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No. 2.—PRE-CAMBRIAN ALGONKIAN ALGAL FLORA

(With Plates 4 to 23)

BY

CHARLES D. WALCOTT

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CONTENTS

ILLUSTRATIONS

PLATES

INTRODUCTION

This is a preliminary paper on a fossil algal flora from the Algonkian formations of the Cordilleran area of western America. What has been found as yet appears to have been formed through the agency of algæ closely allied to the Cyanophyceæ (Blue-green Algæ). The associated fauna as it occurs in the Belt series of Montana is illustrated on Plates 21 and 22.

The subject matter is divided into a geologic and a biologic section. The first gives a brief outline of continental conditions and sedimentation of Algonkian time, and the second deals with the algal flora and the traces of a contemporaneous aquatic fauna.

There are a number of algal forms known to me from the Cambrian formations that are allied to *Cryptozoon* and *Collenia* which will not be referred to further in this preliminary paper on the Cordilleran pre-Cambrian forms. The field of investigation is a large one, however, and promises most interesting results.

Acknowledgments.—I am indebted to Mr. M. Collen, who has a ranch on the eastern slope of the Big Belt Mountains south of White Sulphur Springs, for observations on the occurrence of the algal flora in the Newland limestone and Spokane shales. Mr. Collen called my attention to the remarkable forms in the Newland limestone, and made a large collection of material for the United States Geological Survey. I have given his name to a genus that occurs in the Spokane shales in recognition of his great interest and for his persevering search to explain the origin and mode of occurrence of the fossil remains that he suspected to be corals.

In connection with the search for microscopic characters of the algæ, Dr. Albert Mann of Washington took the greatest interest and first discovered cells of the type of those of the Cyanophyceæ, Blue-green algæ (pl. 20, fig. 2), and notwithstanding his many duties made the micrographs of the chains and groups of cells. In the later part of this work he was ably assisted by Mr. Charles Resser of the United States National Museum.

Dr. Charles A. Davis of the Bureau of Mines very kindly advised in relation to the recent fresh-water algæ and their calcareous deposits and called my attention to the remarkable bank deposits in the lakes of Michigan and New York State.

To Dr. John M. Clarke, State Geologist of New York, I am indebted for a small collection of the Lake Balls from Canandaigua Lake, New York, and the electrotype of plate 16.

Dr. George T. Moore, Director of the Missouri Botanical Garden, referred me to authors who had written on the deposition of lime and magnesia through the agency of algæ, and Dr. M. A. Howe of the New York Botanical Garden sent a number of publications bearing on the coralline algæ.

I also consulted with Dr. T. Wayland Vaughan, of the United States Geological Survey, and Dr. Austin H. Clark, of the United States National Museum, in regard to the recent calcareous algæ.

CONTINENTAL CONDITIONS DURING ALGONKIAN TIME

The character and structure of the pre-Algonkian formations[1] indicate that toward the close of the Archeozoic era a period of world-wide diastrophism ensued, resulting in the receding of ocean waters or in the uplift of the American and all other continental masses in relation to the oceans. This great change (Laurentic Revolution) was accompanied or followed by local disturbances which produced profound folding and the metamorphism of the pre-Proterozoic complex, with the formation of mountain ranges, uplands, valleys and lowlands.

Two broad continental geosynclines subparallel to the western and eastern coast lines of the North American continent began to form early in Algonkian (Proterozoic) time. When cut off from the outer oceans or while the surface of these great areas was above the level of marine waters, they received terrigenous Algonkian sediments which began to accumulate on river flood plains and other favorable areas, or were deposited in the epicontinental fresh and brackish water seas or lakes that filled the shallow depressions within the area of the geosynclines. The western or Cordilleran geosyncline extended from the vicinity of the head of the Gulf of California northward probably to the Arctic Ocean.

In Arizona what is left of the Algonkian period of sedimentation is represented by nearly 12,000 feet (3,658 m.) in thickness of sandstones, shales, and limestones of the Grand Canyon group. In Utah and Nevada sediments forming only sandstone and siliceous shale appear to have gathered, while in Montana there is a develop-

[1] Van Hise and Leith, Monogr. U. S. Geol. Survey, Vol. 52, 1911. Table facing p. 598. Also see map 1, accompanying Bull. No. 360, U. S. Geol. Survey, 1909.

ment of limestone 4,800 feet (1,463 m.) in thickness in addition to nearly 20,000 feet (6,093 m.) of siliceous and arenaceous beds.[1] To the north, the Siyeh limestone has a thickness of 4,000 feet (1,220 m.).[2]

In western Alberta and eastern British Columbia to about 54° north latitude the Algonkian sediments are much like those of Montana. In the Montana region of greatest accumulation of Algonkian sediments the Cordilleran trough appears to have been filled to such an extent before Cambrian time, possibly by a river delta, that the Cordilleran Cambrian sea, advancing to deposit its sediments, encountered a central barrier[3] extending out from the eastern side of the trough.

