and rests upon about six feet of sandy oölitic, dolomitic limestone, as seen in the crevices, below which occurs a coarse calcareous sandstone.

The cabbagelike heads or stocks of *proliferum* are composed of alternating limy and sandy layers. As pointed out above (p. 12), due to the shearing off of the surface by the ice during the Pleistocene time, they have been given the appearance of circular or subcircular discs made up of concentric layers, resembling most strongly a cabbage head sliced horizontally. The attachment of the individuals by a small point from which they expand upward into a hemispheric or turbinate

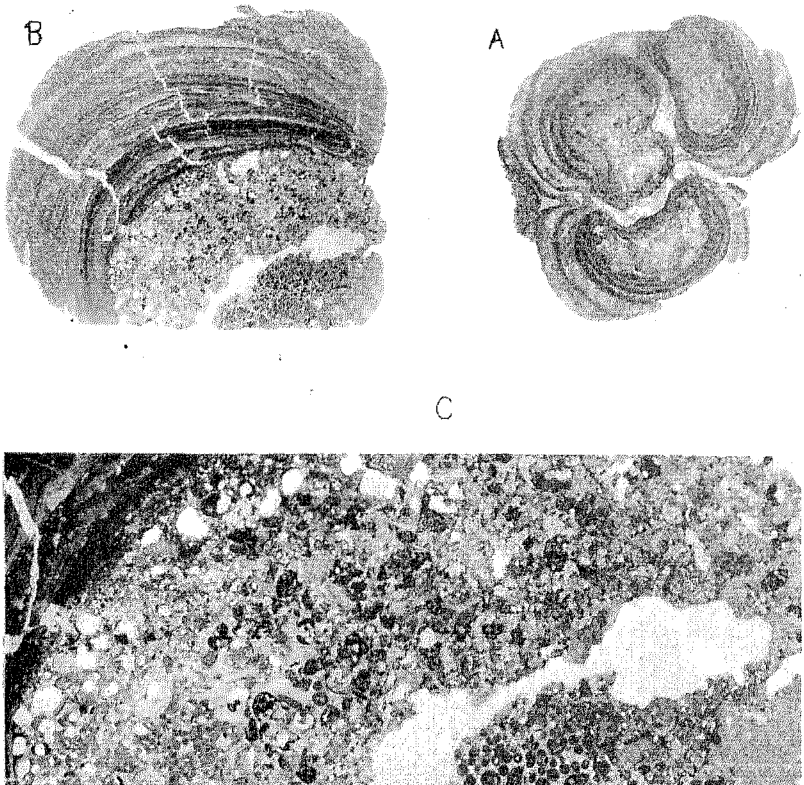
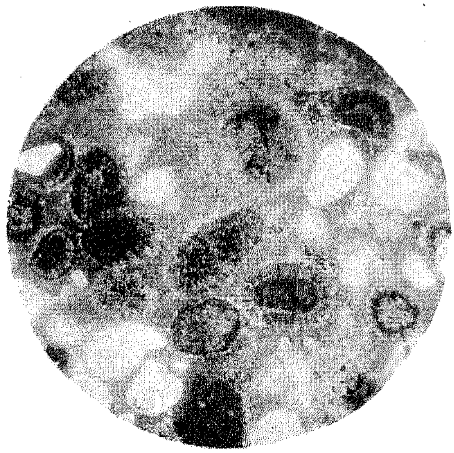


FIGURE 12 Thin sections of *Cryptozoön proliferum* from the Hoyt limestone, Greenfield. *A*. Portion of individual with three buds; oölites and quartz grains between the laminae. *B*. Portion of a larger individual with center filling of oölites and some quartz (clear). *C*. Enlargement of oölitic area of same, x3. (Photographs by E. J. Stein).

A



B

FIGURE 13 *A*. Photomicrograph, x30, of a thin section of *Cryptozoön proliferum*, showing oölites and quartz grains (clear); Hoyt limestone, Greenfield. *B*. Polished vertical section of a small head of *Cryptozoön proliferum* from Lester park, x½. (Photographs by E. J. Stein).

form is shown in the crevices and in a few places, in vertical sections in crevices, where the stocks are well covered by the rock the upper surface is seen to be slightly rounded (figure 7, 8, 13B). Stocks of *proliferum* grew to a large size reaching two or three feet and over in diameter, the larger specimens being composed of a number of budded individuals, according to the writer's interpretation. Rothpletz (p. 10), regarding these organisms as stromatoporoids, interprets the condition differently. He believes the larger stocks are composed of neighboring smaller stocks which have grown together and become surrounded by a common layer. The largest and best developed stocks, as discussed above, are found in Ritchie park, particularly in the southern area (figures 3, 4, 5) which has been interpreted as the seaward side of the reef. Here the stocks are so crowded that they touch and the spaces between are filled with coarse sand carrying fragments of trilobites and macerated *Cryptozoön*. Pieces of macerated *Cryptozoön* also fill the sandy limestone covering of the stocks, when preserved. Approaching the shore, that is northward in this area, the stocks become smaller and are more scattered in the rocks until, as north of Lester park, in the rill channels the individuals lose their characteristic shape and have grown out into long stringers (figure 10). These must be the specimens referred to by Rothpletz (p. 11) as having a breadth of one hand and a length of two meters.

Rothpletz, from thin sections, describes the structure of the *C. proliferum* as that of a branching network or mesh of thicker and finer branches composed of coarsely crystalline calcite, appearing lighter in section, with a filling of a microscopic, crystalline, dense aggregate of calcite; and points out that in all its peculiarities "this network agrees completely with the coenosarc tubes of the Spongiostroma and the dense filling in the interspaces to the original coenosteum of these Hydrozoans. Corresponding to this the lighter line aggregate represents the filling of coenosarc tubes which did not form until the death of the animal and during the process of fossilization. The dolomitization, however, as far as it has affected not only this filling but also the coenosteum must be considered as a still later process which has changed the original material partly, and in many places totally, and thereby has also eradicated the Hydrozoan structure more or less. The calcite filling of the coenosarc tubes on the other hand was perhaps affected already through the decaying organic substance of the *Cryptozoön* animals or at least initiated by it. For the dolomitization, however, this cause can hardly be cited, at least microscopic study gives no clues in that direction" (*ref. cit.* p. 13).

The photomicrographs in figure 14 and figure 15A show well the structure of this species. The general ground mass or background is formed by a very finely granular calcite in which banding is shown by clearer areas against dense dark areas. In this ground mass are seen the branching tubes of varying thickness filled with microscopic, crystalline calcite, lighter than the background. Any structure that may have been present in these tubes has been obliterated. Small pressure cracks likewise have a filling of this lighter crystallized calcite. Scattered quartz grains are present in the ground mass and fine dark iron particles. In the specimens of *proliferum* studied little dolomitization has taken place, less than in either of the other two species. The filling of the meshwork of tubes is somewhat affected and in places coarse dolomite crystals encroach upon the dense, granular ground mass. The difference undoubtedly has something to do with the water content of the beds in which this species occurs.

Cryptozoön ruedemanni Rothpletz

Figures 15B–18

The distribution of the *ruedemanni* reef is discussed above. The species has the same distribution as *proliferum* in the Hoyt limestone, and occurs five to eight feet above the latter following beds of sandy dolomite and coarse limy sand or thin-bedded limestone and sandstone. The species was described by Rothpletz in 1916:

> Already from their outer form these stocks are seen to be different from those of the Hoyt farm and make it apparent that they belong to another species. . . . The characteristic construction of a single stock from a number of smaller stocks grown together is absent here (p. 16).

These simple individuals (figure 17) show sizes up to about four feet in diameter, and in them the wavy concentric layers are more regularly distributed. Rothpletz continues his discussion of the small piece of a specimen of this species which he had for study:

> But one can see quite well from the edge of this piece that there the layers of the stock quickly bend down and over into a steeper position from the wavy horizontal position which controls the whole center of the stock, just as is the case with *Cryptozoön proliferum*. A peculiarity of the stocks of this locality, which I have not observed in *Cryptozoön proliferum*, is the fine bands which stand forth in brownish colors through the weathering of the upper surface . . . and give this *Cryptozoön* a peculiar appearance. They run almost in the direction of the larger structure of the *Cryptozoön* and could be interpreted as sand layers lodged in it. But the agreement is only apparent for often they cut the *Cryptozoön* bands at varying angles and enter into connection with the neighboring strands, so that in the stock they

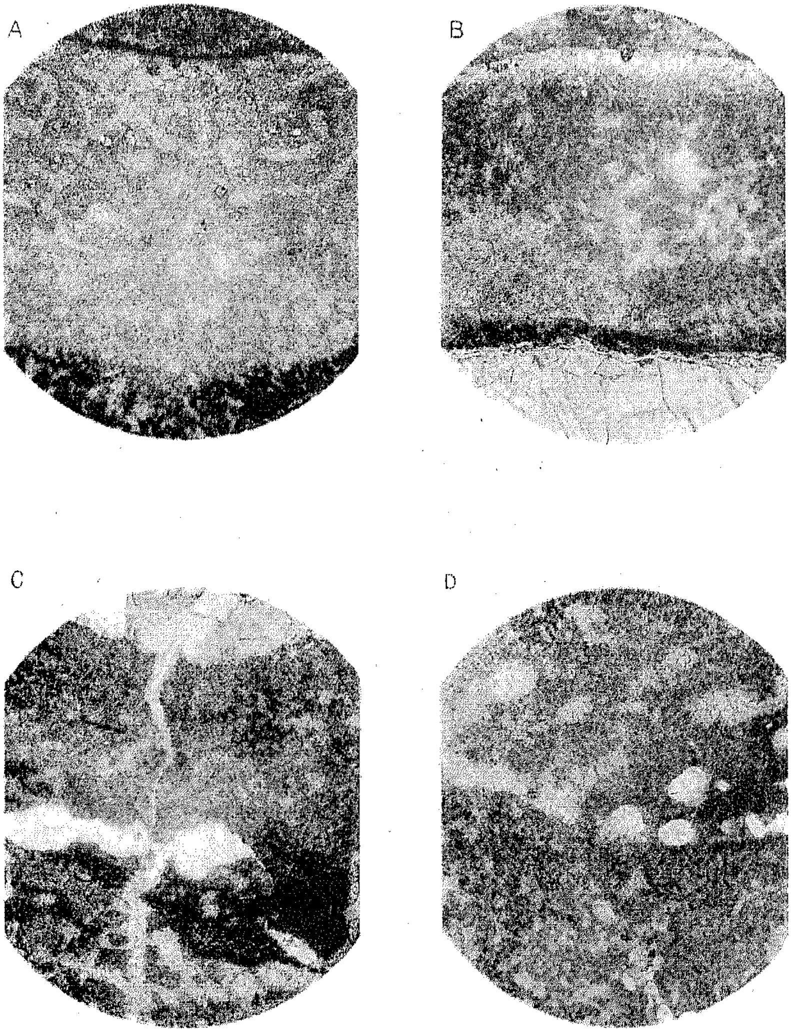
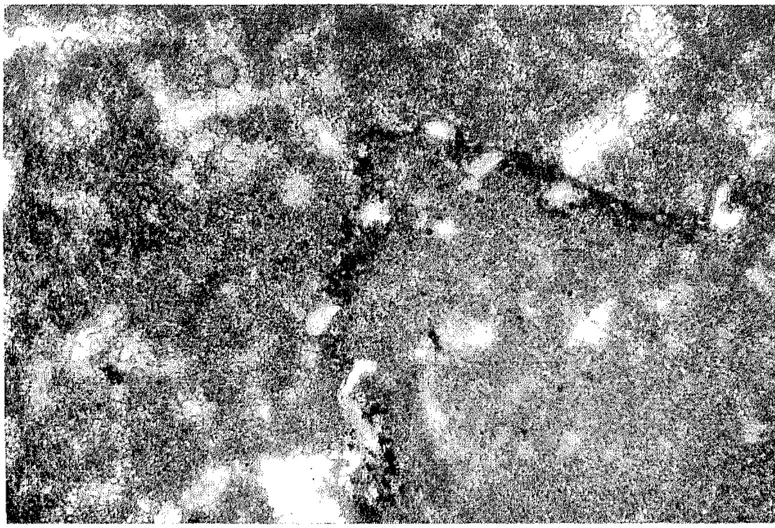


FIGURE 14 Photomicrographs of *Cryptozoön proliferum* from Ritchie park, x30. *A*. Horizontal section: general ground mass of finely granular calcite with branching tubes filled with microscopic, crystalline calcite; banding shown by clearer area against dense dark areas. *B*. Horizontal section: dolomitization shown in lower portion. *C*. Vertical section: pressure cracks filled with calcite; dolomitization in upper portion. *D*. Vertical section: large tubes filled with crystalline calcite; scattered quartz grains (clear). (Photographs by E. J. Stein).

B



A

FIGURE 15 Photomicrographs, x75. *A. C. proliferum*, horizontal section: branching tubes filled with crystalline calcite in ground mass of finely granular calcite; denser granular area at right, separated by dolomitized band with large quartz grains (clear) in lower portion. *B. C. ruedemanni*, horizontal section; branching tubes in dense ground mass; iron particles and quartz grains (clear) in filling at center. (Photographs by E. J. Stein).

