NOTES ON STROMATOLITES.

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ABSTRACT. Those structures commonly called fossil calcareous algae, but more accurately known as stromatolites, are summarily discussed. It is concluded that most such objects should not be given generic and specific names. The evidence indicates that stromatolites are rarely, if ever, of use as interregional stratigraphic indexes, although some of them may be used as clues to correlation within a basin of deposition. Stromatolites in most instances probably indicate growth at a depth of less than 30 meters in salt water or 10 meters in fresh water, but they are of little use in determining the temperatures under which they were formed. Bioherm forming stromatolites of the type which is digitate and branching in vertical sections (gymnosolen) suggest but do not prove origin in fresh water; other types are useless as clues to degree of salinity. It is pointed out that the laminae of many stromatolites which grow fast to the substratum are convex upwards, and that the forks of the branching forms are open toward the top; suggesting their use in determining tops of beds. The question of possible seasonal lamination is briefly considered and reference is given to sources of further information on stromatolites. A digitate stromatolite from Arctic Canada is described.

INTRODUCTION.

SINCE Wieland's review of 1914 it has never been seriously questioned that many of the laminated but otherwise structureless objects variously called cryptozoon, collenia, gymnosolen, and so on were actually formed by lime-secreting algae. It is well known that the calcareous structures precipitated about the thalli of the lime-secreting algae are not part of the algal body and at best form a cast of it. Although organic in origin, these structures are themselves neither organisms nor parts of organisms. Nevertheless, they must be called something and the term *stromatolite* (Kalkowsky, 1908, p. 68; Gr. *stroma*, bed or layer, and *lithos*, stone) seems most appropriate for the simply laminated forms.

In the course of an investigation of the stratigraphy of portions of Arctic Canada by the A. L. Washburn Expedition of 1939, stromatolites of several types were found. Some occurred in sections yielding no other traces of life and it became important, therefore, that a critical study be made to learn if anything could be done with them. The results of that study are so far outside the scope of any paper dealing with the stratigraphy and paleontology of the areas investigated that they are presented here separately. The need for such a summary was evident from the many hours of search required to reach the conclusions suggested.

The ensuing discussion is based in part on fossil and recent specimens but mostly on the literature. Every title dealing with algae that is listed in the U. S. Geological Survey bibliographies of North American geology was consulted, as well as a number of European papers and some concerning recent algae. Of a few more than 100 papers examined 50 were considered important to this study. Wherever feasible definite sources of information have been cited. Citation of a single paper means that it is the most appropriate or most convenient source of reference, not the only one. Because the intention here is to compress rather than to expand, discussion is abbreviated.

It is a pleasure to acknowledge my indebtedness to Prof. Charles Schuchert and to Mr. A. L. Washburn who jointly sponsored the field work that led to this study and who have maintained a critical interest in its progress. For their stimulating discussion and constructive criticisms I am grateful to Prof. and Mrs. Adolph Knopf, Prof. A. E. Parr, and Prof. G. E. Hutchinson. To my wife I am grateful for assistance in the research.

SHOULD STROMATOLITES BE NAMED?

Among the lime-secreting red algae (Rhodophyta) the limy external crust is ordinarily secreted by a single species. Genera such as *Lithothamnium* have a well-defined cellular microstructure resembling that seen in some stromatoporoids (see illustrations in Howe, 1918; Rama Rao and Pia, 1936). It is quite proper that these structures should bear generic and specific names; but a different situation exists among most members of the only other important groups of normally lime-secreting algae, the blue-green and green algae (Cyanophyta and Chlorophyta), which are ordinarily held responsible for most of the ancient stromatolites.

Bradley dissolved the calcium carbonate from algal masses collected by him at Green Lake, New York, and found that the felt of thalli obtained consisted of blue-green algae plus a few green algae (Bradley, 1929, p. 205). He lists nine genera with six named species occurring in this assemblage. In the organic residue from a lime "biscuit" in South Australia T. G. Osborne identified two genera of blue-green algae (Mawson, 1929). From algal crusts (Schnegglisteinen) in the Bodensee on the