From the Cordilleran trough depressions probably stretched eastward to central Texas, central Colorado, South Dakota, and it may be to the Lake Superior basin.[4]

Briefly summarized, the Algonkian period in North America with its great epicontinental formations was a time of continental elevation and largely terrigenous sedimentation in *non-marine bodies of water,* and of deposition by aerial and stream processes in favorable areas. Marine sediments accumulated in the waters along the outer ocean shores of the continent and great quantities of eruptive matter were extruded into the central Lake Superior region (Keweenawan). The agencies of diastrophism continued to exert their influence for a long period, though with decreasing energy, until they became practically quiescent during the latter part of Algonkian time.

The North American continent was larger at the close of Algonkian time than at any subsequent period other than possibly at the end of the Paleozoic and the end of the Cretaceous, when the land was equally extensive. Indeed, it is highly probable that its area was greater then than even now, for no marine deposits of Algonkian age containing pre-Cambrian life, as they were laid down in

[1] Bull. Geol. Soc. America, Vol. 17, 1906, p. 7.

[2] Daly has placed the Siyeh limestone of the Algonkian in the Cambrian, but, in the absence of direct areal stratigraphic relations and all Cambrian fossils in the Siyeh limestone, I do not see my way clear to accept his conclusions based on lithologic similarity of the Siyeh and the Middle Cambrian limestones of the Bow Valley and Kicking Horse Canyon.

Rept. Chief Astronomer for year 1910, Ottawa, 1913, Geol. North American Cordillera, Pt. 1, R. A. Daly, pp. 174-178 and accompanying table.

[3] Smithsonian Misc. Coll., Vol. 53, No. 5, 1908, p. 169.

[4] See map of Van Hise and Leith (Bull. No. 360, U. S. Geol. Survey, 1909, p. 1).

Lipalian[1] time immediately preceding the Cambrian period, have been discovered on the North American continent or elsewhere so far as known.[2]

Diastrophism.—The most important diastrophic movement within the Cordilleran area in Proterozoic time was the formation and gradual deepening of the great geosyncline extending from the Gulf of Mexico north to the Arctic Ocean. This geosyncline was broader when the Algonkian sediments of the Grand Canyon, Llano, Needle Mountain, Uinta and Black Hills[3] series were being deposited than at the beginning of Cambrian time. Indeed, it is highly probable that it extended eastward to central Texas, Colorado and South Dakota where a depression connected it across the upper Mississippian region with the Lake Superior depression.

Narrowing of the Cordilleran sea.—Before the Lower Cambrian transgression into the Cordilleran area a diastrophic movement began which resulted in a broad geanticline which raised the areas of the Grand Canyon in Arizona, Needle Mountain in Colorado, Uinta in Utah, the Black Hills of South Dakota, and the present site of the Rocky Mountains, above the horizon of wide sedimentary deposition and subjected the region affected by the uplift to erosion during Lower and Middle Cambrian time. This uplift[4] narrowed

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[1] Smithsonian Misc. Coll., Vol. 57, 1910, p. 14 (footnote).

Lipalian (λειπα + αλs) is proposed for the era of unknown marine sedimentation between the adjustment of pelagic life to littoral conditions and the appearance of the Lower Cambrian fauna. It represents the period between the formation of the Algonkian continents and the earliest encroachment of the Lower Cambrian sea.

[2] In this connection the theory of Chamberlin and Salisbury on the cause of the disappearance of the coastal or fringing deposits should be carefully considered by the student. Their conclusion is that "The theoretical continental fringe of sediments has been borne downward and thrust landward by each general deformation, and has crept outward and downward with each relaxation. The whole series is to be regarded as present in the continental shelf and the coast border tract, but as largely concealed by this combination of disturbing processes. When the great depth of the ocean-basins at the edge of the continental shelf is considered, it is obvious that the volume of sediment required to build the shelf seaward is large in proportion to the extension of the shelf, and hence the fringing zone is not very broad." (Geology, Vol. 3, 1906, p. 529.)

[3] Bull. U. S. Geol. Survey, No. 360, 1909, pp. 45, 46.

[4] This movement began some time before the Lower Cambrian transgression, but how long we have no means of determining, as it is not until the beginning of the Upper Cambrian that we find transgressing Cambrian deposits. It also undoubtedly raised the Sierran geanticline west of the Cordilleran area and kept this barrier intact throughout Cambrian time.

the Cordilleran sea on its eastern side and kept it out of the area captured until the Upper Cambrian transgression came. From the distribution of the Algonkian formations enumerated above there must have been a revival of the broad geanticline of early Proterozoic or late Archeozoic time that initiated the Rocky Mountain line of uplift. The pre-Proterozoic geanticline was largely reduced to base level before the first Cambrian transgression and the late Proterozoic uplift resulted in relatively minor stratigraphic disturbance. This is shown by the broad, comparatively low undulations of the Algonkian formations subjected to erosion in Lower and Middle Cambrian time. This late Proterozoic movement on the eastern side of the Cordilleran geosyncline was not as great in the Rocky Mountain area of Canada. This is proven by the Lower Cambrian sea having deposited its sediments over the slightly disturbed Algonkian Bow River series of Alberta.