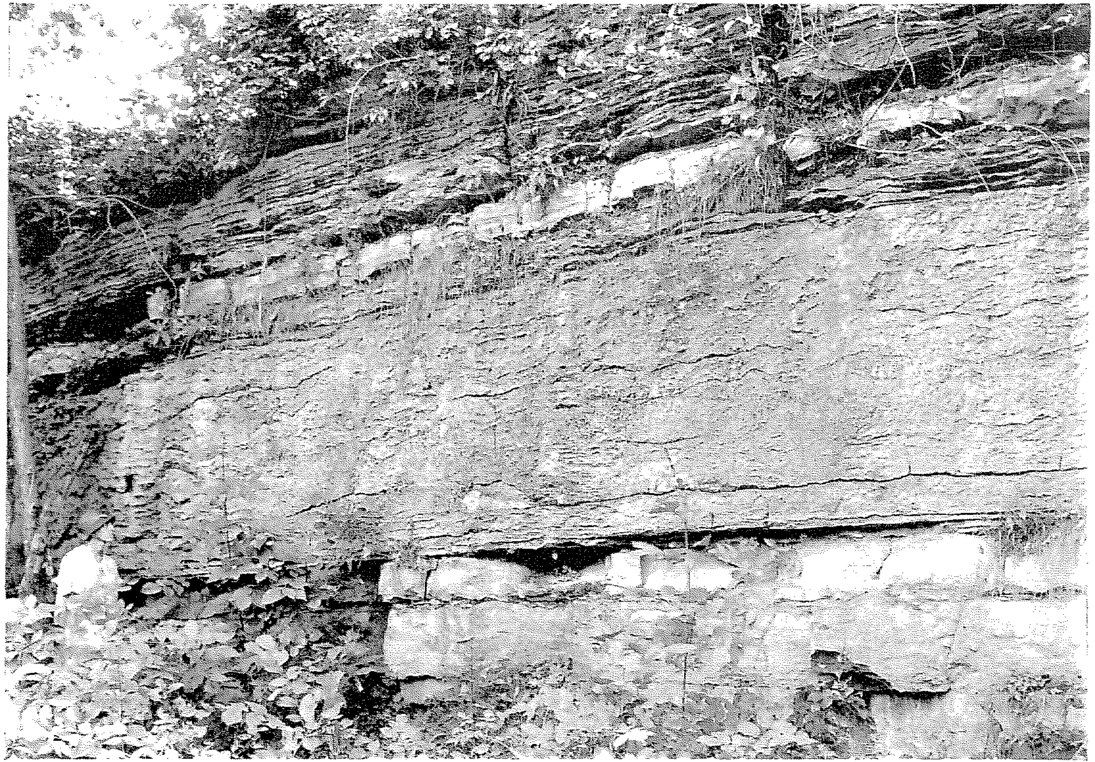


FIGURE 16 The five-foot thick *Cryptozoön ruedemanni* reef shown in the face of the Hoyt quarry, across the road (west) from Lester park. (Photograph by E. J. Stein).

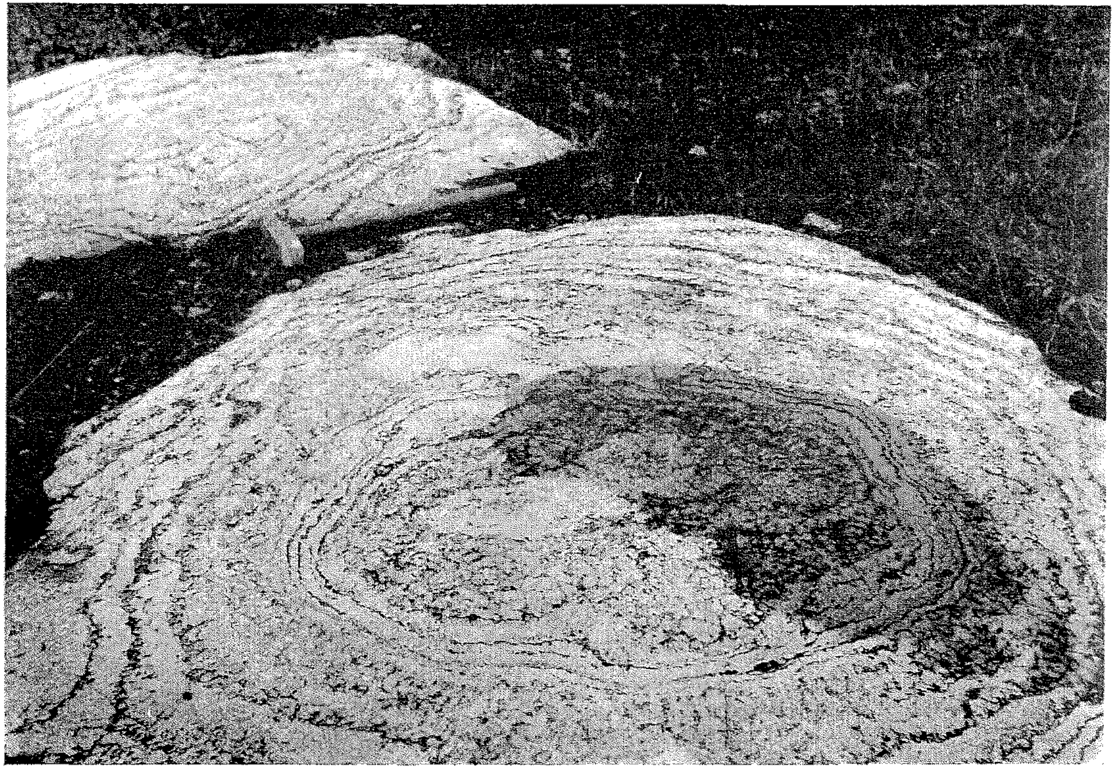


FIGURE 17 *Cryptozoön ruedemanni* stock, summit of hill four miles west of Saratoga Springs and three quarters of a mile south of South Greenfield. (Photograph by H. P. Cushing; plate 10, N. Y. State Mus. Bul. 169).

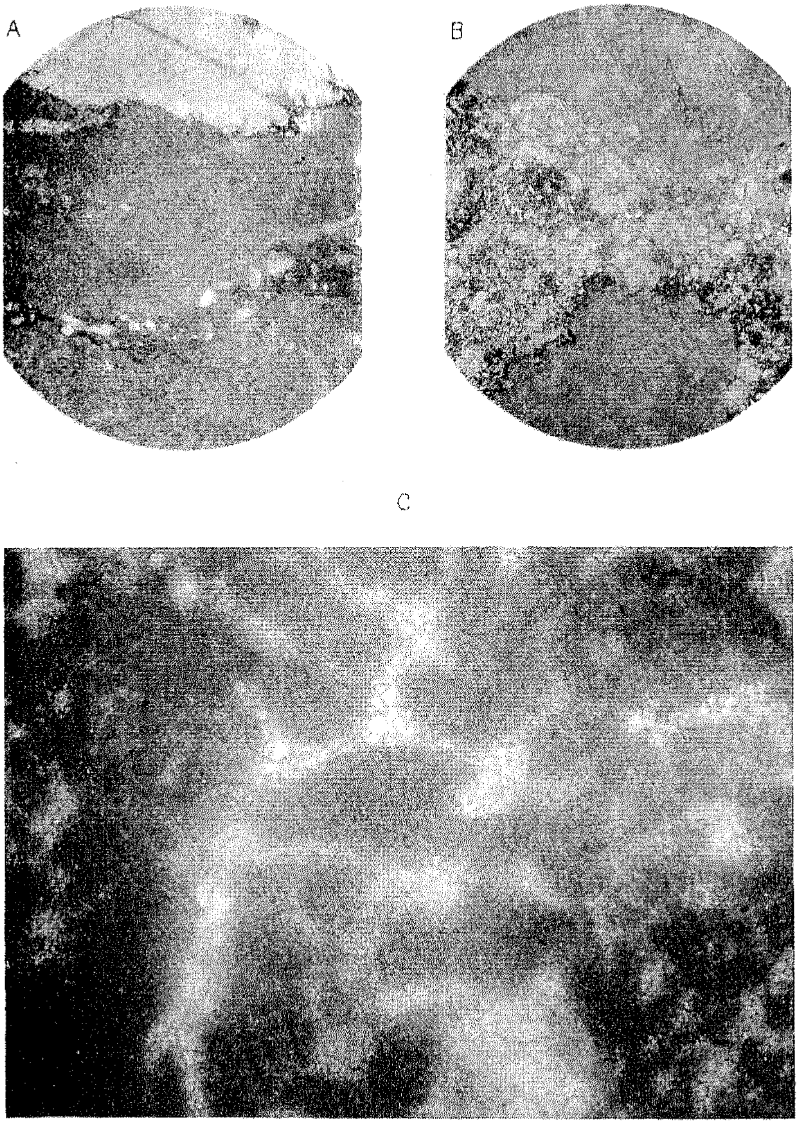


FIGURE 18 Photomicrographs of *Cryptozoön ruedemanni.* *A.* Vertical section x30; upper portion dolomitized; sandy band (quartz grains clear) between dense areas of granular calcite with branching tubes filled with finely crystalline calcite. *B.* Horizontal section, x30; sandy band with abundant quartz grains between densely granular calcite areas with fine branching tubes. *C.* Vertical section, x75; dense granular calcite ground mass and branching tubes. (Photographs by E. J. Stein).

build an anastomosing network which by its origin is at any rate younger than the *Cryptozoön.* Under the microscope one recognizes that it is composed of a stratified accumulation of finest quartz dust and dark little iron bodies which are welded together through a dolomitic binder. These layers are usually only 60μ to 120μ thick and only here and there increase to greater breadth. The course of these lace-like bands reminds one throughout of that of pressure sutures and as such must accordingly be interpreted, for they are properly not other than a distribution of insoluble constituents which otherwise are enclosed in the *Cryptozoön* layers. The structure of the lime stock is similar to that of *Cryptozoön proliferum,* only the coarse coenosarc tubes are not so close together. The coenosteum takes up more space and the finer coenosarc tubes prevail over the coarser ones. . . .

Likewise in this species dolomitization has taken place, but in still another way than with *Cryptozoön proliferum.* The coenosteum has remained calcareous and is quickly dissolved in diluted acid with strong effervescence. The coenosarc tubes on the other hand are filled with a light dolomitic aggregate which after careful etching on polished surfaces stands up distinctly above the coenosteum portion. Apparently also the hollow coenosarc tubes have here become filled with dolomite immediately after the death of the animals and not as with *Cryptozoön proliferum* at first with a lime filling which was only later changed into dolomite.

The structure of *C. ruedemanni* is well shown in thin sections as seen in the photomicrographs in figures 15B, 18. The anastomosing sandy bands referred to by Rothpletz show numerous, mostly angular pieces of quartz in the filling in places and dark iron particles. The iron particles and some quartz grains are scattered through the ground mass. The ground mass, as in *proliferum* is composed of dense, granular calcite in which is seen a meshwork of anastomosing tubes filled with clear crystallized calcite. Pressure cracks are also filled with calcite. Dolomitization has gone further than in *proliferum* and in places is seen to encroach considerably upon the ground mass as well as the filling of the meshwork of tubes. In some sections the granular background shows dark, denser bands and lighter bands which brings out the laminations distinctly. The anastomosing tubes are fewer and finer in the denser areas.

Cryptozoön undulatum Bassler

Figures 19–22

This species was recognized as possibly new by Rothpletz (1916) in his discussion of the Cryptozoön species in the Saratoga area and referred to as the Cryptozoön in the Greenfield railroad cut. In comparing with *C. proliferum* Rothpletz writes:

In outer form both have great similarity, though the explanation is of a different kind. While at the Hoyt farm in particular the upper surfaces of the stocks are separated, in the railroad cut this is not the case. Therefore one has here excellent vertical sections, which show well the growth of the stock from the stock-forming floor and from that spreading out universally in peripheral direction. The internal microscopic structure has become entirely lost through complete dolomitization, so that an identification with *Cryptozoön proliferum* is not possible. Also the heterogeneous layers, so far as they stand out of the limestone, are altered so that only the quartz grains can be distinguished as such. The dolomite stands out in an aggregate of polygonal crystals which lie close to one another and fluctuate in diameter mostly between 60μ and 300μ, but they also grow up to 500μ at times. They are covered over with the finest dust and appear likewise somewhat discolored. Many times there lie enclosed in these dolomite crystals still smaller rhombohedrons which resemble those isolated dolomite rhombohedrons in *Cryptozoön proliferum* and therefore indicate that here complete dolomitization apparently was a gradual process, having first passed through the dolomite stage of *Cryptozoön* of the Hoyt farm. The irregular, angular dolomite crystals are surrounded almost always by a fine, brownish film whereby their outlines stand out clearly. It appears then as if these substances were collected on their sides with the crystallization of the limestone. As it appears the lime content of the sandy layers is doubtless likewise dolomitized, but the dolomite crystals, for the most part much smaller and more robust, are discolored by dust particles and small iron particles. Accordingly one can already recognize with the naked eye the order and dissemination of sand layers. Of oölites, which apparently were also present here, nothing more is seen. Under these conditions it is possible to place and recognize this species; but its identity with *Cryptozoön proliferum* is not excluded, for the apparent greater beveling of the upper side of the stocks at the Hoyt farm is only a consequence of the erosion [glaciation] which has befallen the limestone beds and with them also the separated *Cryptozoön* stocks and has scoured away their uppermost part (p. 15).