Swiss-Bavarian border Pia (1933, p. 172) has listed 12 species in seven genera of blue-green and green algae, several species of diatoms, and one fungus. Of these algal crusts he says (Pia, 1933, p. 174), "Die ähnlichkeit zwischen den Schnegglisteinen und Fossilen wie *Pycnostroma* and *Sphaerocodium* springt in die Augen." Roddy (1915, p. 258) lists eight genera of blue-green algae "associated with the calcareous concretions occurring in Donegal Creek, Lancaster County, Pa.;" he says, "there are also species of *Protococcus*, many species of Diatoms, several species of Desmids, various species of the Chlorophyceae, several species of Phaeophyceae, and species of Rhodophyceae." As a matter of taxonomic procedure the giving of generic and specific names to structures formed by assemblages of genera is to be decried. The only proper solution to the problem is to name only the actual thalli or the cells as Bradley (1929) and Johnson (1937) have done. Of course some stromatolites are formed by single species of blue-green or green algae (Bradley, 1927, p. 232), but this would be almost impossible to prove in most of the ancient rocks.

It is true that there is ample precedent for giving generic and specific names to stromatolites. Many paleontologists have done this even though aware of the impropriety of so doing. Perhaps their feeling in the matter is expressed by the Fentons (1931, p. 632), who protest that many of these objects are better defined than some species of compound corals. This argument, however, seems irrelevant. Kalkowsky (1908) studied over 300 thin sections of oölites and stromatolites from the Triassic rocks of North Germany and appears to have found more variety of microstructure in the oölites than in the stromatolites, yet it is doubtful if any modern biologist would give biologic names to oölites. In the stromatolites I have studied the only visible microstructure is a transverse, upwardly convex lamination; probably the result of irregularity in growth, with accompanying slight differences in the character of the precipitated material. This structure is almost as well defined in hand samples as it is in thin sections. Except for the deposits of the red algae, most of the calcareous algal structures I have seen figured show no structure other than this simple lamination or a nondescript vesicular structure. Mawson (1929, p. 617) and Berckhemer (1923, p. 22) have specifically noted the absence of structural features other than a crude lamination in specimens studied by them, and it is probably generally known among other writers who have failed to mention it. Clearly, even if it were desirable to name stromatolites their names would have to be based largely on external form; and external form seems to be closely dependent on the degree of crowding during growth, rapidity of growth, agitation of the water, and relation to the shore profile (Bradley, 1929, pp. 206-207; Howe, 1931, p. 62, Pls. 19, 21). Høeg (1929, p. 8) says, "There are two facts rendering it preposterous to create binomial names for these structures, however useful such names may be: We cannot be sure that identical coenoplases[1] are not formed by systematically widely different organisms; and in most cases, the coenoplases will certainly come into existence through the cooperation of more (than one) species."

I believe, with Høeg and with Holtedahl (1919, pp. 95-97), that stromatolites should not be named. It seems better to describe the peculiarities of stromatolites in the same manner that one would describe types of chert or textural characters of sedimentary rocks. As a matter of convenience it is perhaps well to retain such familiar form designations as cryptozoon, gymnosolen, and collenia. These, however, should be used in a vernacular sense, without being italicized or capitalized.

STROMATOLITES IN CORRELATION.

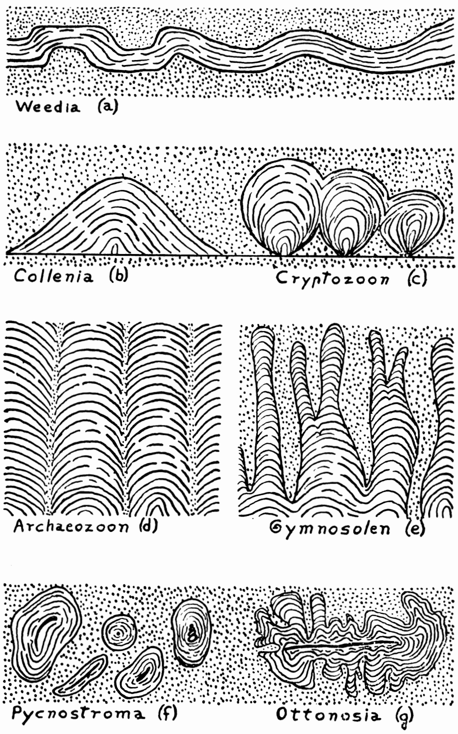
Maslov (1939a, 1939b) has made cautious but ambitious attempts to use stromatolites as a basis for correlation of unfossiliferous beds in Siberia and the Ural Mountains. Pia (1936) believes that some[2] algal structures can be used as index fossils in stratigraphic correlation but that the stromatolites of the blue-green algae are of almost no value in this respect except for some "species" of "*Girvanella.*"

One of the most remarkable-looking stromatolites forms bioherms consisting of branching, laminated subcylinders (Fig. 1 e; Pl. 1, Figs. 1, 3; Pl. 2, Figs. 1-4). This digitate form

[1] Høeg is here using the word coenoplase (Twenhofel, 1919, p. 343) to designate structures known to be algal as distinct from the term stromatolite which, to him, means any laminated structure, whether algal or not.