Coastal deposits.—By coastal or shelf sea deposits I mean the deposits made along the coasts of the Pacific or other oceans either in the open ocean or in bays or other bodies of water in immediate connection with the ocean during Algonkian time. As far as known to me there are no known marine continental fringing or slope deposits or faunas laid down in Algonkian time on or about any of the continents or islands of the world.

A great work of the future will be the finding of marine deposits of Algonkian time and their contained life.

Cambrian basal unconformity.—From the Robson Peak region of British Columbia and Alberta to Arizona and southern California, a distance of over 1,000 miles (1,600 km.), clear evidence of a transgressing Cambrian sea has been found in many localities, proving conclusively that a general unconformity occurs here between the Algonkian and Cambrian. This marked unconformity is the record of the advancing, overlapping Cambrian sea.

Climate.—The presence of great thicknesses of red sandstones and shales in the Algonkian sections of the Grand Canyon and Belt series of Montana suggests an arid and possibly a cold climate. Opposed to this are the great limestone beds which indicate a fair supply of water to form inland seas whose temperature was sufficiently high to permit of an abundant growth of algæ of a simple type that served as the agency for the precipitation of vast quantities of calcareous matter. The only characterizing fossil of this period, possibly of marine derivation, was a crustacean, *Beltina* *danai*,[1] which, like the Atlantic coast lobster (*Homarus americanus*), might have lived in quite cold water, or adapted itself to warmer, muddy water, when cut off from marine waters.

In China a cold period near the close of the Algonkian is suggested by the presence of glacial deposits at or below the base of the Man-t'o formation.[2]

ORIGIN OF ALGONKIAN LIMESTONES

The origin of the great pre-Cambrian limestones of western America has long been a mooted question and the nature of the concretionary-like *Cryptozoon* has not been so definitely determined as to be accepted by common consent either as an alga or a Stromatoporoid. Twenty years ago I had a number of thin sections made of the matrix and " fossils " from the limestones of the Chuar terrane of the Grand Canyon series of Arizona [3] and later of specimens from the Belt series of Montana. Not being able to discover any traces of detailed or minute structure I put the specimens and slides aside for future study. Recently I have had occasion to consider the question of the origin of the magnesian limestones of the Algonkian formations of the Cordilleran area and in this connection to determine if possible whether there was any relation between the so-called Cryptozoöns and the presence of the great series of limestones.

As the thought that the entire Algonkian series of western America were of epicontinental origin was forced upon me, I began to doubt the marine origin of the limestones. It then occurred to me to seek further information from the geologists who have been studying the origin of fresh-water calcareous deposits and the paleobotanists acquainted with the calcareous algæ as active agents in secreting and depositing the calcium and magnesian carbonate. The result of these inquiries has led me to the conclusions that the origin of the Cordilleran Algonkian limestones is largely owing to the action of lime-secreting algæ and bacteria and that precipitation of calcium and magnesian bicarbonates from a saturated solution is of very rare occurrence and not an important agent of deposition in geologic time and that marine waters are not necessary for the deposition of magnesian limestones.

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[1] Bull. Geol. Soc. America, Vol. 10, 1899, p. 239, pls. 25-27.

[2] Willis, Research in China, Vol. 2, 1907, p. 39.

[3] *Cryptozoan ? occidentale* Dawson, Bull. Geol. Soc. America, Vol. 10, 1899, pp. 232-234, pl. 23, figs. 1-4.

Recent calcareous deposits.—In discussing with Dr. Charles A. Davis of the United States Bureau of Mines the question of the origin of calcareous deposits in fresh and brackish waters, he called my attention to the Natural History of Marl in volume 8 of the Geological Survey of Michigan.[1]

Dr. Davis here disposes of the theory that the mineral salts are deposited as the result of certain portions of the lake waters reaching the saturation point by showing that the outflow of the lakes is practically the same as the inflow and that the loss by evaporation is too small a factor to be taken into account. He considers the possibility of the plant and animal organisms living in the waters of the lakes being the agents which bring about the results of the deposits of the soluble calcium bicarbonate as the insoluble carbonate. He shows that the deposits of marl that were largely contributed to by Mollusca and other invertebrate shells are of minor importance, and that the commercially valuable calcareous marl deposits do not contain recognizable shell fragments in any preponderance, usually not to exceed 1.04 per cent.