In good exposures of *C. undulatum* its distinction from *C. proliferum* may be clearly seen. *C. undulatum,* as pointed out above (p. 21), differs strikingly from the other two species in that the laminae composing this form begin horizontal to the bedding and soon develop a strong wavy character with frequent narrow or broad undulations with narrower or sharper down-binding of the laminae (figure 19). On the bedding planes the wavy outlines seen in cross-section appear as concentrically lined areas of varying diameter (figure 21) giving a superficial resemblance to *Cryptozoön proliferum,* as noted by Rothpletz. In his paper on The Cambrian and Ordovician Deposits of Maryland Bassler (1919) notes the occurrence of this new species forming reefs in the Ozarkian with the well-known *C. proliferum,* and discusses it as follows:

Comparison of the two species will bring out the essential characters of the present new one. . . In *C. undulatum* the laminae are at

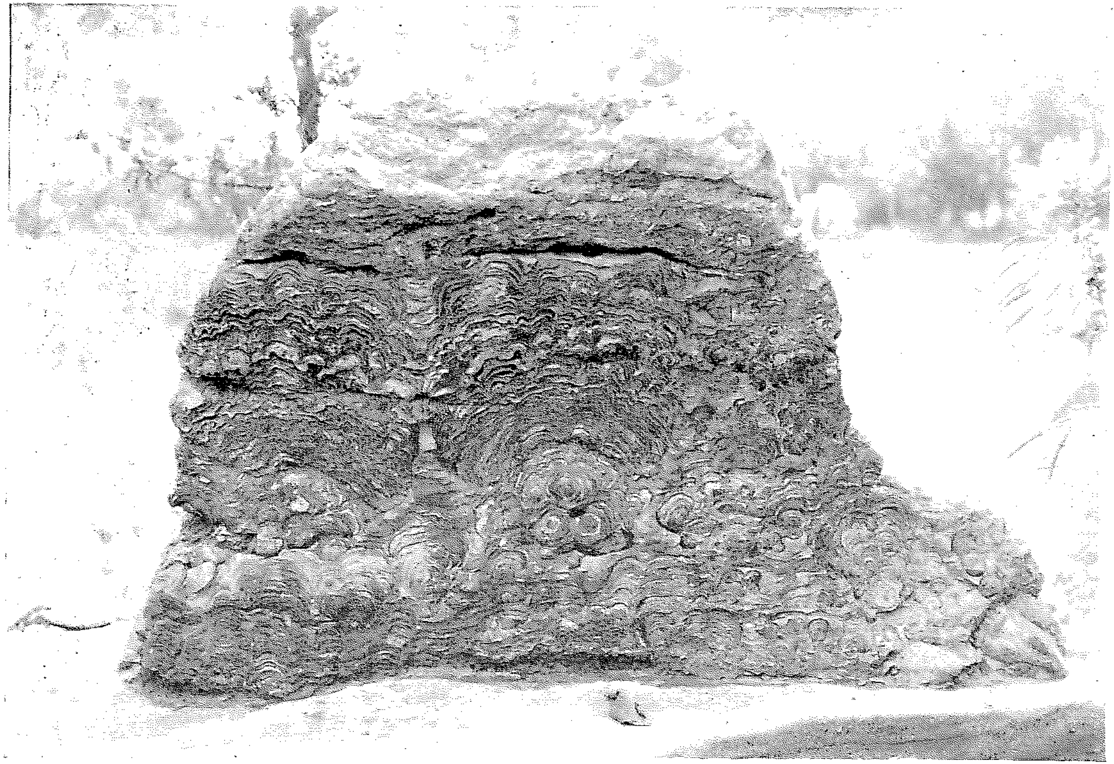


FIGURE 19 Slab of *Cryptozoön undulatum* from the reef forming the ledge at Ritchie house; Ritchie park ("Petrified Gardens"). This specimen has been set up in the rock garden. The strong undulating character of the laminae is particularly well shown. (Photograph by E. J. Stein).

FIGURE 20 Specimen of *Cryptozoön undulatum* used as a bird bath in the rock garden at Ritchie house, "Petrified Gardens." The center has been removed through frost action; the undulations are well shown at the water's edge. (Photograph by E. J. Stein).

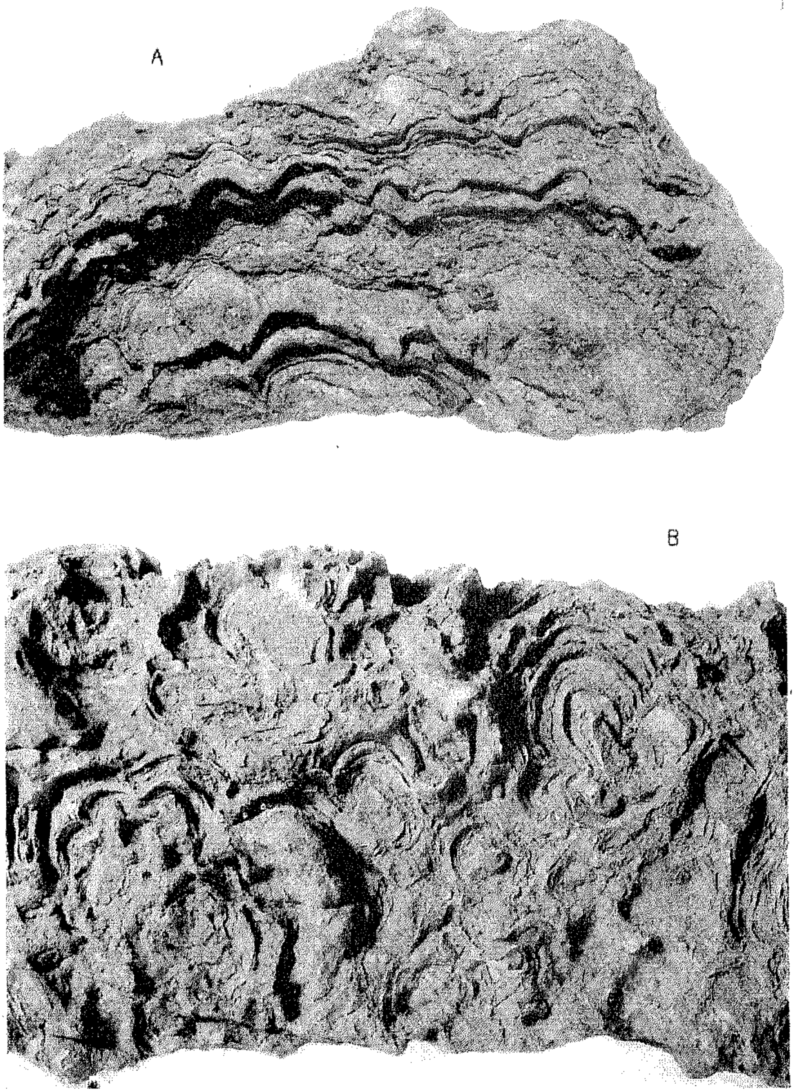


FIGURE 21 Weathered specimen of *Cryptozoön undulatum* from Disappearing brook, east of Ritchie house, Ritchie park. *A*. Vertical surface; length of original 8¼ inches. *B*. Horizontal surface, length of original 10½ inches. (Photographs by E. J. Stein).

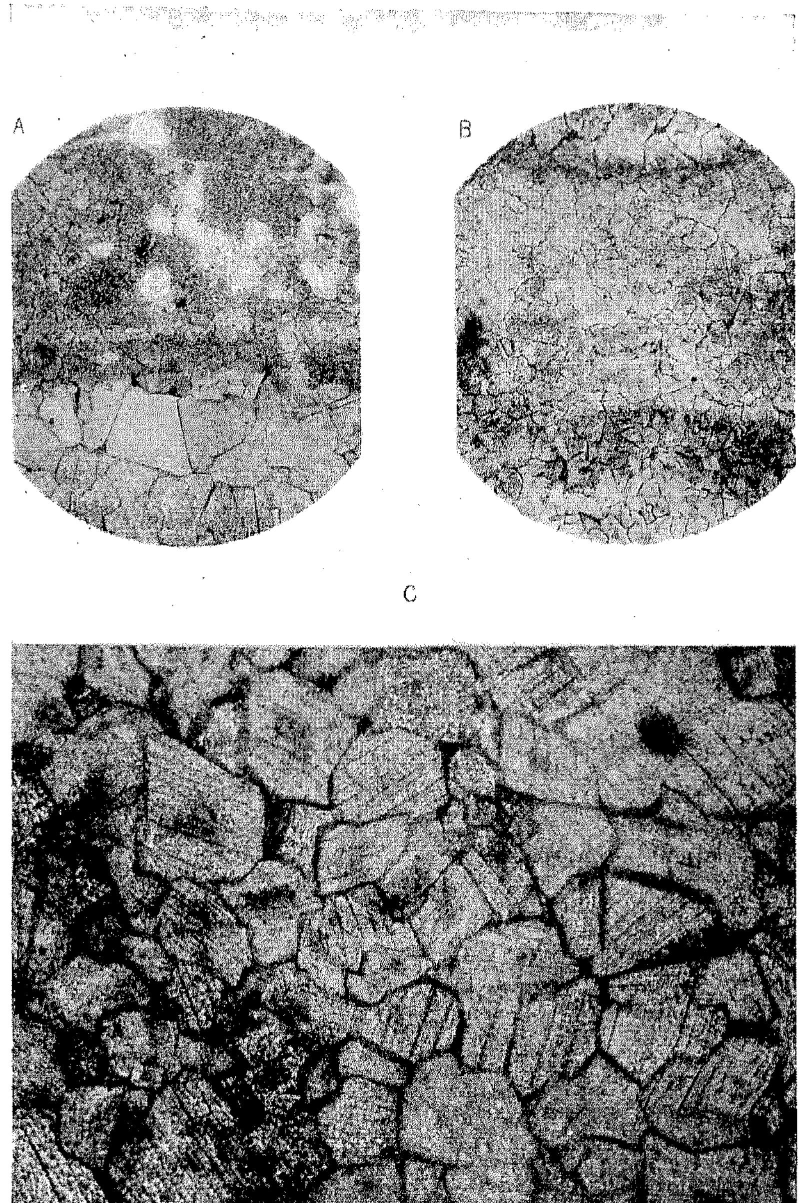


FIGURE 22 Photomicrographs of *Cryptozoön undulatum*. *A*. Vertical section, x30; incomplete dolomitization with scattered quartz grains (clear); lack of structure. *B*. Vertical section, x30; complete dolomitization and lack of structure. *C*. Similar section, x75. (Photographs by E. J. Stein).

first evenly undulating, forming in edge view, a pseudo-columnar structure, the columns averaging 20 mm in width. A cross-section through this part of the fossil shows these column-like areas to be of equal size and totally unlike the corresponding portion of *C. proliferum.* Following the undulating zone in *C. undulatum* the laminae go through a stage in which the distinct lamination disappears. Then, with a new growth, the characteristic undulations of the species reappear (p. 190).

The photomicrographs in figure 22, show the almost complete dolomitization of this species, with consequent loss of internal structure. The laminations are shown because their boundaries are marked by a fine dust. In some sections there are areas still showing a granular ground mass, but with dolomite crystals rapidly encroaching upon it. In these areas the granules are coarser than in the ground mass of either *proliferum* or *ruedemanni.* In general the dolomite crystals are coarse but finer crystals are seen near the edges of the layers where they are stained with a fine dark dust. Scattered quartz grains are seen throughout the ground mass and in some places are quite abundant and comparatively large. The more complete dolomitization of *undulatum* is probably due to some difference in the water content.

ALTERATION OF CORALLINE ALGAL DEPOSITS

It can be readily understood that little or no structure could be expected in algae from Cambrian rocks in which such a high degree of metamorphism has taken place. Alteration in the structure of organisms composing a reef, even recent ones, has been recognized for some time. Walther in his Allgemeine Palaeontologie (1919, Pt I, p. 181) states:

The earthy decay and the succeeding consolidation of the reef limestone causes most of the organic remains active in the upbuilding of the reef to become so indistinct that well-formed corals are changed into branching "Lithodendrons," finely decorated echinoderms into crystalline "crinoidal limestones," calcareous algae and Stromariae into granular amorphous limestone, between the masses of which appear only isolated nests of well-preserved fossils, especially so in the area of the "fore-reef," where the metamorphism of the organic tissues was less thorough in the limestone tongues.