[2] It seems generally to be agreed that members of the well characterized families Dasycladaceae (siphonales), Characeae, and some Codiaceae, all green algae, may be important and reliable index fossils. Pia (1926, pp. 105-143) gives a well illustrated discussion of these groups. See also Johnson, J. H., and Dorr, M. E.; 1942, Jour. Paleont., vol. 16, no. 1, pp. 63-77, Fig. 1, Pls. 9-12; for a discussion in English of the genus *Mizzia* (Dasycladaceae).

was called "*Gymnosolen*" by Steinmann (1911) who thought it was an aseptate coral of some kind. Steinmann's material came from the beach float on the Kanin peninsula in northern Russia, but it was similar in aspect to a form described by Holtedahl from the Porsanger series, which rests "apparently conformably upon the Lower Cambrian series" of northern



TEXT FIG. 1. Diagrammatic representation of some forms of stromatolites[3] with the vernacular names applied to them. Figures 1a to 1e greatly reduced, 1f and 1g slightly reduced. (After Pia, 1929, Fig. 1, p. 212; except that ottonosia has been redrawn to correspond more closely with the original illustration of Twenhofel, 1919, Fig. 3.)

[3] Pia would call the attached forms *Stromatolithi*, the unattached forms *Oncolithi* (*fide* Høeg, 1929, p. 6).

Norway (Holtedahl, 1919, p. 90, Fig. 3). I have at hand specimens from western Victoria Island in Arctic Canada that correspond very closely in size and structure to the illustrations and description given by Steinmann for "*Gymnosolen ramsayi*." In an early stage of this study it was hoped that a correlation could be made on the basis of this structure. That now appears to be impossible. Structures that would readily pass for gymnosolen are known from the Huronian to the Recent. Indeed the only visible distinction between the various forms is in the cross-sectional diameter of the component subcylinders and the distance between them, distinctions that bear an obvious relationship to stage and conditions of growth. The following list gives reference to illustrations of stromatolites of the digitate or gymnosolen type at various localities and positions in the geological column:

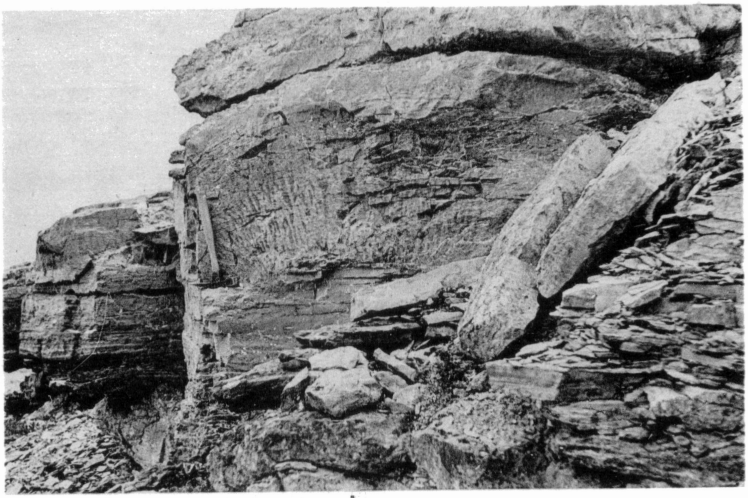
Upper Huronian, Minnesota—Grout and Broderick, 1919, Figs. 1-3.
Lower Cambrian or Proterozoic, eastern Siberia—Maslov, 1937b, Fig. 3, Pl. 2, Fig. 1.
Middle Cambrian, eastern Siberia—Maslov, 1937b, T. Fig. 2, Pl. 3, Fig. 1; 1939b, T. Figs. 3-4, Pls. 1-2.
Ordovician ?, eastern Siberia—Maslov, 1937a, T. Fig. 6, Pl. 4, Figs. 1-3, 1937b, Fig. 1, Pl. 1, Figs. 1-2; 1939b, T. Figs. 1-2, Pls. 3-4.
Ordovician ?, northern Russia—Steinmann, 1911, Pl. 3.
Ordovician ?, northern Norway—Holtedahl, 1918, T. Fig. 18; 1919, Fig. 3.
Silurian, eastern Siberia—Maslov, 1937b, T. Fig. 4, Pl. 3, Fig. 2.
Lower Triassic, northern Germany—Kalkowsky, 1908, Pl. 8.
Eocene, Utah—Bradley, 1929, Pl. 42.
Oligocene, Colorado—Johnson, 1937, Pl. 1, Fig. 3, Pl. 2, Figs. 1-2.
Recent, Switzerland—Pia, 1933, Fig. 6 on p. 147 (after F. A. Forel, 1904; Le Léman, Monographie limnologique, Tome 3, Lausanne).
Recent, New York—Bradley (1929, p. 214) states that the stromatolite referred to under Eocene above "resembles the algae reefs now being formed in Green Lake, N. Y."