Next, considering the action of plants as precipitating agents for calcium salts, he gives the following two possible general causes for the formation of the lime incrustation upon all aquatic plants:[2]

> All green plants, whether aquatic or terrestrial, take in the gas, carbon dioxide, through their leaves and stems, and build the carbon atoms and part of the oxygen atoms of which the gas is composed into the new compounds of their own tissues, in the process releasing the remainder of the oxygen atoms. Admitting these facts, which are easily demonstrated by any student of plant physiology, we have two possible general causes for the formation of the incrustation upon all aquatic plants.
>
> If the calcium and other salts are in excess in the water, and are held in solution by free carbon dioxide, then the more or less complete abstraction of the gas from the water in direct contact with plants causes precipitation of the salts upon the parts abstracting the gas, namely, stems and leaves. But in water containing amounts of the salts, especially of the calcium bicarbonate, so small that they would not be precipitated if there were no free carbon dioxide present in the water at all, the precipitation may be considered a purely chemical problem, a solution of which may be looked for in the action upon the bicarbonates, of the oxygen set free by the plants. Of these, calcium bicarbonate is the most abundant, and the reaction upon it may be taken as typical and expressed by the following chemical equation:

$$CaH_2(CO_3)_2 + O = H_2O + CaCO_3 + CO_2 + O$$

$$\left.\begin{array}{l}\text{calcium}\\ \text{carbonate}\end{array}\right\} + \text{oxygen} = \text{water} + \left\{\begin{array}{l}\text{calcium}\\ \text{carbonate}\end{array}\right\} + \left\{\begin{array}{l}\text{carbon}\\ \text{dioxide}\end{array}\right\} + \text{oxygen}$$

[1] Geol. Survey Michigan, Vol. 8, part 3, 1903, pp. 65-96.

[2] Idem. p. 69.

in which the calcium bicarbonate is converted into the normal carbonate [1] by the oxygen liberated by the plants, and both carbon dioxide and oxygen set free, the free oxygen possibly acting still farther to precipitate calcium monocarbonate.

He concludes that the alga *Chara* is the great agent for the concentration and precipitation of the calcium carbonate, and that the Blue-green algæ are also largely concerned in the formation of the massive beds of lake tufa and the calcareous pebbles which show both radial and concentric structure. Dr. Davis describes the pebbles as roughly ellipsoidal in shape, the radial lines shown in the sections [Idem, p. 91] being formed by the growth of the filaments while the concentric lines probably represent periods of growth of the plants either seasonal or annual. Included within this structure are great numbers of plants, besides the lime-secreting *Zonotrichia* and considerable numbers of diatoms. These pebbles have quite a wide distribution in the lakes of Michigan, Wisconsin and elsewhere.

Those interested should consult Dr. Davis's paper on the mineral deposition of calcium carbonate through the agency of algæ, also Dr. John M. Clarke's paper on "Water Biscuit." [2] Dr. Clarke kindly sent me specimens of the "Water Biscuit" from Canandaigua Lake. A number of transverse sections were made of these, some of which show a very distinct concentric structure (pl. 14). Dr. Clarke in describing the origin of the "Water Biscuit" states that: [3]

It is quite clear that the process of formation of these peculiar bodies has been the following. The beach shale and débris have become incrusted by a growth of algæ, and the latter, stealing away for their requirements the excess of free carbon dioxide in the water necessary to keep the carbonate of lime in solution, have thus caused a precipitation of the lime salts. The process has been continuous, as when a new precipitation formed a concentric continuous deposit of lime carbonate, the new surface became coated with the algæ and in consequence fresh precipitation followed. The whole forms a most interesting instance of the influence of plant growth on the formation of lime deposits.

At my request Dr. Davis gave me the following notes on the calcareous deposits in Green and Round Lakes, situated two miles (3.2 km.) southwest of Kirkville, Onondaga County, New York:

These lakes are located in a deep valley which is apparently rock walled, with the rocks covered from four to ten feet, apparently, with drift. The walls of the valley are wooded and may be a hundred or more feet high. Green

[1] Which is only very slightly soluble, 100 parts to the million.

[2] Bull. N. Y. State Mus., No. 39, Vol. 8, 1900, pl. 14, pp. 195-198, pls. 12-15.

[3] Idem, p. 197.

Lake is reported to be about 125 feet deep at the deepest part by Mr. C. M. Crouse, of Syracuse, who has sounded it. The rock seen in the ravines at the head of Round Lake was a gray, rather thin-bedded limestone, not much weathered or disintegrated. Fragments of the wall rock are abundant in the drift.

The region around the valley, judging from the shape of the hills, is morainal. A considerable stream connects the two lakes and flows out from Green Lake through an artificial, straightened and deepened channel which has been cut through a swamp. This ditch cuts through beds of tough white and rather porous calcareous tufa and beds of loose granular marl. Tufa also appears in great blocks on the sides of the principal ravine leading out from the head of Round Lake near the rock outcrops but none was seen in the lake.