An earlier paper (1885) embodies the results of studies of a *Lithothamnium* bank in the Bay of Naples, about 30 meters below the surface of the water, which are summarized by Seward (1894):

By action of the percolating water the *Lithothamnium* structure is gradually obliterated, and the calcareous mass becomes a structureless limestone. Walther applies his knowledge of this recent algal deposit to the examination of a Tertiary "Nulliporenkalk" near Syracuse. In many parts of this formation there occur well-preserved specimens of *Lithothamnium*, but in others a gradual obliteration is observed of all plant structure until the rock becomes entirely structureless. A similar instance of structureless limestone is described from the Lias of the Todte Gebirge; the strata consist of coral rock, detrital calcareous deposits, and associated with these, masses of limestone in which microscopic examination fails to detect either vegetable or animal structure. These structureless beds are considered to have been *Lithothamnium* banks from which percolating water has removed all trace of algal cells. It is suggested that the infiltrating water was supplied by the *Lithothamnium* thallus with the necessary amount of carbonic acid, and was thus enabled to remove all direct evidence of the existence of calcareous algae. In connection with this solvent power of the water Walther asks the question: "What becomes of plant cellulose in the process of fossilization?" An instructive comparison is made between the chemical composition of compact *Lithothamnium* masses from the Secca di Penta palumno and the Tertiary *Lithothamnium* limestones in the neighborhood of Syracuse; in the former the $CaCO_3$ reaches 86% and the organic substance 5%; in the latter the $CaCO_3$ reaches 98%, and the organic substance 0.28%. The organic substance of the algae became chemically altered in the Syracuse beds, and in the course of such changes carbonic acid was evolved; this was readily taken up in solution by percolating water which was thus supplied the means of obliterating all traces of *Lithothamnium* structure.

Thus it is shown that in masses of calcareous algal remains there is an "endogenous source" of carbonic acid which may frequently result in the removal of all signs of phytogenetic origin. On the other hand, in many calcareous beds the percolating waters have not found the same amount of carbonic acid, and their solvent power has not been sufficient to effect the destruction of the organic remains from which the strata have been formed. If the calcareous deposits are protected from the circulation of carbonated water by overlying impervious beds, the organic structures would not be removed. It would seem, therefore, that under certain circumstances, in which calcareous deposits are freely exposed to infiltrating water, there is much greater probability of all structure being removed in the case of those formed from calcareous algae than in deposits which are not of phytogenetic origin (p. 19, 20).

In his paper Origin of the Bighorn Dolomite (1913) Blackwelder suggests, because of certain peculiar structures, the influence of marine algae of the bank-forming type in the deposition of this comparatively pure Ordovician dolomite. He points out the dichotomous habit of branching, repeated *ad infinitum*, among these structures in successive outcrops, which with their form are more or less significant of colonial organisms, particularly certain types of corals and calcareous algae; and adds, "It is an unfortunate fact, however, that no trace of definite internal structure now remains" (p. 615). After a discussion of recent lime-secreting red algae, he continues (p. 618):

> These facts have been discussed in some detail in order to show that the modern coralline algae seem to fill the requirements of the case for the Bighorn dolomite . . . Therefore it appears to me probable that the peculiar structures of the Bighorn dolomite are of organic origin, and that the more massive coralline algae, such as the modern genus *Lithophyllum,* may fairly be regarded as competent to make such structures, if indeed they are not the only organisms which could have done so.
>
> Since the positive identification of algae depends almost entirely on the recognition of their delicate, cellulose structures under the microscope, it is unlikely that the problematical growths of the Bighorn terrane can ever be satisfactorily recognized, inasmuch as nearly all traces of original organic structures have been obliterated. The cells of the modern algae, such as *Lithophyllum,* average about .01 millimeter in diameter, but the Bighorn rock is crystallized in grains .05 to .10 millimeter in diameter. Under these circumstances we ought not to expect to find the algal cells preserved. . .
>
> This disappearance of minute structures, one of the inevitable results of the process of crystallization, may well explain the fact that marine algae, although often reported from Paleozoic limestones, have in perhaps no instance been satisfactorily identified from internal cell characters.

In a recent paper on algal limestones from the Oligocene (Tertiary) of South Park, Colorado, J. Harlan Johnson (1937) in his discussion of the character of the reef-forming organisms points out (p. 1233) that "unforunately, at many localities, the limestones, even though showing some macro-structure, have been so altered by solution, recrystallization, and silicification that all trace of the original cellulose structure has been obliterated." (*See* p. 66).

THE IMPORTANCE OF CORALLINE ALGAE AS REEF-BUILDERS THROUGH THE AGES

The literature relating to the importance and geologic significance of calcareous algae has become extensive in recent years, so much so that there will be no attempt here to give a complete review of it. Most of the papers cited in the bibliography give footnote references or bibliographies, but especially among these are to be consulted Bigelow (1905), Blackwelder (1915), Bonney and others (1904), Fenton (1931, 1933), Garwood (1913, 1931) Hadding (1933), Høeg, (1932), Howe (1912, 1932), King (1930, 1932), Pia (1924, 1926), Seward (1898, 1931), Van der Gracht (1931), Wieland (1914).

In Great Britain, A. C. Seward (1894, 1898, 1923, 1931) and E. J. Garwood (1913, 1931), especially, have emphasized the geologic importance of calcareous algae, although Seward casts doubt (1931, p. 83–87) on the algal nature of the so-called organisms which have been referred to Cryptozoön (see p. 27) and the Algonkian limestones which have been described and figured by Walcott (1914; see below, p. 60).

Calcareous algae are commonly referred to by geologists and zoologists, and sometimes botanists, as nullipores, and include in their numbers genera belonging to both red and green algae. Among the red algae the genera belonging to the subdivision Corallinaceae, *Lithothamnium*, *Lithophyllum*, *Melobesia* and others, are those that play a very important part in the building and cementing of coral reefs (Seward 1898, p. 184, 185); among the green algae *Halimeda* holds a prominent place. Setchell (1926, p. 136) discussing Nullipore Versus Coral in Reef-Formation points out that

> The presence of nullipores (or corallines) as well as corals as components of a coral reef was recognized by Darwin and noted for particular reefs in the Indo-Pacific region (1842, etc.). Dana (1849, 1872, etc.) also mentions nullipores (as included under the term coral) but neither he nor Darwin seem to have considered the association of nullipores with corals as of significance in any way except possibly as contributing to bulk. Semper (1863) and Sir John Murray (1880) have practically disregarded nullipores in their theories, although the latter was certainly in a position to be aware of their existence and to a certain extent at least of their prevalence and striking association with corals on the reefs of Tahiti and elsewhere . . . Alexander Agassiz (1888) realized that calcareous algae were important in reef formation, particularly as contributors to bulk. The true relation of nullipore to coral in reef formation began to be visualized during the Funafuti Expeditions (1896, 1897, 1898).

Even as late as 1911 and still later in 1919 a coral reef was authoritatively defined (Vaughan, p. 238) as "a ridge or mound of limestone, the upper surface of which lies, or lay at the time of its formation, near the level of the sea, and is predominately composed of calcium carbonate secreted by organisms of which the most important are corals." Since the publication by the Royal Society of London in 1904 of the results of the work on Funafuti, increased attention has been given to the importance of certain lime-secreting marine algae. Howe in his paper The Building of "Coral" Reefs (1912) challenges the above definition, remarking (p. 839):

> It is not to be denied that this last statement embodies the long-standing and still prevalent view as to the origin and composition of coral reefs and, in fact, it might seem at first to be quite axiomatic

that corals should be the most important constructive agents in the formation of "coral" reefs. But in view of the fact that some rather recent studies indicate that lime-secreting plants have been much more important than the corals in the formation of "true coral reefs" and in view of the few borings and analytical studies of so-called "coral" reefs thus far made, there would seem to be sufficient ground for contending that the whole question as to the relative general importance of lime-secreting animals and lime-secreting plants in the formation of reefs is still an open one. From what may be observed today in the tropics as to the relative abundance of calcareous marine plants and calcareous marine animals and from what has been determined by the study of the cores obtained by boring into coral reefs, it would appear that sometimes the plants predominate and sometimes the animals.

After a discussion of some of the work that has been done in this field he comes to this conclusion (*ref. cit.* p. 841):

With the dominance in reef-building activities resting sometimes with the calcareous algae and sometimes with the corals, and with the Foraminifera and other groups also playing their parts, the problem of determining "the most important" constructive element in the calcium carbonate reefs of the world, ancient and modern, is naturally a most complicated and difficult one and one that may never be solved to the full satisfaction of those most interested. . . . However, since the day of the first illuminating borings into the "true coral atoll" of Funafuti, much evidence has accumulated tending to show that the importance of the corals in reef-building has been much over-estimated and that the final honors in this connection may yet go to the more humble lime-secreting plants."

In his later work on The Importance of the Lime-Secreting Algae (1931) Howe refers to the above quotation and adds (p. 59): "It seems to me that the final honors can now be bestowed, and, without minimizing the contributions of the corals, there may be added that without nullipores no 'coral reefs' can be or would be formed."

The atoll of Funafuti was selected for study by the reef committee of the Royal Society of London because it was considered to be a "typical coral" reef or island. There were three successive expeditions, the results of which were made known in a report of the Royal Society (Bonney and others, 1904). Several borings were made, the main boring having a depth of 1114½ feet (Judd, 1904, p. 169). Judd in his discussion of the materials sent from Funafuti remarks, "Dr. Hinde's carefully drawn-up lists show that from top to bottom the same organisms occur, sometimes plants, sometimes foraminifera and sometimes corals predominating" (*ref. cit.* p. 173). *Lithothamnium* occurred more or less abundantly through the entire length of the boring and *Halimeda* was locally abundant. A. E. Finckh, one of the members of the expedition, wrote for the report a chapter on Biology of Reef-forming Organisms at Funafuti Atoll in which he groups the organisms found in the order of their importance as reef-builders (1904, p. 133): (1) *Lithothamnium,* (2) *Halimeda,* (3) Foraminifera, (4) Corals (see also David, 1904, p. 155). The calcareous algae thus are seen here to hold the first two places, while the "corals, the 'most important' reef-building organisms of Vaughan's definition and still prevalent popular belief hold fourth place" (Howe, 1912, p. 838). In his later paper on the importance of calcareous algae Howe adds that "there are doubtless 'true coral reefs' and islands that have been actually built, in a predominant way by corals, but Funafuti is evidently not one of them" (1931, p. 58), and points out that Funafuti is not an isolated example of reefs built by plants rather than animals. The correctness of this statement is attested by the observations of many students of coral reefs, particularly in the Pacific ocean, among them Chapman and Mawson (1906), Finckh (1904), Foslie (1907), Gardiner (1898, 1931), Hoffmeister (1929, 1932), Mayor (1921), Pollock (1928), Setchell (1926).

Besides Funafuti (Ellice islands), among the Pacific coral reefs studied are the Fiji islands, Rotumna, the New Hebrides, Gilbert islands (Onoatoa), Tongan group, Samoan group (Tutuila, Rose atoll), Solomon islands, Society islands (Tahiti), Hawaiian islands (Oahu) and the Great Barrier Reef of Australia, Gardiner in his paper on The Coral Reefs of Funafuti, Rotumna and Fiji, in connection with a discussion of the structure of a reef, observes (1898, p. 477):

The parts of "compact homogeneous texture" are very numerous and are formed, I believe, mainly of the carbonate of lime secreted by incrusting nullipores. The importance of the incrusting nullipores, in the formation of the reefs of the Central Pacific, cannot be overestimated. . . The incrusting nullipores of the reef belong to the genus *Lithothamnion,* which Walther [1885, p. 329] has shown covers and has apparently formed the greater part of certain shoals in the Bay of Naples.

This observation is emphasized in his later (1931) work on Coral Reefs and Atolls where he states:

The importance of "nullipores," as these algae are usually termed in the literature of coral reefs, in the formation of exposed coral reefs has been emphasized by all recent investigators of the same.

. . . It is not until a depth of 5 to 6 fathoms is reached that the position is reversed, and corals become the important builders, nullipores now merely serving to fill up their interstices (p. 72, 75).

Setchell (1926) also discusses the reefs of the Pacific and concludes (p. 138): "It is sufficient here to call attention to the fact that nullipore action is not only the controlling factor in each form (or type) of reef or bank but that there is also a definite nullipore specificity, due to ecological and growth form peculiarities, for each type of reef or bank as well as for depth." Yonge (1930, p. 67, 145) points out the importance of nullipores and in particular *Lithothamnium* in building the outer barrier reefs of the Great Barrier Reef of Australia (see Seward, 1898, p. 184). "They appear to grow in the greatest abundance on the weather surface of the reefs in the region where the surf strikes and where, incidentally, their cementing action is most urgently required" (*ref. cit.* p. 67).