PLATE I.

Fig. 1. Bioherm composed of digitate stromatolites of the gymnosolen type (hammer at left gives scale), north shore of Prince Albert Sound, Victoria Island, District of Franklin, Northwest Territories, Canada. Age unknown.

Fig. 2. Biostromal layer packed with kettle-formed stromatolites of the cryptozoon type. The rock is dolomite and the individual heads range from 0.3 to 1.5 meters in diameter. Rocks of lower Paleozoic age, Read Island, District of Franklin, Northwest Territories, Canada. Compare this figure with that of Blackwelder (1915, Fig. 1) showing similar structures from Wyoming.

Fig. 3. Longitudinal section (x3) of part of a digitate stromatolite. The right three-fifths and the left one-fourth of the figure show parts of two fingers which are very close together. Same locality and bed as Pl. 1, Fig. 1. Peabody Museum, Yale University.



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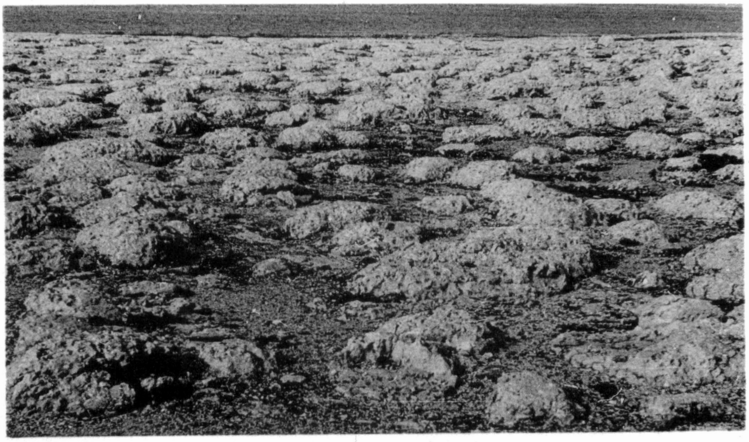

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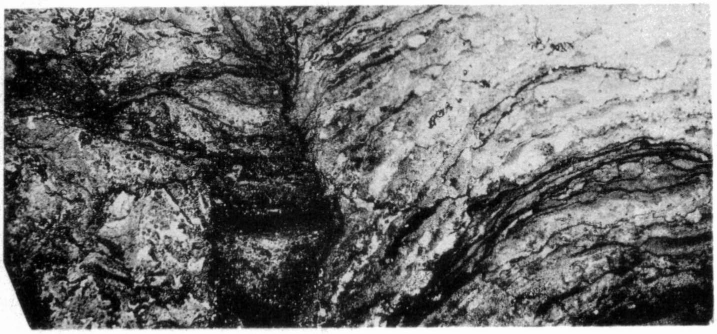

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STROMATOLITES

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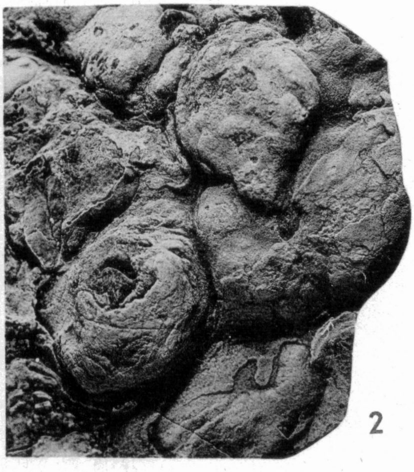

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STROMATOLITES

The evidence shows that the digitate, branching type of stromatolite cannot be relied upon as a stratigraphic index. If this is true for one of the most distinctive types of stromatolite, it is logical to suspect that it is also true for the more generalized types such as have been called cryptozoon and collenia. The present study confirms that suspicion. This means that most stromatolites have no clear-cut characters from which one could say, for instance, that the beds in which they occur are Proterozoic or Silurian in age. Within a basin of deposition, however, certain stromatolites may be useful clues to correlation once their occurrence has been established in standard sections. This is probably most likely to be true among rare and distinctive forms such as the gymnosolen type.