In Green Lake considerable spaces along the shore have deposits of tufa which extend out into the lake from the shore for as much as twenty feet, or more in places, forming perpendicular or overhanging sub-aquatic cliffs or terraces. These terraces extend from slightly above the surface, at the stage of water when visited, to below the level to which one can see through the greenish, somewhat turbid water. The terraces are covered, wherever examined, with an incrustation of calcareous marly substance, which shows bluish-green wherever it is freshly broken, especially near the surface. This covering layer is, in general, weakly cemented and friable and is easily scraped from the more consolidated portions which it sometimes covers to the depth of an inch or more. This living layer covers not only the rock, but other substances which are in the water, often coating branches of fallen trees to a thickness of one to two inches, while stumps of trees which are favorably located often appear like heads of coral near the water surface.

In two places, logs of white cedar (*Thuja*) were noted which were completely imbedded in the solid faces of the cliff and projected from them. One of these logs passed diagonally through the deposit, appearing both above and below it. In many cases the dead trees and branches form dense mats on sides of the steep wall of the lake below water level and are apparently in the process of being covered with the algal incrustation, as there are thick deposits of the limy matter characteristic of these in many places. It may be that these collections of woody débris form the foundations on which the terraces which have developed have been started.

Specimens broken from the underlying tufa show a considerable amount of porosity, but the limestone from the terraces is not friable like the incrustation, although apparently of the same origin, since some of the twigs included in it run through both hard and soft material. The under sides of fragments of the compact rock which lie submerged on the surface of the terraces often appear to have botryoidal structure.

The tufa of the terraces is quite different in appearance and apparent origin from that in the valley below the lake. *Chara* remains are frequent in the tufa of the ditched level, but none were noted in the material forming the terraces, and no *Chara* was seen in the lake, except in the outlet, and that was but slightly incrusted with lime.

The occurrence of the terraces in spots along the lake suggests special reasons for the development of these terraces at certain points, but no such reasons appear from casual examination. A slightly higher level than that at present held was apparently indicated by a small terrace which appears a foot or 18 inches above the present level of the water, and the limy deposit was apparently formed at this level as well as at the present one.

It was noted that the branches of trees and other drift material which had settled to the bottom of the lake were covered by the incrusting algal deposits as far down as twelve or fifteen feet. These fragments may possibly have rolled down the steep slope after the formation of the incrustation, but of this there was no good evidence visible. If deposition as the result of the activities of the algæ went on faster near the water surface, as theoretically it should, since here the plants find most favorable light conditions, the peculiar overhanging form of the terraces might easily result. This type of deposit is what should theoretically result from the work of *Zonotrichia,* if it grew under very favorable conditions and in great abundance. It is probable, from the color of the broken fragments, that the algæ are responsible for the formation of the whole of these deposits, or for most of them.

Further work on the identity of the Blue-green alga most abundant in the spongy calcareous covering of one of the branches which was collected at the time of my visit to the locality shows that the organism is a cellular Blue-green alga, and not a filamentous one like *Zonotrichia.* This cellular type develops irregular aggregations of rounded or oval, very small cells, which apparently seldom arrange themselves in strings. The genus or species has not been identified.

Mr. G. W. W. Barclay, when describing some "Algoid Lake-balls" that he found in Loch Kildonan in the Hebrides,[1] states that the balls are from a quarter of an inch to 3 or 4 inches in diameter and lie side by side in great numbers. In some cases a complete small ball is found inside a larger one and the balls while usually spherical may be irregular in shape. He found them composed of innumerable algal filaments, so intertwined and matted together as to form an outer covering of an almost felt-like consistency that is about one-twentieth to two-twentieths of an inch in thickness. The interior seems to consist of mud but the microscope shows that they are composed of a filamentous alga (*Cladophora glomerata*). The decomposed remains of the inner ends of the filaments are mingled with diatoms, but there does not appear to be any calcareous matter present.

Somewhat similar lake balls have also been found in several other European lakes.

Mr. A. C. Seward in his "Fossil Plants"[2] writes as follows:

On the shores of the Great Salt Lake, Utah, there are found numerous small oölitic calcareous bodies thrown up by the waves.[3] These are coated with the

[1] Proc. Royal Soc., Edinburgh, 1886, Vol. 13, pp. 845-848, pl. XXX.

[2] Cambridge Univ., Press, Vol. 1, 1898, pp. 122, 123.

[3] Rothpletz, A., Über die Bildung der Oolithe, Bot. Cent., Vol. 51, p. 265, 1892.

cells of *Glœocapsa* and *Glœotheca,* two genera of the Chroococcaceæ. Sections of the grains reveal the presence of the same forms in the interior of the calcareous matrix, and it has been concluded on good evidence that the algæ are responsible for the deposition of the carbonate of lime of the oölitic grains. By extracting the carbonic acid which they require as a source of food, from the waters of the lake, the solvent power of the water is decreased and carbonate of lime is thrown down. In similar white grains from the Red Sea[1] there is a central nucleus in the form of a grain of sand, and cells of Chroococcaceæ occur in the surrounding carbonate of lime as in the Salt Lake oölite.