Corals do not flourish below a certain level so that if the surface of a submarine bank "lies below the depth limit of reef-building corals, other organisms, such as foraminifera and algae, will be the important limestone builders until the bank reaches a level at which corals can flourish" (Hoffmeister, 1929, p. 470). All of the investigations made in the Pacific ocean show that the calcareous algae which play an important part in reef-building are *Halimeda* and especially, the *Lithothamnium* group (*Archaeolithothamnium, Lithothamnium, Goniolithon, Lithophyllum* and *Mastophora*), which has been shown to be richly represented in the tropics (Foslie 1903, p. 460; Gardiner 1931, p. 68) and for representatives of which many writers, in describing the occurrence of nullipores, use *Lithothamnium* only as an all-inclusive term. In this group *Lithothamnium* is an important builder up of submerged shoals in the tropics, but *Lithophyllum* is the chief genus in the seaward growth of the reef edge (Gardiner, 1931, p. 77). Chapman and Mawson in a discussion of the importance of *Halimeda* and the *Halimeda*-limestone of the New Hebrides remark that "the importance of *Halimeda* as a reef-forming agent has, until of late years, been greatly overlooked" (1906, p. 702) and call attention to the record of a true *Halimeda*-limestone by Dr H. B. Guppy (1887, p. 74) in his description of the calcareous rocks of the Solomon islands. A specimen of rock obtained at the island of Santa Anna was entirely composed of the joints of *Halimeda opuntia*. The *Halimeda*-limestones of the New Hebrides, also "calcareous rocks, formed almost entirely of the remains of *Halimeda*-joints, are represented in three of the islands. . ." (*ref. cit.* p. 706;

see Mawson 1905). These authors also cite the older Tertiary limestone of Christmas island, Indian ocean, shown in specimens from the central plateau at 800 feet above sea level to be a crystalline limestone crowded with *Halimeda* and *Lithothamnium* which, they remark, "in its general manner of occurrence may be compared with *Halimeda*-limestones from the New Hebrides" (p. 704). As pointed out by Gardiner and others, "the genus *Halimeda* is almost confined to tropical seas, the lowest suitable temperature being about 60° F., this allowing it to live also in the warm Mediterranean. Less than ten species are known. . . Their importance on coral reefs is that they can grow on every kind of bottom found in the lagoon and on the encircling reef. Indeed, in some of these positions *Halimeda* was the chief builder" (Gardiner, 1931, p. 79). Calcareous algae, which flourish in greater depths than the corals, also in general "are not primarily associated with tropical areas, about twice as many species being found in temperate as in warm seas, a few extending into the Arctic regions. In such temperate areas there are many known banks covered by these plants in such numbers as appreciably to raise their surfaces; a bottom of less depth than 50 fathoms recorded on charts of temperate regions as 'coral' very frequently consists of them" (*ref. cit.* p. 76). The *Lithothamnium* group has such a wide temperate range. *Lithothamnium* is the most widely distributed and best known genus. It occurs in all parts of the world from 73½° south latitude to 79° 56′ north latitude, that is from Arctic Ellesmere Land to South Victoria Land and Louis Philippe Land in the Antarctic (Foslie, 1903, p. 462; 1907*b*, p. 177; Howe, 1912, p. 841; Seward, 1931, p. 102; Kjellmann, 1883, p. 88, 96). "In company with large Brown Algae it flourishes in Arctic seas, and off the coasts of Spitzbergen it forms calcareous banks many miles in extent where the temperature does not usually rise above 0°C" (Seward, *ref. cit.*).

A few examples may be cited to show that calcareous algae rather than corals are at least sometimes the dominant reef formers in the Indian ocean as well as the Pacific. Gardiner in his paper Investigations in the Indian Ocean writes:

The reefs of the Chagos are in no way peculiar, save in their extraordinary paucity of animal life. . . However, this barrenness is amply compensated for by the enormous quantity of Nullipores (*Lithothamnia,* etc.), incrusting, massive, mammilated, columnar and branching. The outgrowing seaward edges of the reefs are practically formed by their growth, and it is not too much to say that, were it not for the abundance and large masses of these organisms, there would be no atolls with surface reefs in the Chagos (Gardiner 1906, p. 332, 333; *see* Howe 1912, p. 839; Foslie 1907*b*, p. 177, 178).

The Siboga Expedition found *Lithothamnium* forming extensive banks and reefs near the southwest point of Timor, in the Dutch East Indies (Weber-van Bosse, 1904, p. 4; quoted in Howe, 1912, p. 840). The important part played by both *Lithothamnium* and *Halimeda* in the coral reefs of the Indian ocean is discussed by Gardiner in The Fauna and Geography of the Maldive and Laccadive Peninsulas (1903, ch. I). In the chapter on their formation he remarks, "It has been pointed out by myself and others that reefs are largely formed by calcareous algae *(Lithothamnion)*, and that corals, which cover the reefs, feed mainly by their commensal algae. . . . It would seem to me that about 30 fathoms is the extreme limit in depth of the growth of the effective reef-building corals" (p. 175, 176); and refers to the "increasing importance of the nullipores on increase in depth" (p. 179). The *Halimeda*-limestone of Christmas island is mentioned above.

Gardiner (1931, p. 77) calls attention to the fact that calcareous algae only play a part in the coral reefs discussed though

> no coral reef is known in the Indo-Pacific which could be conceived as reaching the surface and forming a firm front to the ocean without their help. . . It is different in the Atlantic where off certain bays in the Cape Verde islands fringing reefs have been formed almost entirely by them, no true reef corals being found thereon. Off the Brazilian coast, too, they are described as the chief consolidators of sand and builders of reef from 18° S. to the freshwaters off the Amazon mouth.

The extensive banks of the Arctic and Antarctic have been touched upon above (p. 56). Foslie (1903, p. 462) notes banks formed by a species of *Lithothamnium* off the coasts of Ireland and Greenland, north of the polar circle on the coast of Norway where "banks have been met with which cover the bottom for several miles," also farther to the south, as in the Trondhjem fiord and along the southwest coast where a solitary species forms rather large banks. True nullipore reefs flourish in the Mediterranean, one of which described by Walther (1885, p. 329) from the Gulf of Naples is referred to in the discussion of the *Cryptozoön* reefs (p. 49). As pointed out by Howe:

> Bermuda was commonly considered a "true coral" island until the studies of Alexander Agassiz [1895] and Henry B. Bigelow [1905]

indicated that the corals have played a rather minor part in its upbuilding. Bigelow believes [*ref. cit.* p. 583] that "algae probably form the greatest mass" of what he terms the "shell sands" of Bermuda, and it is of interest to note that Sir John Murray in reporting the results of the *Challenger* Expedition intimates that the calcareous seaweeds and their broken down fragments were the dominating elements in three out of four analyzed samples of so-called "coral" sand or mud from Bermuda (1912, p. 840).

Bigelow in his paper, The Shoal-Water Deposits of the Bermuda Banks, discusses the dredgings on the Challenger Bank and concludes that they

add to the evidence already accumulated to prove the great importance of the nullipores as reef builders. . . The nullipores gradually form incrusting masses about various objects or grow up independently on stalks which later become broken; in these ways the spherical concretions begin. . . This process taking place over the Challenger Bank, where there is no direct evidence of either elevation or subsidence, has raised it to within some thirty to fifty fathoms of the surface of the sea, a depth where a few corals already flourish. If we imagine this process as continuing until the bank rises to within about twenty fathoms of the surface, we should then have excellent conditions for the formation of a coral reef. Of course in such upbuilding the nullipores constitute only a part, though a most important one, of the whole growth" (*ref. cit.* p. 589, 590).

Agassiz (1895, p. 253) remarks in reference to the "serpentine reefs" which are most numerous off the south shore that "in fact, it would be as correct in some localities to call them Algae or Coralline Atolls." In his summary of conditions in Bermuda, southern Florida and West Indies Howe (1912, p. 840) points out that, even though the "true atolls" of the Pacific and Indian oceans may be rare or quite wanting, in their distribution and association many of the general types described for those areas are found. His discussion continues:

There are banks and reefs that appear to consist almost wholly of calcareous plants, others that are almost "pure stands" of corals, and yet others where these two elements are intermingled. . . It would be a bold man who would venture to say that the corals are secreting any more calcium carbonate in the West Indian region than are the calcareous algae. The massive beds of *Halimeda opuntia* off the Florida Keys are striking, as are the banks of *Goniolithon strictum* in the Bahamas and reefs of *Lithophyllum daedaleum* along the shores of Porto Rico, yet probably none of these are so conspicuous and massive as are certain local aggregations of living corals in the same general regions (*ref. cit.* p. 842).

In his discussion of calcareous algae Garwood (1913*a*, p. 552) remarks,

> Another interesting point is the constant association of fossil Calcareous Algae with oolitic structure and also with dolomite. Thus oolites occur in connection with Solenopora in the lower Cambrian of the Antarctic, in the Craighead limestone at Tramitchell in the Ordovician rocks of Christiana and the Silurian of Gotland and in the Lower Carboniferous limestone of Shap; while in the Jurassic rocks of Gloucestershire and Yorkshire it occurs in the heart of the most typical oolitic development to be met with in the whole geological succession.

The association of calcareous algal deposits, recent and fossil, with oölites has been noted by a number of other writers, among them Seward (1894, p. 12–17; 1931, p. 80–83), Rothpletz (1892, 1916, 1922), Seely (1905), Wieland (1914), Bucher (1918), Bassler 1919, p. 101), Bradley (1929). The association of oölites with *Cryptozoön* has been discussed above (p. 21–23). A recent example from the Bay of Naples of alteration of algal *(Lithothamnium)* deposits (*see* p. 49) was studied by Walther (1885) and these studies have been summarized by Seward (1894, p. 19, 20) and others. In his Allgemeine Palaeontologie (1919) Walther again discusses the alteration of reef limestones (*see* p. 49). Skeats (1918*b*, p. 185), refers to this widespread dolomitization and states that "long before the rock is completely dolomitized it must be reduced to a quite structureless mass, and all traces of organisms must necessarily disappear" (p. 190; *see* also Seward 1895, p. 175). Garwood also points out that, "the presence of dolomites in connexion with algal growths at different geological horizons appears to show that the beds have accumulated under definite physiographical conditions similar to those which obtain today in the neighborhood of coral reefs" (1913*a*, p. 552). Howe (1931, p. 59, 60) discusses the importance, as agents of limestone production, of the blue-green algae (Cyanophyceae), of greater antiquity than the coralline *(Lithothamnium)* group, and notes the

> superficial evidence that many, at least of the most ancient limestones of Cambrian and pre-Cambrian age were laid down by the agency of these blue-green algae and that in mass production of limestone these lowly organisms were much more active than they are at the present time. . . It is to be freely conceded, however, that no one of these supposed algal limestones of Cambrian or pre-Cambrian age, when examined microscopically, either decalcified or in ground section, shows any incontestable evidence of an algal nature. In view of the extreme age of these supposed plants and the extreme delicacy

of the gelatinous cell walls . . . it seems unreasonable to expect any preservation of their microscopic cell structure. . . In the calcareous travertine or tufa now being laid down by various blue-green algae in lakes and streams in the United States, it is commonly difficult to demonstrate and identify the contributing organisms except in the superficial layers. Why should one expect then delicate structure to persist for millions of years? Nevertheless, one who is accustomed to see and to handle the algae of the present day may feel convinced from the macroscopic characters that certain laminated ancient limestones were laid down by algae. . .

It is not intended here to make a complete survey of even all of the more extensive fossil algal deposits. Seward and Garwood, who have probably done more than any others to emphasize the importance of the algae, have given full surveys of the geologic occurrences and distribution of calcareous algae through the ages (Seward, 1894, 1898, 1923, 1931; Garwood, 1913, 1931). In closing one such discussion (1913, p. 121) Garwood remarks:

The facts given above regarding the geological distribution and mode of occurrence of these organisms lead us to several interesting conclusions. In addition to the evidence of the important part they play as rock-builders, it is evident that certain forms flourished over wide areas at the same geological periods, and might well be made use of in many cases with considerable reliability as proofs of the general contemporaneity of two deposits. Thus, as general examples, we may cite the wide distribution of *Solenopora compacta* in the Baltic provinces, Scotland, England, Wales, and Canada during Llandeilo-Caradoc (Ordovician) times.

Among the Precambrian deposits should be cited the Algonkian algal formations of the Cordilleran area described by Walcott (1914), although doubt has been cast upon their algal nature by Seward (1931, p. 80). Walcott assigns these deposits to the activity of the blue-green algae. These structures, believed of algal origin, form, in Montana, reefs and banks through a thickness of several thousand feet of strata (Walcott, *ref. cit.* p. 94–100). Of these beds Walcott says (p. 94): "The limestones of the Newland formation have more or less magnesian content, but many of the layers are pure limestone, especially those containing the reefs or banks of algae." Later studies (1931, 1933, 1936) were made in these formations by C. L. and M. A. Fenton and in concluding a paper on the Beltian algae of Glacier National Park, Montana, they state "the formation of the masses which we regard as algal deposits cannot at present be explained as an inorganic process. On the other hand, analogy furnishes strong evidence that these masses were organic in origin"

(1931, p. 681). Answering English geologists (Seward) and Holtedahl's suggestion that they either are a "chemical precipitation that probably came into existence through the organic processes of living organisms" (1919, p. 90) or "formed secondarily by very important radical internal changes in the rocks" the Fentons say:

> For the second of these interpretations no field evidence could be found. The characters of these supposed algal colonies are surprisingly uniform at given horizons regardless of obvious secondary changes—very rarely uniform over wide areas—in the strata bearing them. . .
>
> Of greater weight, at least in the present case, is Holtedahl's first suggestion that the "algae" are consequences of organically initiated precipitation, but are not actual petrifactions. . . We have such species as *Collenia columnaris*, *C. symmetrica* and *C. undosa*, all forming sharply delimited masses, all as stable in their characters as any coral, all readily recognizable in the field. We wish to emphasize that, so far as general characters alone are considered, all of the forms just named are more readily and more uniformly recognizable than are members of such genera as *Prismatophyllum*, *Favosites* or *Columnaria*. That such structures should result from chemical precipitation alone, even though originated by the action of organisms, is very difficult to believe (1931, p. 681).