STROMATOLITES WITH REFERENCE TO TEMPERATURE, DEPTH, AND SALINITY OF WATER.

At the present day the lime-secreting algae flourish from the tropics to north of the Arctic circle. E. M. Kindle (1935) has recorded four species in as many genera of blue-green algae actively engaged in making calcareous crusts at about 64° north latitude on Southampton Island in Hudson Bay, and I have seen calcareous incrustations, probably algal in origin, in fresh water north almost to 71° latitude in Arctic Canada. The red alga *Lithothamnium*, a common associate of reef-building corals in tropical waters, is said to occur on the coast of Svalbard, or Spitzbergen (Diener, 1925, p. 37), and is reported "in great abundance on the coasts of Norway and northern Newfoundland" (Twenhofel *et al.*, 1932). It has been said that deposits of algal lime indicate a warm climate, but the foregoing observations do not warrant this belief. Glock

PLATE II.

FIG. 1. Polished surface (x1) of a digitate stromatolite of the gymnosolen type showing bifurcation in the upper left hand corner.

FIG. 2. Portion of an upper surface (x1) of a bioherm formed by gymnosolen.

FIG. 3. Longitudinal section[4] (x3) of part of a single finger from a gymnosolen. Dashed line outlines edges of finger, matrix on either side.

FIG. 4. Portion of a weathered surface (x1) of a gymnosolen showing parts of two fingers.

All specimens from the same locality and bed as Pl. 1, Fig. 1. Peabody Museum, Yale University.

[4] No transverse section is illustrated for it shows only concentric rings where it intersects the successive convex laminae.

(1923, p. 393) believes that "the Blue-green algae . . . are of no particular value in disclosing the temperature conditions under which they lived." Probably the best that can be said is that the lime-secreting algae seem generally to grow better in warm water than in cold water and that thick accumulations of algal lime are presumptive evidence, not proof, of a warm or temperate climate. After an exhaustive review of accessible chemical analyses of the structures formed by marine lime-precipitating algae, Clarke and Wheeler concluded (1922, p. 55) that, with one notable exception (Högbom, 1894, pp. 272-273), most of the available evidence suggested that "the proportion of magnesia in the algae is influenced by temperature." "As a rule," they say (1922, p. 61), "the organisms from warm waters are much richer in magnesia than those from cold waters." As far as stromatolites are concerned, however, it seems unlikely that this tendency will ever be of any importance in determining ancient climatic conditions due to the complications introduced by secondary dolomitization and the difficulty of establishing reliable reference standards for comparison of unknown samples. Needless to say, it would be imperative in any such comparison that identifications be generically accurate. As Clarke and Wheeler (1922, p. 48) have noted, the marine, lime-secreting algae fall into two groups; one (*e.g. Lithothamnium*) "highly magnesian," the other (*e.g. Halimeda*) "almost free from magnesia." Representatives of both groups are well known as common inhabitants of Recent coral reefs in the same latitudes.

"All algae are holophytic; *i.e.*, they contain chlorophyll" (Fritsch, p. 591). Algae, therefore, cannot grow below the depth to which light will penetrate. Obviously this depth will vary depending upon such factors as turbidity and agitation of the water. In the coastal waters of the ocean there is a general reduction of light by absorption to about 10 per cent of its surface value at a depth of 20 meters, and sufficient light for the support of plant life will probably nowhere penetrate deeper than 200 meters (A. E. Parr, oral communication). This suggests figures such as are given by G. M. Smith who says, "Algae in the north Atlantic rarely grow beyond the 30-meter level," and, "the greatest depth at which algae have been found is about 200 meters" (Smith, 1938, p. 296).[5] Dr.

[5] Smith notes that greater depths have been recorded but thinks the records unreliable.