The analyses of the Michigan Lake deposits show from 2 to 13 per cent of magnesian carbonate, the amount varying with the magnesian content of the lake water. The amount of calcium and magnesium carbonate is determined by the amount of the two minerals available for solution in the rocks and soils of the drainage basin tributary to the pond or lake in which the deposits occur.

Algonkian lakes.—The lakes of Algonkian time were not much if any larger in area than the "Great Lakes" of the St. Lawrence drainage basin and they were much shallower and more laden with mud and mineral matter in solution.[2]

The area of the Belt terrane in Montana is about 6,000 square miles. This seems large when studying it in the field, but it is only one-fifth of the size of our great fresh-water Lake Superior.[3]

DEPOSITION OF LIMESTONE THROUGH THE AGENCY OF ALGÆ

The drainage into the Algonkian lakes undoubtedly afforded all of the soluble mineral matter necessary to account for the limestones, siliceous shales and sodium chloride deposits of the Algonkian series of formations.[4]

From a study of the water of the principal rivers of the world Sir John Murray compiled the following table, showing the average amount of mineral matter in solution in one cubic mile of average river water. [Scottish Geol. Mag., Vol. 3, 1887, p. 76.] The propor-

[1] Walther, J., Die Korallenriffe der Sinaihalbinsel, Abh. math. phys. C. K. Sächs. Ges., Vol. 14, 1888.

[2] Geology, Chamberlin and Salisbury, Vol. 1, 1904, p. 102.

[3] Lake Superior has an estimated area of 32,060 square miles. It is 400 miles long and 160 miles wide. The combined area of the five great lakes is estimated at 94,605 square miles.

[4] For the areas of the known Algonkian deposits see plate 1 accompanying report of Van Hise and Leith on pre-Cambrian Geology of North America, Bull. U. S. Geol. Survey, No. 360, 1909.

tionate amount have varied in the river waters of Algonkian time, but probably it was essentially similar in composition and larger in quantity.

Constituents.	Tons in a Cubic Mile.
Calcium carbonate ($CaCO_3$)	326,710
Magnesium carbonate ($MgCO_3$)	112,870
Calcium phosphate ($Ca_3P_2O_8$)	2,913
Calcium sulphate ($CaSO_4$)	34,361
Sodium sulphate (Na_2SO_4)	31,805
Potassium sulphate (K_2SO_4)	20,358
Sodium nitrate ($NaNO_3$)	26,800
Sodium chloride (NaCl)	16,657
Lithium chloride (LiCl)	2,462
Ammonium chloride (NH_4Cl)	1,030
Silica (SiO_2)	74,577
Ferric oxide (Fe_2O_3)	13,006
Alumina (Al_2O_3)	14,315
Manganese oxide (Mn_2O_3)	5,703
Organic matter	79,020
Total dissolved matter	762,587

Many authors have written on the limestone-forming algæ that should be referred to in a memoir on the subject, but in this preliminary paper on the Algonkian forms of the Cordilleran area only a few will be noticed.

In a recent paper on "The Important Part Played by Calcareous Algæ at certain Geological Horizons"[1] Professor E. J. Garwood gives a brief historical account of the genera and then discusses the influence of algæ in the formation of sedimentary rocks. He mentions the presence of oölites in the Archean and Algonkian rocks.[2] Very few traces have been found in Cambrian rocks, but in the Ordovician they become much more abundant. He does not mention the Cambrian genus *Cryptozoon*. After reviewing the algæ of geologic time Professor Garwood concludes that it plays a very important part as rock builders at many different horizons in the geologic series; that certain forms are restricted to definite geologic periods, but that they had a wide geographic range. He calls attention to the constant association of fossil calcareous algæ with oölitic structure and also with dolomite. In regard to the latter he says:[3]

The presence of dolomites in connection with algal growths at different geological horizons appears to show that the beds have accumulated under

[1] Geol. Mag. n. s., Dec. 5, Vol. 10, 1913; pp. 440-446, 490-498, 545-553.

[2] Idem, p. 491.

[3] Idem, pp. 552-553.

definite physiographical conditions similar to those which obtain to-day in the neighborhood of coral reefs. Such lagoon conditions would tend to come into existence during periods of subsidence or elevation, and this is just what we find when we examine the periods at which these reefs are most persistent.

Thus the Girvan Ordovician lagoon-phase occurred during an elevation which culminated with the deposition of the Benan Conglomerate; the Lower Carboniferous "Algal band" in Westmorland was laid down during the subsidence which followed the Old Red Sandstone continental period, while the Upper *Girvanella* Nodular band occurred when the marine period of the Lower Carboniferous was drawing to a close and a general elevation was taking place. Similar conditions could be drawn from the Gotlandian and other periods recorded above.

A table which shows the known occurrence of fossil algæ from the Cambrian to the late Tertiary accompanies the paper.