Moore (1918, p. 420–29) describes algal concretionary deposits from the iron-bearing formations of the Belcher islands, situated off the coast of Hudson bay. Although bearing a strong resemblance to *Cryptozoön* they are regarded as deposits made by a new group of algae, and the similarity to the forms described by Walcott from the Algonkian rocks of Montana is pointed out. These bodies form whole reefs in the more or less silicified limestone of the Belcher series, making up a thickness of over 400 feet. By some these rocks are considered Precambrian; others have considered them Cambrian. Twenhofel (1919) describes reeflike masses (referred to *Collenia*) over 22 feet in thickness and 55 feet wide from the Precambrian (Lower Huronian, Kona dolomite) of the Marquette region Michigan; and Rutherford (1929) describes concentric structures of supposed algal origin from a limestone of Precambrian age in the Great Slave Lake region, with a thickness of some 50 feet and extending for about three miles along the lake. In discussing Precambrian algal deposits Garwood (1931, p. lxxvii) writes, "It is evident that structures attributed to an algal origin were developed over a large area in North America in Pre-Cambrian times, and that they play an important part in the formation of the calcareous deposits in the Huronian rocks."

The wide distribution of species of *Cryptozoön* in beds of Ozarkian age (uppermost Cambrian of authors) has been discussed above (p. 23). Blackwelder (1915, p. 646–49) has described from the Middle Cambrian of the Teton mountains, about 400 feet below the base of the Bighorn dolomite, a seven-foot reef bottomed by limestone and characterized by nearly hemispherical bodies which he ascribes to colonial organisms, such as corals, hydroids, bryozoans or algae. He concludes, however,

> Since corals and bryozoans are often found well preserved in rocks no more altered than these, their absence here creates a strong presumption that the domes are not of coralline or bryozoan origin. They are best referred to some organism of extremely delicate internal structure such as many of the modern calcareous algae. In view of the fact that algae even today are known to construct large and strong masses of lime carbonate which constitute important or even predominant parts of many so-called coral reefs, the writer believes that the bee-hive shaped masses here described were built by colonies of algae (p. 650).

Algal deposits of a *Cryptozoön*like nature have been described from the Cambrian and Precambrian of South Australia, and in Central Australia in pre-Ordovician rocks, believed to be most likely of Cambrian age, extensive deposits occur (McDonnell Ranges). Here series of limestones 1330 feet thick "appear moderately dolomitic" and exhibit "an extraordinary development of fossil algae of several varieties. . . Much of the limestone is solidly made up of the remains of these algae. They evidently flourished in dense masses, growing in shallow waters. The living growth was analogous to the coral-reef formations of later times" (Mawson and Madigan, 1930, p. 422).

Of the Ordovician algae Garwood writes: "The very important part played by calcareous algae in the formation of rocks of Ordovician age in the Baltic Provinces, Scandinavia, and Scotland is well known, and was described some years ago by Stolley, Kiaer, Nicholson and others, and a summary of their distribution was given in my 1913 British Association address. Since then further investigation has tended to confirm the importance of these organisms as rock-builders in Ordovician times in northern Europe" (1931, p. lxxxii). He cites among recent literature Kiaer's summary of Norwegian occurrences published in 1920 (*see* Hφeg, 1932). A noteworthy Ordovician deposit ascribed to calcareous algae is the Bighorn dolomite (Blackwelder, 1913) discussed above (p. 50).

No particularly considerable Silurian deposits have been reported, and not many Devonian occurrences. Rothpletz (1908, 1913) describes the algal development (*Solenopora, Sphaerocodium* and *Hedstromia)* in the Silurian of Gotland and refers to their importance as rock-builders and their wide distribution. Garwood calls attention to the extensive occurence of *Solenopora* in the Silurian (Woolhope limestone) of the Old Radnor district of Southern Wales, where it "forms a considerable portion of the limestone and extends through the whole 60 feet of the deposit, though most abundant near the base" (*ref. cit.*, p. lxxxvii).

Among Carboniferous algal deposits Garwood (*ref. cit.* p. lxxxv and lxxxvi) mentions the *Fusulina* limestone of Carinthia, Austria, in which the "coralline alga not infrequently forms nearly the whole of the deposit," and the Mizzia dolomite of northern Dalmatia. In Britain "in Lower Carboniferous times calcareous algae attained their widest geographical distribution . . . extending then from the Scottish Border through Northumberland, Cumberland, Westmorland and West Yorkshire and reaching Mitcheldean and the Bristol district" (*ref. cit.* p. xc). The most striking and most important algal development is in the Cementstone Group near the Scottish Border where the development consists of a number of algal bands, occuring at intervals through the Cementstones, which extend over an area of at least 1200 square miles (*ref. cit.* xci, xcii). Garwood states:

> At one horizon, so abundant are these algal growths that the beds in which they occur assume a reef-like development which may be compared with recent *Lithothamnion banks.* An interesting feature of these algal bands is their constant association with annelids (Serpula and Spirorbis) and also with oolites and occasional dolomite. They seem to have flourished under lagoon conditions and to have extended over a considerable area (*ref. cit.* p. xci).

A large mass of limestone of Permo-Carboniferous age occuring in Queensland, Australia, is described by Richards and Bryan (1932) as "made up almost entirely of the microscopic remains of calcareous algae" (p. 289). The limestone examined for the presence of algae "extends as an irregular lenticular mass in a north-northwesterly direction for approximately four miles, its greatest width being a little under one mile. The main mass, composed essentially of algal remains, measures approximately 1,100 feet in stratigraphical thickness, while the ascertained stratigraphical range of the algal limestones is considerably more than twice as great" (*ref. cit.* p. 291). In concluding their paper Richards and Bryan state that "the comparatively poor development of reef-building corals at this time, as compared with the present day, may have been an important negative factor contributing towards the purity of the algal reef, although pure stands of *Lithothamnion* are known to occur at the present day" (p. 300).

One of the most striking examples of a fossil reef is found in the Capitan limestone and equivalent formations of Permian age in New Mexico and Texas, about which, because of its importance in the field of oil geology, many papers have been written in recent years (among them Blanchard and Davis, 1929; Crandall, 1929; Keyes, 1929, 1936; King, P. B., 1930, 1932, 1934; King, P. B. & King R. E., 1928; Lloyd, 1929; Ruedemann, 1929; Van der Gracht, 1925, 1926, 1929, 1931). This immense reef, first, described as a coral reef (Van der Gracht, 1925, 1926) was discovered by Ruedemann in the early summer of 1927 to be in large part of algal origin (in King, 1928, p. 139; in Lloyd, 1929, p. 648). Ruedemann writes: "The coralline algae appear mostly as more or less rounded balls, ranging from the size of a pea to that of a cabbage head and showing concentric structure. . . Much of the limestone of the Guadalupe range consists of such variously shaped nodules, mostly of smaller size. . . It seems to me the problem of the algal reefs in the southwest is a big one and also very important for the oil geologist" (1929, p. 1079). Lloyd (1929, p. 645) points out that the Capitan formation is dolomite, though referred to as a limestone and continues:

Dolomitization is a characteristic feature of almost all reefs, both recent and fossil. Dolomite is probably not deposited as such, but results from the alteration of calcite or aragonite by reactions within the sediments of the sea bottom. Dolomitization destroys the fossils, as does change from aragonite to calcite. In general, the more complete the dolomitization, the more complete is the destruction of the organic remains until a perfectly homogeneous dolomite may be formed. . . The Capitan reef rock shows plentiful organic remains, but for the most part so altered that few recognizable forms can be collected. Oölites are a common feature associated with reefs and these are found plentifully northwest of the reef rock proper. . . In the Capitan fauna as described by Girty corals are very poorly represented. . . Locally the reef rock contains numerous fragments of unidentified corals (*ref. cit.* p. 647, 648). . . The Capitan reef is one of a group of reefs on the southwest side of the Permian basin beside which the Niagaran reefs pale into insignificance. These have been described as "the grandest system of fossil reefs in the American Continent" (*ref. cit.* p. 655; Niagaran reefs: Cumings and Schrock 1928, p. 599).

The Capitan reef, or series of reefs, extends through the Guadalupe mountains (Capitan limestone: 1800 feet at Guadalupe Point) and also the Apache, Glass and Delaware mountains (Lloyd, 1929;

Van der Gracht, 1931; King, P. B., 1930, 1932, 1934; King, P. B. & King R. E., 1928). Crandall (1929, p. 944) in discussing its extent writes:

The great thickness of the Capitan and its remarkable lateral persistence of at least 25 miles in the Guadalupe Mountains, 20 miles in the Glass Mountains on the southeast, where P. B. King and R. E. King have suggested both the time equivalency with the Capitan and the reef origin of the Vidrio, Gilliam and Tessey formations, make it and its related formations the largest fossil reef yet described with the exception of the Schlern dolomite of Triassic age in the southern Tyrol. The similarity evidently existing between this latter formation and the Capitan is noteworthy (*see* Blanchard and Davis 1929, p. 975; Keyes 1929; Lloyd 1929, p. 655; Van der Gracht 1931, p. 83).

Keyes in a recent paper (1936) dealing with the Guadalupe reef states, "Originally such a reef probably extended from El Paso to Omaha, a distance of 1000 miles, and it thus rivaled the present-day 1000 mile long Great Barrier reef of Australia. . . " (p. 38).

Of the Triassic deposits referred to in the quotation above Seward writes (1931, p. 295):

From the limestones and dolomites of the Tyrolese Alps and the Himalayas it is possible to form a general idea of the algal flora of the Triassic sea. Scattered through the uplifted rocks carved into the peaks and precipitous walls of the Dolomites are shattered masses of old coral reefs, of reefs made of calcareous seaweeds. . . The sloping strata of the Schlern dolomite on the face of the Fermeda Turm . . . are rich in the calcareous casings of *Diplopora* and other algae.

Solenopora, a calcareous alga agreeing closely in its compact cellular structure with *Lithothamnium*, which is recorded from Ordovician and later rocks in many parts of the world, "played a prominent part also in the construction of Jurassic limestones. In later geological periods *Lithothamnium* and allied genera carried on the tradition established in earlier times by *Solenopora*" (Seward 1931, p. 108). *Lithothamnium* and its allies began to make their appearance in the Cretaceous and their deposits are widely distributed (Garwood 1913*a*, p. 551), but it is not until we reach the Tertiary rocks that *Lithothamnium* is found occuring massively (Seward, 1931, p. 424; Murray, 1894, p. 44). Its recent importance is discussed above (p. 55). Seward (1898, p. 187, 188) calls attention to the Miocene Leithakalk of the Tertiary Vienna basin, which consists in part of limestone rocks composed to a large extent of *Lithothamnium*, and to a "*Lithothamnium* bank, probably of Upper

Oligocene age, in Val Sugana, in the Austrian Tyrol"; and Murray *(ref. cit.)* notes, besides the Leitha limestones, the "Pisolitic limestone and the Nummulitic rocks" which "owe their origin in great part to this contemporary genus." Howe (1934) in a paper on the Eocene Marine Algae (Lithothamnieae) from the Sierra Blanca Limestone discusses the Sierra Blanca reef, Santa Barbara county, California, described by Keenan (1932) as 160 feet thick and characterized by its high content of calcareous algae. "It is not simply a matter of the algae being imbedded in a limestone matrix: the algae themselves, with microscopic cell structure beautifully preserved, are the dominant factor in the composition of the limestone" (Howe, *ref. cit.* p. 508). Howe reviews the occurrence of fossil Lithothamnieae noted at several localities on the Pacific coast of North America, mostly within recent years, and then states:

The most massive deposit of marine-algal limestone thus far described from the Pacific Coast, except for the Sierra Blanca (reef), appears to be one (or more?) of Paleocene age in the Santa Ynez Canyon of the Santa Monica Mountains, Los Angeles County, California, described by Hoots. . . Hoots writes of this Eocene reef: "The algal limestone is one of the most striking and probably the most unusual rock type in the Santa Monica Mountains. It occurs in prominent white reefs from a few feet to several hundred feet thick, which vary in lateral extent from only a few feet to about 4000 feet and commonly terminate in an abrupt wall" (*ref. cit.* p. 510).