G. E. Hutchinson states (written communication): "The transparency of fresh water is almost invariably much less than that of the sea; photosynthesis at 100 meters in a lake is very exceptional, and in most cases the lower limit will be less than 30 meters.[6] The building of an algal reef, however, presumably would require considerably more light than is available at the lower limit of photosynthesis; and in view of the probability that a considerable amount of suspended calcium carbonate, now represented by the matrix, would have been present in the water, a maximum depth of 10 meters might well be an overestimate." It is undoubtedly conservative to say that stromatolite-forming algae will not ordinarily flourish below a depth of about 30 meters in marine waters or about 10 meters in fresh waters.

It would be important if stromatolites could be used as indexes of the salinity of the water in which they were formed. Most stromatolites are believed to be the work of the blue-green or green algae, and a majority of these algae are inhabitants of fresh waters (Smith, pp. 12, 277). It is probably well known among geologists that stromatolites of the mound-like to subhemispherical, concentrically laminated type (collenia, "girvanella," cryptozoon, etc.) occur in association with marine fossils from Cambrian to Jurassic time (Pia, 1936, p. 12) and that similar objects occur at the present day in fresh waters. The digitate, branching stromatolites (gymnosolen) offer more possibilities. At present they are being formed by lime-precipitating algae in fresh waters (Bradley, 1929, p. 214; Pia, 1933, p. 147) and I find no record of such in marine waters. One record of similar digitate forms from a marine environment is the description by Howe and Goldman (1925) of structures occurring 6 feet below a layer full of *Gryphea calceola* in the Jurassic (Ellis formation) of Montana. These, however, had sufficient microstructure to be considered related to *Lithothamnium* by one of the best modern students of that genus (Howe). More difficult to explain is the so-called ottonosia of Twenhofel (1919, Fig. 3. See also the present paper, Text Fig. 1 g). This form occurs in small concretionary masses and has marine shells for nuclei. Although only imperfectly digitate and much smaller than "typical" gymnosolen, it approaches the gymnoso-

[6] Pia (1933, p. 146) notes that Forel has recorded "Kalkkrusten" from a depth of 60 meters in the Genfer See but considers this extremely remarkable.

len-like forms illustrated by Bradley (1929, Pl. 42) and Johnson (1937, Pls. 1-2). Other recorded occurrences of the gymnosolen type of stromatolite in the geologic past are either in known non-marine strata such as the Eocene Green River formation (Bradley, 1929), the Oligocene lake deposits of the Antero formation (Johnson, 1927), and the Lower Triassic Buntsandstein (Kalkowsky, 1908); or else they are in otherwise unfossiliferous beds.

Pending further investigation of ottonosia, it seems almost allowable to exclude that form from the gymnosolen group on the basis of its small size and imperfectly developed digitation and to think of gymnosolen as typified by the larger, generally bioherm-forming, stromatolites. If ottonosia could be fairly excluded from the gymnosolen group, one could generalize to say that where a stratum contains branching, digitate stromatolites whose substance is simply laminated and without cellular microstructure the chances are in favor of it being non-marine, and the burden of proof is on the dissenter from this conclusion. On the other hand, it is hardly scientific to exclude even questionable evidence and one seems forced to conclude that, although stromatolites of the gymnosolen type may suggest a fresh water habitat, they can be only contributory evidence and other criteria must be sought.

SEASONAL LAMINATION IN STROMATOLITES.

Bradley (1929, pp. 219-221) has given an interesting discussion of this subject. He quotes H. J. Roddy and W. Schmilde to show that some students of recent laminated fresh-water algal deposits regard the pairs of laminae as annual deposits, although they differ in their explanation for the lamination. Pia (1933, pp. 143, 171) likewise believes that the laminae of certain algal crusts are annual deposits. It is Bradley's opinion (*loc. cit.*) that even if the layers are not annual, "probably none of them represent less than one year." It is not apparent that this conclusion logically follows. The growth of algae and the rate of lime-secretion by them is probably inhibited for greater or less periods of time by increased turbidity or changes in depth or temperature of the water resulting from any of various self-evident factors. The pairs of laminae of a stromatolite might represent annual or larger cycles; but they might also be seasonal, or they might mark a succession of storms, or they might even be largely fortuitous. In the polished specimens and thin sections I have studied, numerous minor pairs of laminae intervene between more prominent interruptions in the homogeneity of the stromatolitic substance (Pl. 2, Fig. 3) so that it becomes a question whether one should count the thinner or the thicker layers. Bradley calculated that one seven-foot-thick bioherm illustrated by him would have required at least 355 years to form. Calculations based on the major layers in specimens from Arctic Canada give between 640 and 850 years for a deposit of the same thickness to have formed there. If the minor pairs of laminae were considered this figure would have to be multiplied by a factor of four to seven. In view of the objection expressed above, the speculation that two cycles might be represented here would be at best highly conjectural.