A brief paper by Dr. Marshall A. Howe of the New York Botanical Garden on "The Building of Coral Reefs,"[1] cites a number of writers to sustain his contention that the calcareous algæ are the largest contributors to the building of the "Coral Reefs and Islands." Dr. Howe in summing up on his subject says:

With the dominance in reef-building activities resting sometimes with the calcareous algæ 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.[2]

As an illustration of the dominance of the lime secreting plants he quotes Prof. J. Stanley Gardiner as follows:

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, mammillated, columnar and branching. The outgrowing seaward edges of the reefs are practically formed by their growths 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.[3]

Again he quotes Professor Seward's summary of the results of J. Walther's studies of a *Lithothamnion* bank in the Bay of Naples about 30 m. below the surface of the water:

By action of the percolating water the *Lithothamnion* structure is gradually obliterated, and the calcareous mass becomes a structureless limestone.

[1] Science, n. s., Vol. 35, 1912, pp. 837-842.

[2] Idem, p. 842.

[3] Trans. Linn. Soc. London, Zool., 2d ser., Vol. 12, pp. 177, 178, 1907. Also, Nature, Vol. 72, pp. 571, 572, where a photograph of this *Lithothamnion* reef is published.

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 *Lithothamnion,* but in others a gradual obliteration is observed of all plant structures until the rock becomes entirely structureless. A similar instance of structureless limestone is described from the Lias of Todten Gebirges [Todtes Gebirge].[1]

In an interesting paper on the "Origin of the Bighorn Dolomite"[2] Dr. Eliot Blackwelder considers the influence of calcareous algæ in the deposition of this Ordovician dolomite. After a very clear discussion he concludes that an alga of the type of the modern coralline alga *Lithophyllum* is the most likely form to have made the structure that is very widely present in the dolomite. The absence of microscopic cells is explained by the crystallization of the dolomite. Of the branching structures he says, "It seems more likely that they represent banks of calcareous algæ than any of the plant-like animals."[3]

One of Dr. Blackwelder's illustrations (pl. 33, fig. 1) suggests a form allied to *Greysonia basaltica* (pl. 17, fig. 2; pl. 18, fig. 2) of the Newland limestone. There is to me no apparent reason why the Blue-green algæ (Cyanophyceæ) should not have lived in the marine waters in which the Big Horn dolomite was deposited and also reproduced forms allied to those of the Algonkian. This comment is made with the hope that a thorough search will be carried on throughout the Palæozoic group for forms resembling those of the Belt series of limestones.

Bacterial deposits.—Dr. Alfred G. Mayer in speaking of the work of the late Mr. George H. Drew wrote as follows:[4]

In 1910, Sanford, and also Vaughan, published the conclusion that a considerable portion of the calcareous muds in the bays and sounds of southern Florida was precipitated out of the sea-water in some unknown manner. It remained for Drew, in 1911, to discover that there is in the warm surface waters of the West Indian and Florida region, and especially in the limestone mud itself, a bacillus which deprives the sea-water of its nitrogen, thus causing the calcium to combine with the dissolved carbon dioxide and to form the finely-divided limestone mud so characteristic of coral-reef regions. Drew isolated this bacillus and found that it became inactive in even moderately cold water, and thus it functions only in warm or tropical seas, thriving best at depths of less than 100 fathoms. In the surface waters of the Bahamas and Florida it is the most abundant marine bacillus.

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[1] Gardiner, "The Fauna and Geography of the Maldive and Laccadive Archipelagos," Vol. 2, pp. 10-26.

[2] Bull. Geol. Soc. America, Vol. 24, pp. 607-624, pls. 28-35.

[3] Idem, p. 624.

[4] Papers from the Tortugas Laboratory, Carnegie Institution of Washington, Vol. 5, 1914, p. 5.

In the paper by Drew "On the Precipitation of Calcium Carbonate in the Sea by Marine Bacteria" there are two paragraphs that sum up the results of his work.[1]

The observations so far available are too few, and the area they cover too small, to attempt to make any broad generalization at present. However, it can be stated with a fair degree of certainty that the very extensive chalky mud flats forming the Great Bahama Bank and those which are found in places in the neighborhood of the Florida Keys are now being precipitated by the action of the *Bacterium calcis* on the calcium salts present in solution in sea-water. From this the suggestion is obvious that the *Bacterium calcis,* or other bacteria having a similar action, may have been an important factor in the formation of various chalk strata, in addition to the part played by the shells of Foraminifera and other organisms in the formation of these rocks. Dr. T. Wayland Vaughan has also suggested that the Miami oölite and other oölitic rocks may owe their origin to the occurrence of some diagenic change in the precipitate of very finely divided particles of calcium carbonate produced in this way by bacterial action. If this view as to the formation of chalk and oölite rocks is correct, it would seem probable that these strata must have been deposited in comparatively shallow seas whose temperature approximated to that of tropical seas at the present time. . . . .