Bradley (1929) describes algal reefs occurring abundantly in the Green River (Eocene) formation of Wyoming, Colorado and Utah. "Locally they constitute more than 8 per cent of the basal member of the formation and occur in single reefs or groups of reefs as much as 5.5 meters (18 feet) thick. Oölitic limestone and algal pebble beds are also plentiful but thinner . . . although formed in inland lakes during the middle part of the Eocene epoch, (these reefs) are remarkably similar to those found in the Miocene lake beds of the Rhine Valley, Germany" (*ref. cit.* p. 203). Bradley also calls attention to algal reefs of the same nature now forming in Green Lake, N. Y., fringing reefs and thick incrustations which owe their origin to Blue-green and some Green algae (p. 204). (*See* Johnson, p. 51).

Future studies will undoubtedly add to the importance of calcareous algae, particularly in fossil deposits. We see, as Garwood points out (1913*a*, p. 551), that "there can be no doubt from the examples described above that they play a very striking part as rock-builders at many different horizons in the geological series";

and, as rocks today built up largely of calcareous algae have lost their structure, so it is legitimate to infer that some of the limestone rocks of yet unknown or doubtful origin "which show no traces of organic structure may have been in part derived from the calcareous incrustation of various algal genera" (Seward, 1898, p. 175).

BIBLIOGRAPHY

Agassiz, A.

1888 Three Cruises of the United States Coast and Geodetic Survey Steamer "Blake," etc. v. 1, Mus. Comp. Zool. Harvard Coll. Bul., 14: xxii, 314; v. 11, 15: 220

1895 A Visit to the Bermudas in March 1894. Mus. Comp. Zool. Harvard Coll. Bul., 26, no. 2: 205–81, 30 pls.

Bassler, R. S.

1919 The Cambrian and Ordovician Deposits of Maryland. Md. Geol. Survey Rep't: Cambrian and Ordovician. p. 23–187

Baudisch, O.

1937 The Isotopes of Potassium and Lithium in Saratoga Mineral Water and Cryptozoön. Jour. Amer. Chem. Soc., 59: 1578–79

Bigelow, H. B.

1905 The Shoal-Water Deposits of the Bermuda Banks. Amer. Acad. Arts & Sci. Proc., 40: 557–92

Blackwelder, E.

1907 Research in China. Carnegie Institution of Washington. v. 1, pt 2, Petrography and Zoology, p. 378–79

1913 Origin of the Bighorn Dolomite of Wyoming. Geol. Soc. Amer. Bul., 24: 607–24

1915 A Fully Exposed Reef of Calcareous Algae (?) in the Middle Cambrian of the Teton Mountains. Amer. Jour. Sci., 4th ser., 39: 646–50

Blanchard, W. G. jr & Davis, M. J.

1929 Permian Stratigraphy and Southwestern Texas. Amer. Ass'n. Petroleum Geol. Bul., 13, pt 2: 957–95

Bonney, T. G. & others

1904 The Atoll of Funafuti. Borings into a Coral Reef and the Results. Being the Report of the Coral Reef Committee of the Royal Society. The Royal Society, London, 428p., 19 maps. (T. G. Bonney, chairman)

Bradley, W. H.

1929 Algae Reefs and Oolites of the Green River Formation. U. S. Geol. Surv. Prof. Paper, 154: 203–23

Bucher, W. H.

1918*a* Inorganic Production of Oolitic Structures (Abstract). Geol. Soc. Amer. Bul., 29: 103

1918*b* On Oolites and Spherulites. Jour. Geol., 26: 593–609

Chaney, L. W.

1892 *Cryptozoön minnesotense* in the Shakopee Limestone at Northfield, Minn. Minn. Acad. Nat. Sci. Bul., 3: 280–84

Chapman, F. & Mawson, D.

1906 On the Importance of *Halimeda* as a Reef-forming Organism; with a Description of the *Halimeda*-limestone of the New Hebrides. Quart. Jour. Geol. Soc. London, 62: 702–10

Clarke, F. W. & Wheeler, W. C.

1917 The Inorganic Constituents of Marine Invertebrates. U. S. Geol. Surv. Prof. Paper, 102. 56p.

Colony, R. J.

1930 Report to the Saratoga Springs Commission on a Restudy of the Geology of the Saratoga Area and the Problem of the Mineral Waters. Report of the Saratoga Springs Commission, New York. Legis. Doc. No. 70: 73–216, 43 pls., map

Crandall, K. H.

1929 Permian Stratigraphy of Southeastern New Mexico and Adjacent Parts of Western Texas. Amer. Ass'n Petroleum Geol. Bul., 13, pt 2: 927–44

Cumings, E. & Shrock, R. R.

1928 Niagaran Coral Reefs of Indiana and Adjacent States and Their Stratigraphic Relations. Geol. Soc. Amer. Bul., 39: 579–620

Cushing, H. P.

1916 Geology of the Vicinity of Ogdensburg (Brier Hill, Ogdensburg and Red Mill Quadrangles) N. Y. State Mus. Bul., 191. 64p., map

——— & Ruedemann, R.

1914 Geology of Saratoga Springs and Vicinity. N. Y. State Mus. Bul., 169. 177p., maps

Dake, C. L. & Bridge, Josiah

1932 Faunal Correlation of the Ellenburger Limestone of Texas. Geol. Soc. Amer. Bul., 43: 725–48

Dana, J. D.

1895 Manual of Geology. 4th ed. 1087p. New York

David, T. W. E., Halligan, G. H. & Finckh, A. E.

1904 Report on Dredging at Funafuti. In Bonney & others: The Atoll of Funafuti; Report of the Coral Reef Committee, Royal Society of London, p. 151–59

Davis, W. M.

1928 The Coral Reef Problem. Amer. Geog. Soc. Spec. Pub. no. 9, 596p.

Dawson, *Sir* W.

1897 Note on Cryptozoön and Other Ancient Fossils. Can. Record Sci., 7: 203–19

Fenton, C. L. & Fenton, M. A.

1931 Algae and Algal Beds in the Belt Series of Glacier National Park. Jour. Geol., 39: 670–86

1933 Algal Reefs or Bioherms in the Belt Series of Montana. Geol. Soc. Amer. Bul., 44: 1135–42

1936 Walcott's "Pre-Cambrian Algonkian Algal Flora" and Associated Animals. Geol. Soc. Amer. Bul., 47: 609–20. 3 pls., 1 fig.

Finckh, A. E.

1904 Biology of the Reef-forming Organisms at Funafuti Atoll. In Bonney & others: The Atoll of Funafuti; Report of the Coral Reef Committee, Royal Society of London, p. 125-50

Foslie, M.

1903 The Lithothamnia of the Maldives and Laccadives. In J. Stanley Gardiner: The Fauna and Geography of the Maldive and Laccadive Peninsula, 1: 460-71, pls. 24, 25

1907*a* Marine Algae II, Corallinaceae. Natural History 3. 2p.

1907*b* The Lithothamnia. Linn. Soc. London Trans. 2d ser., Zoology, 12, pt 11: 177-92. pls. 19, 20

Gardiner, J. Stanley

1898 The Coral Reefs of Funafuti, Rotumna and Fiji together with Some Notes on the Structure and Formation of Coral Reefs in General. Camb. Philos. Soc. Proc., 9: 417-503

1906 Investigations in the Indian Ocean. British Ass'n Adv. Sci. Rep't, 76: 331-39

1931 Coral Reefs and Atolls. 181p. London

——————— & others

1903 The Fauna and Geography of the Maldive and Laccadive Peninsula. v. 1. 472p., 25 pls.

Garwood, E. J.

1913*a* On the Important Part Played by Calcareous Algae at Certain Geological Horizons, with Special Reference to the Paleozoic Rocks. Geol. Mag., dec. 5, 10: 440-46, 490-98, 545-53

1913*b* Rock-building Algae. Opening Address of the President to Section C (Geology) at Birmingham. British Ass'n Adv. Sci. Rep't.: 453-72. *Also* Nature, Sept. 25: 111-21

1931 Important Additions to Our Knowledge of the Fossil Calcareous Algae Since 1913, with Special Reference to the Pre-Cambrian and Palaeozoic Rocks. Quart. Jour. Geol. Soc. London, 87: lxxiv-c

Glock, W. S.

1923 Algae as Limestone Makers and Climatic Indicators. Amer. Jour. Sci., ser. 5, 6: 377-408

Grabau, A. W.

1909 North American Index Fossils. v. I. 853p.

Guppy, H. B.

1887 The Solomon Islands: Their Geology, General Features and Suitability for Colonization. London.

Hadding, A.

1933*a* The Pre-Quarternary Sedimentary Rocks of Sweden. Med. Lunds Geol.-Min. Inst. No. 55. 93p.

1933*b* The Pre-Quarternary Sedimentary Rocks of Sweden. V. On the Organic Remains of the Limestones. Lunds Universitels Årsskrift n.f. 2, 29, no. 4: 87 Kungl. Fysiografiska Sällsk. Handl. n.f., 44, no. 4: 87

Hall, James

1847 Natural History of New York. Organic Remains of the Lower Division of the New York System. Paleontology, 1: 1-338. 99 pls.

1883 Cryptozoön N. G.; *Cryptozoön proliferum* n. sp. N. Y. State Mus. Ann. Rep't, 36: Plate VI and explanation

Hinde, G. J.

1904 Report on the Materials from the Borings at the Funafuti Atoll. In Bonney & others: The Atoll of Funafuti; Report of the Coral Reef Committee, Royal Society of London, p. 186–361

Høeg, O. A.

1929 A Postglacial Marine Stromatolite from Southeastern Norway. Studies in Stromatolites I. K. Norsk. Videnskap. Selskaps. Skrift. no. 1: 49

1932 Ordovician Algae from the Trondheim Area in Kiaer, J: The Hovin Group in the Trondheim Area. Skrift. av Norsk, Vidensk.— Adad. Oslo I. Mat.-Natur. Klasse, no. 4: 63–96

Hoffmeister, J. E.

1932 Geology of Eua, Tonga. Bernice P. Bishop Mus. Bul., 96. 93p. 22 pls.

——————, Ladd, H. S. & Alling, H. L.

1929 Falcon Island. Amer. Jour. Sci., 5th ser., 18: 461–71

Holtedahl, Olaf

1917 Report of the Second Norwegian Arctic Expedition in the "Fram" 1898–1902: Summary of Geological Results. No. 36: 26. 6 pls. Soc. Arts and Sciences of Kristiana

1919 On the Paleozoic Formations of Finnmarken in Northern Norway. Amer. Jour. Sci., 47: 85–107

1921 On the Occurrence of Structures Like Walcott's Algonkian Algae in the Permian of England. Amer. Jour. Sci., ser. 5, 1: 201

Hoots, H. W.

1931 Geology of the Eastern Part of the Santa Monica Mountains, Los Angeles County, California. U. S. Geol. Surv. Prof. Paper, 165–C: 83–134. 19 pls.

Howe, Marshall A.

1912 The Building of "Coral" Reefs. Science, ser. 2, 35, pt 2: 837–42

1919 Tertiary Calcareous Algae From the Islands of St. Bartholomew, Antiqua, and Anguilla. Carnegie Inst. Washington, Pub. no. 291: 9–19. 6 pls.

1922 Two New Lithothamnieae, Calcareous Algae, from the Lower Miocene of Trinidad, British West Indies. U. S. Nat. Mus. Proc., 62, art. 7: 3p., 4 pls.

1931 The Geologic Importance of the Lime-secreting Algae. U.S. Geol. Surv. Prof. Paper, 170: 57–64. pls. 19–23

1934 Eocene Marine Algae (Lithothamnieae) from the Sierra Blanca Limestone. Geol. Soc. Amer. Bul., 45: 507–18

—————— & Goldman, M. I.

1925 *Lithothamnium ellisianum,* sp. nov., from the Jurassic Ellis formation of Montana. Amer. Jour. Sci., 5th ser. 10: 314–24

Johnson, J. H.

1937 Algae and Algal Limestone from the Oligocene of South Park, Colorado. Geol. Soc. Amer. Bul., 48: 1227–35, 2 pls.

Judd, J. W.

1904 General Report on the Materials Sent from Funafuti, and the Methods of Dealing with Them. In Bonney & others: The Atoll of Funafuti; Report of the Coral Reef Committee, Royal Society of London, p. 167–85

Keenan, M. F.

1932 The Eocene Sierra Blanca Limestone at the Type Locality in Santa Barbara County, California. San Diego Soc. Nat. Hist. Trans., 7: 53–84. pls. 2–4

Keyes, C.

1929 Guadalupian Reef Theory. Pan-Amer. Geol., 52: 41–61

1936 Guadalupian Series: Its Span and Affinities. Pan-Amer. Geol., 65: 35–56

Kiaer, J.

1920 Oversigt over Kalkalgefloraene i Norges Ordovicium og Silur. Norsk geol. Tidsskr., 6: 113–42

King, P. B.