When based on factors as difficult to evaluate and to apply as the lamination of stromatolites, it would seem that calculations of absolute time in years can have little real value. The laminated stromatolites, however, probably do indicate that atmospheric conditions were not generally uniform at the time of their formation.

STROMATOLITES AS CRITERIA FOR TOPS OF STRATA.

Oriented specimens were collected by me from digitate stromatolites forming small bioherms (Pl. 1, Fig. 1). These bioherms were clearly in the position of growth in gently dipping strata in an area of inconsiderable structural complexity. In these stromatolites the laminae of their substance are convex toward the top, and, where the subcylinders branch, the forks are open toward the top. Excluding from consideration unattached forms and the teicholites noted below, laminated stromatolites of other types seen in the field also appear to have the laminae convex upwards. These observations suggest criteria for use in determining the tops of folded strata containing stromatolites. It should be kept in mind that the interspaces between stromatolites may also be laminated, roughly in continuation with but with inverse convexity from the laminae of the stromatolite itself (Pl. 2, Figs. 1, 3). If, then, the stromatolitic portions of a mass are not fairly well defined the convexity of the laminae is not valid evidence.

Hadding (1939) used the name teicholite (Gr. *teichos*, wall) for stromatolites which grow as incrustations on rock walls. In this type of incrustation the laminae are parallel to the surface of the rock wall on which they form, but the surface is marked by furrows and "drop formed, half-conic lumps" (Hadding, 1939, p. 3, Fig. 3). These semi-conic lumps, Hadding notes, "have their points turned upwards," their flattened bases down.

FURTHER INFORMATION ON FOSSIL STROMATOLITES.

The most important contributions to the understanding of stromatolites are those of Julius Pia. His published work on this and related subjects is voluminous, scholarly, and documented by extensive bibliographies. Particularly noteworthy at this place is his discussion of the possibilities of algae and stromatolites as guide fossils in a general sense (Pia, 1936). V. P. Maslov has made significant contributions to the knowledge of stromatolites; among these, the papers noted as 1937a (bibliography of 99 titles) and 1939a and b are perhaps the most important. E. J. Garwood (1913) has reviewed and tabulated the occurrence of stromatolites in time and space as known to him. A. C. Seward (1923) has expressed healthy scepticism about the nature of many of the so-called "calcareous algae." Høeg has given a good summary of the beliefs about the nature of stromatolites and discusses some of the terminology that has been applied to them (1929, pp. 5-13). Probably the most important publications in North American literature are those of W. H. Bradley (1929), M. A. Howe (1932), and W. S. Glock (1923). Other useful sources of reference are indicated in the bibliography, which consists only of papers important to this study and eliminates those superseded by other works.

In conclusion, it is perhaps well to remind the reader that many objects resembling stromatolites may be inorganic in origin. On the other hand, some structureless masses of limestone or dolomite may be the result of algal precipitation of carbonates.[7]

[7] Blackwelder (1913) has developed this hypothesis with reference to the origin of the Bighorn dolomite. Similar opinions have been expressed, generally without amplification, for the origin of other formations. Seward (1923, p. lxxiii) says, "The examination of calcareous reefs in the Mediterranean, which unquestionably owe their origin to masses of lime-secreting algae, has demonstrated that portions of the rock have lost all traces of plant-origin."

DESCRIPTION OF A DIGITATE STROMATOLITE (GYMNOSOLEN) FROM ARCTIC CANADA.

(Pl. 1, Figs. 1, 3; Pl. 2, Figs. 1-4.)

Gross features: The stromatolite forms small biohermal lenses not known to exceed 2.8 to 3.7 meters in basal diameter and 0.6 to 1.2 meters in height. These lenses occur in a zone of thinly bedded, compact, dove-gray to greenish-gray limestone 0.6 to 1.2 meters thick. They are unbedded and show, on weathered, vertical surfaces, branching, finger-like processes as greener patches against a pinkish matrix. The bases of these bioherms are flat or very slightly undulatory, while the tops are dome shaped with botryöidal upper surfaces. In transverse diameter the component "fingers" of the stromatolites range from 1 to 3 centimeters but average 2 to 2.5 centimeters. The branching of the fingers is irregularly dichotomous and they are about equal in volume and width to the spaces between them.