1930 Geology of the Glass Mountains, Part 1, Descriptive Geology. Univ. Texas Bul., No. 3038. 167p.

1932 Limestone Reefs in the Leonard and Hess Formations of Trans-Pecos Texas. Amer. Jour. Sci., 24: 337–54

1934 Permian Stratigraphy of Trans-Pecos Texas. Geol. Soc. Amer. Bul., 45: 697–797

———— **& King, R. E.**

1928 The Pennsylvanian and Permian Stratigraphy of the Glass Mountains. Univ. Texas Bul., No. 2801: 109–45

Kjellmann, F. R.

1883 The Algae of the Arctic Sea. Kongl. Svenska Vetenskaps. Akad. Handl., 20, no. 5, p. 96, Stockholm

Knopf, E. B.

1927 Some Results of Recent Work in the Southern Taconic Area. Amer. Jour. Sci. ser. 5, 14: 429–58

Kobayashi, T.

1931*a* Studies on the Stratigraphy and Paleontology of the Cambro-Ordovician Formation of Hua-Lien-Chai and Niu-Hsin-Tai, South Manchuria. Jap. Jour. Geol. and Geog., 8, no. 3: 131–88, pls. 16–22

1931*b* Studies on the Ordovician Stratigraphy and Palaeontology of North Korea with Notes on the Ordovician Fossils of Shantung and Liautung Geol. Surv. Chosen (Korea) Bul., 9, no. 1: 60. 9 pls.

1933*a* Upper Cambrian of the Wuhutsui Basin, Liaotung with Special Reference to the Limit of the Chaumitian (or Upper Cambrian), of Eastern Asia, and Its Subdivision. Jap. Jour. Geol. and Geog., 11, nos. 1–2: 57–155, pls. 9–15

1933*b* Faunal Study of the Wanwanian (Basal Ordovician) Series With Special Notes on the Ribeiridae and the Ellesmereoceroids. Jour. Faculty Sci. Imp. Univ. Tokyo, Section II Geology, Mineralogy, Geography, Seismology 8, pt 7: 249–322. 10 pls.

Lloyd, E. R.

1929 Capitan Limestone and Associated Formations of New Mexico. Amer. Ass'n Petroleum Geol. Bul., 13, pt 1: 645–58

Mawson, *Sir* D.

1905 Geology of the New Hebrides. Linn. Soc. Proc., n.s. 30: 400–84

———— **& Madigan, C. T.**

1930 Pre-Cambrian Rocks of the McDonnell Ranges (Central Australia). Quart. Jour. Geol. Soc. London, 86: 416–28

Mayor, A. G.

1921 Rose Atoll, American Samoa. Amer. Philos. Soc. Proc., 60: 62–70

Moore, E. S.

1918 The Iron-formation on Belcher Islands, Hudson Bay, with Special Reference to Its Origin and Its Associated Algal Limestones. Jour. Geol., 26: 412–38

Murray, G.

1894 Fossil Algae. Science Progress, 2: 37–47

Nicholson, H. A. & Etheridge, R.

1880 A Monograph of the Silurian Fossils of the Girvan District in Ayrshire. (Fasc. I. 1878: 1–137) 341p. 24 pls. London

Pia, Julius

1924 Geological Alter und geographische Verbreitung der wichtigsten Algengruppen. Österreich Bot. Zeitschr., 73: 174–90

1926 Pflanzen als Gesteinsbildner. 355p., 166 figs. Berlin

Pollock, James B.

1928 Fringing and Fossil Coral Reefs of Oahu. Bernice P. Bishop Mus. Bul., 55: 1–56. 3 figs., 3 pls.

Richards, H. C. & Bryan, W. H.

1932 Algal Limestone from Gigoomgan, Queensland. Geol. Mag., 69: 289–301

Rothpletz, A.

1892 On the Formation of Oölite. Amer. Geol., 10: 279–82. (Trans. by F. W. Cragin from the Botanisches Centralblatt, Nr. 35, 1892).

1908 Über Algen und Hydrozoen im Silur von Gotland und Oesel. K. Svensk. Vetenskapsakad Handl., 43, no. 5. 25p., 4 pls.

1913 Über die Kalkalgen, Spongiostromen und einige andere Fossilien aus dem Obersilur Gotlands. Sverig. geol. Unders. Afh. och uppsatser, Ser. Ca, Nr. 10

1916 Über die systematische Deutung und die stratigraphische Stellung der ältesten Versteinerungen Europas und Nordamerikas mit besonderer Berücksichtigung der Cryptozoon und Oolithe. Teil II. Über Cryptozoon Eozoon und Artikokania. Abhandl. Bayer. Akad. Wiss., 28, no. 4. 91 p., 8 pls.

——— & Geisenhagen, K.

1922 *Ibid.* Teil III, Über Oölithe. *Ibid.* 29, no. 5. 41p., 1 pl.

Ruedemann, R.

1906 Cephalopoda of the Beekmantown and Chazy Formations of the Champlain Basin. N. Y. State Mus. Bul., 90: 389–611. 38 pls.

1914 *See* Cushing & Ruedemann

1929 Coralline Algae, Guadalupe Mountains. Amer. Ass'n Petroleum Geol. Bul., 13, pt 2: 1079, 1080

Rutherford, R. L.

1929 Pre-Cambrian Algal Structures from the Northwest Territories, Canada. Amer. Jour. Sci., 5th ser., 17: 258–59

Seely, H. M.

1906 Cryptozoa of the Early Champlain Sea. Vt. State Geol. Rep't, 5: 156–73

Setchell, W. A.

1903 The Upper Temperature Limits of Life. Science, n.s. 17: 934–37

1926 Nullipore Versus Coral in Reef-formation. Amer. Philos. Soc. Proc., 65: 136–40

Seward, A. C.

1894 Algae as Rock-building Organisms. Science Progress, 2: 10–26

1898 Fossil Plants. v. 1. 452p. Cambridge

1923 The Earlier Records of Plant Life. Quart. Jour. Geol. Soc. London, 79: lxvi—civ

1931 Plant Life through the Ages. 601p., 139 figs. New York, Cambridge

Skeats, E. W.

1918*a* The Coral-reef Problem and the Evidence of the Funafuti Borings. Amer. Jour. Sci., ser. 4, 45: 81–90

1918*b* The Formation of Dolomite and Its Bearing on the Coral Reef Problem. Amer. Jour. Sci., ser. 4, 45: 185–200

Steele, J. H.

1825 A Description of the Oolitic Formation Lately Discovered in the County of Saratoga and State of New York. Amer. Jour. Sci., 9: 16–19

Twenhofel, W. H.

1919 Pre-Cambrian and Carboniferous Algal Deposits. Amer. Jour. Sci., 4th ser., 48: 339–52

Van der Gracht, W. A. J. M. Van W.

1925 Suggestions Concerning the Probable Subsurface Structure of the High Plains of Western Texas, as Deduced from Observations on the Surface in Trans-Pecos Texas. Read before the 10th Ann. Meeting, Amer. Ass'n Petroleum Geol., Wichita, Kans., 1925 (Referred to in 1929 letter)

1926 Source Rocks of Petroleum Developed in a Salt Sequence, Illustrated in Particular by Conditions in the West Texas-Oklahoma-Kansas Salt Basin. Read before the 11th Ann. Meeting, Amer. Ass'n Petroleum Geol., Dallas, Texas, 1926. (Referred to in 1929 letter)

1929 Barrier Reefs in West Texas Basin. Amer. Ass'n Petroleum Geol. Bul., 13, pt 2: 1397 (Letter from Austria, Aug. 16, 1929)

1931 The Permo-Carboniferous Orogeny in the South-Central United States—Verhandl. Konink. Akad. Wetensch. Amsterdam Afd. Natuurk, 27, no. 3. 162p.

Vaughan, T. W.

1911 Physical Conditions under Which Paleozoic Coral Reefs Were Formed. Geol. Soc. Amer. Bul., 22: 238–52

1919 Fossil Corals from Central America, Cuba and Porto Rico, with an Account of the American Tertiary, Pleistocene and Recent Coral Reefs. U. S. Nat. Mus. Bul., 103: 189–524

Walcott, C. D.

1912 New York Potsdam-Hoyt Fauna. Cambrian Geol. and Pal. II. Smith. Misc. Coll., 57, no. 9: 257, 258, pl. 37

1914 Pre-Cambrian Algonkian Algal Flora. Cambrian Geol. and Pal. III. Smith, Misc. Coll., 64, no. 2: 77–117. pls. 14–23

1919 Middle Cambrian Algae. Cambrian Geol. and Pal. IV. Smith. Misc. Coll., 67, no. 5: 217–60. 17 pls.

Walther, J.

1885 Die gesteinsbildenden Kalkalgen des Golfes von Neapel und die Entstehung structurloser Kalke. Zeitschr. d. deutschen geol. Gesellschaft, 37: 329–57

1919 Allgemeine Palaeontologie I Teil: Die Fossilien, als Einschlusse der Gesteine. 191p. Berlin

Weber-van Bosse, *Mme.* A.

1904 Siboga-Expeditie. Monographe LXI, p. 4

Wieland, G. R.

1914 Further Notes on Ozarkian Seaweeds and Oölites. Amer. Mus. Nat. Hist. Bul., 33: 237–60. pls. 14–19

Winchell, N. H.

1886 New Species of Fossils. Minn. Geol. Surv. Ann. Rep't, 14: 313–18 (1885)

Yabe, H.

1912 Über einige gesteinbildende Kalkalgen von Japan und China. Sci. Rep. Tôhoku Imp. Univ., ser. 2 (Geol), 1, pt 1. 8 p., 2 pls.

——— & Ozaki, K.

1930 *Girvanella* in the Lower Cambrian of South Manchuria. Tôhoku Imp. Univ. Sci. Rep., ser. 2 (Geol.), 14: 79–85

Yonge, C. M.

1930 A Year on the Great Barrier Reef. 246p. London & New York

SUPPLEMENTARY NOTE

It has seemed advisable, for the benefit of residents of the Capital District, and more particularly for tourists unfamiliar with the area, to give more definite directions for reaching Lester and Ritchie parks and a few more details about these areas. Saratoga Springs is approximately 30 miles north of Albany and may be reached by route 9. In Saratoga Springs take route 29 west and continue for about three miles to the junction with the Greenfield Center road, turning north at this four corners. Mr Ritchie has placed here, on the north side of the state road, a signboard indicating the direction of the "Petrified Sea Gardens" (Ritchie park) which are located on the right side of the road three-quarters of a mile north of the four corners. Lester park is about half a mile beyond this, also on the right (east) side of the road. Traveling by way of Schenectady (route 5, northwest from Albany to Scotia) and Ballston Spa (route 50 out of Scotia, north) one can enter Saratoga Springs and take route 29 west as before, or, better yet, just before the state road crosses the railroad tracks, one mile out of Saratoga Springs, take the road to the left, which meets route 29 one mile to the north.

The Lester Park area, besides the *Cryptozoön proliferum* reef, has, as discussed in the paper, other features of interest such as the *C. ruedemanni* reef in Hoyt quarry and the stringers of *C. pro-*

liferum, developed in rill channels, which are located in the field along the east-west road to the north. The "Petrified Sea Gardens" or Ritchie park, where reefs belonging to three species of Cryptozoön are displayed *(C. proliferum, C. ruedemanni* and *C. undulatum),* is privately owned by Robert R. Ritchie, of Saratoga Springs, and is in a much better state of preservation. The "Gardens" area, comprising some 20 acres of land entirely underlain by these reefs of calcareous seaweeds, constitutes one of the most remarkable displays in the State, even in the country and perhaps in the world. The remarkable nature of this exposure, particularly as regards the *C. proliferum* reef, is to considerable extent due to the fact that the ice sheet which covered this part of the country during the Glacial Period sheared off the tops of the concentric seaweed growths. The wide crevices that are found everywhere cutting through the limestone and the reef, and in which vertical sections of the seaweeds are displayed, are due to solution along the joint cracks that occur in the rocks; and in places pot-holes have been developed. Mr Ritchie is continuing the work of clearing away the veneer of soil that still covers parts of the "Gardens" and has laid out well-kept paths designed to give the best views of the reefs. The place as a whole, particularly the northwest corner where his summer home is located, is attractively landscaped. In addition Mr Ritchie maintains an adequate and well-instructed guide service and has for sale, at a small price, a popular pamphlet on the area written by Professor Harold O. Whitnall, of Colgate University, and a short article by the writer. Near the entrance gate Mr Ritchie maintains a picnic grounds and a small museum in which is an interesting fireplace built of *Cryptozoön* heads or stocks. In this museum are displayed local fossils and minerals, some of which are for sale, as well as specimens acquired from various parts of the country, either through exchange or by gift. So popular have the "Petrified Sea Gardens" become, and so widely known, that in the past season (1936) there were more than 15,000 visitors from 44 states and several foreign countries. Many prominent scientists of this country and from abroad have visited the place.

Lester park may be viewed free of charge. A small entrance fee is asked for the "Petrified Sea Gardens" and special rates have been made for schools. This fee entitles the visitor to the tour of the grounds, including the museum, and he may stay as long as he pleases. Lunches are not yet served there, but picnic parties are encouraged and ice cream and soft drinks are sold in the museum building.