Detailed structure: The only discernible microstructure is a transverse, upwardly convex lamination. Two more or less distinct sets of laminae are present, one averaging 3 to 4 pairs per centimeter, the other ranging from 14 to 24 pairs per centimeter. Each pair of laminae consists of a relatively thick, light-colored layer of granular calcite and a thin, dark-colored layer apparently consisting mostly of a clay-like mineral. When a specimen was left in a 10 per cent solution of HCl for three hours and then studied under the microscope it was seen that the calcitic portions remaining at the surface of the stromatolite were finely fibrous and vesicular but with no recognizable pattern. The interspaces between the fingers of the bioherms have a tendency to be crudely laminated, more or less in continuation with some of the laminae of the fingers but concave instead of convex upwards.

Physical and mineralogical features: The rock of which the stromatolite consists is a compact limestone which yields approximately 9 per cent insoluble residue when dissolved in a 10 per cent solution of HCl. The insoluble residue is a faintly greenish-white, non-plastic, nearly isotropic, flaky mineral resembling a clay mineral.[8] It is quite soft and does not

[8] A sample of this clay-like residue was submitted to Dr. P. G. Nutting of the U. S. Geological Survey who reported on it as follows (March 18, 1942): "In addition to chemical and petrographic examinations, I took the time to run a thermal dehydration curve (weights at various temperatures) of this material. That curve is about midway between those for kaolinite

grit between one's teeth. Pieces of the rock were polished and stained in a molar solution of copper nitrate. In three hours a heavy blue stain formed over the entire surface, excepting the thin, dark-colored layers, showing that the carbonate mineral was largely calcite. A shorter period of staining revealed occasional angular dolomitic fragments between some of the fingers of the stromatolite but not in the fingers themselves. Thin sections of the rock showed the calcite to consist of fine, interlocking grains with no preferred dimensional orientation.

The specific gravity of the sample illustrated as Figure 1 on Plate 2 was determined by Prof. Adolph Knopf to be 2.65.

Occurrence: The foregoing description is based on specimens found in rocks of unknown age on the north shore of Prince Albert Sound, about 1.5 miles north-northwest from the head of the cove on which the Holman Island Post of the Hudson Bay Company is located, Victoria Island, District of Franklin, Northwest Territories, Canada.

Similar stromatolites occur in dolomites elsewhere in the area but will not be discussed at this place.

Disposition of the material: Peabody Museum, Yale University.

Ecological inferences: In an earlier part of this paper it was shown that the available evidence suggests but does not prove that stromatolites of the gymnosolen type inhabited fresh water. For the gymnosolen described above, then, a fresh water habitat may be considered likely but not necessary. The growing surface was probably coarsely botryoidal at all times, with the ends of the fingers never projecting far above the limy paste that accumulated between them.

If these bioherms were formed in fresh water it probably did not exceed 10 meters in depth. If they lived in salt water the limit of depth would have been about 30 meters. Supporting evidence for inferring a shallow water environment is found in tabular limestone fragments a fraction of a centimeter thick and several centimeters across, occurring locally at the bases of the bioherms. They appear to be locally derived and resemble the fragments of "edgewise conglomerates" except that they are scattered instead of being closely packed together.

and for clays of the montmorillonite group, showing 10 per cent structural water at 400° C. compared with 5 for montmorillonite and 16 for kaolinite. A microscopic examination by Mr. C. S. Ross showed two dominant minerals, kaolinite and a mineral resembling illite. The weight curve indicates iron oxidation confined to range 350 to 450° C."

In view of the large number and relatively great bulk of these stromatolitic bioherms it is reasonable to think that the climate under which they were formed may have been considerably milder than the present climate of the area in which they occur. The lamination of the stromatolites probably indicates that atmospheric conditions were not generally uniform at the time they were growing. It does not, I think, warrant any calculations of absolute time in years.

Because the gymnosolen type of stromatolite appears to be rare, its various occurrences within a sedimentary basin are probably to be considered essentially contemporaneous. This seems a valid basis for tentative correlation between sections in certain portions of Arctic Canada. As was shown in a foregoing part of this paper, no interregional correlation is possible on the evidence of gymnosolen.

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