As it now stands, the investigation can, at most, be considered to offer a mere indication of the part played by bacterial growth in the metabolism of the sea. To obtain a real insight into the question, it would be necessary to make more extensive bacterial and chemical observations in tropical, temperate, and arctic waters, to study the bacteriology of other areas where calcium carbonate is being precipitated from the sea, and to make further investigations in the laboratory into the chemistry of the reactions that can be brought about by various species of marine bacteria.

Dr. T. Wayland Vaughan in discussing the formation of the Floridian and Bahaman oölites before the Geological Society of Washington said:[2]

The studies of Dall, Sanford, and the author, in association with Geo. C. Matson, led to the opinion that the finely divided calcium carbonate oozes so abundant in Florida waters are chemical precipitates. Drew showed in 1911 that denitrifying bacteria are an important agent in effecting this precipitation in Florida waters; and in 1912 he extended his researches to the Bahamas, where he found them enormously abundant and active, as many as 160,000,000 being found in 1 cc. of surface mud on the west side of Andros Island. Rainey, in 1858, Harting, in 1871, and Linck, in 1903 (and perhaps others), showed that calcium carbonate precipitated by an alkali forms spherulites; and Drew noted a similar tendency of the calcium carbonate precipitated on his cultures. Murray and Irvine showed that at higher temperature chemically precipitated calcium carbonate is of the aragonite form. . . . .

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[1] Papers from the Tortugas Laboratory, Carnegie Institution of Washington, Vol. 5, 1914, p. 44.

[2] Journ. Washington Acad. Sci., Vol. 3, 1913. p. 302-304.

Although there is need for additional study of the factors that accelerate, retard, or inhibit the formation of spherulites and the growth of the grains, the empirical facts in the process of the formation of the Floridian and Bahaman oölites are demonstrated. They are as follows: (1) Denitrifying bacteria are very active in the shoal waters of both regions and are precipitating enormous quantities of calcium carbonate which is largely aragonite; (2) this chemically precipitated calcium carbonate may form spherulites which by accretion may become oölite grains of the usual size, or it may accumulate around a variety of nuclei to build such grains. . . .

Drew's unfortunately incompleted studies of the distribution of denitrifying bacteria have shown them to be the most prevalent in the shoal-waters of the tropics. They therefore conform to the principles enunciated by Murray for the distribution of lime secreting organisms. By combining the results of Drew and Murray, the deduction seems warranted that great limestone formations, whether they be composed of organic or of chemically precipitated calcium carbonate, were laid down in waters of which at least the surface temperatures were warm, if not actually tropical.

Application.—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 algæ. The specimens of algæ are usually magnesian and siliceous which accounts for the weathering in relief, and the ease by which they are brought into relief by the solution of the limestone in weak hydrochloric acid.

The purer limestones are of considerable vertical thickness and their distribution indicates bodies of water several thousand square miles in area. The banks or reefs of algal deposits make a small percentage of the total mass of limestone, but if we assume, as I think we may, that the Bacteria were active agents in the deposition of the soluble bicarbonate of lime in the Algonkian waters, a plausible explanation is found for the occurrence of the homogeneous limestones of the Algonkian in which no traces of fossils have been found. The presence of a well-developed Blue-green algal flora in the Algonkian limestones prepares one for the view that the still more primitive Bacteria were in existence and at work in the epicontinental Algonkian waters.

Dr. Clement Reid in an article on Palæobotany states that:[1]

the first evidence for the existence of Palæozoic Bacteria was obtained in 1879 by Van Tieghem, who found that in silicified vegetable remains from the Coal Measures of St. Étienne the cellulose membranes showed traces of subjection to butyric fermentation such as is produced at the present day by *Bacillus Amylobacter*; he also claimed to have detected the organism itself. Since that time a number of fossil Bacteria, mainly from Palæozoic strata, have been described by Renault, occurring in all kinds of fossilized vegetable and

[1] Ency. Brit., 11th ed., Vol. 20, 1911, p. 525.

animal débris. The supposed *Micrococci* present little that is characteristic; the more definite, rod-like form of the *Bacilli* offers a better means of recognition, though far from an infallible one; in a few cases dark granules, suggestive of endospores, have been found within the rods. On the whole, the occurrence of Bacteria in Palæozoic times—so probable a priori—may be taken as established, though the attempt to discriminate species among them is probably futile.

It may be that traces of bacteria will be found in the Algonkian limestones when the investigations now planned are carried to completion.

The carbonaceous matter in the dark Newland limestones is shown by the black, floculent residue that accumulates when a fragment of limestone is dissolved in hydrochloric acid, and in the field by the bituminous odor given off when the rock is struck with a heavy hammer. The carbonaceous matter of the Bacteria and Algæ was probably the source of that occurring in the limestone.

MAGNESIAN LIMESTONES

The presence of thick deposits of magnesian limestone in the Algonkian, leads to the conclusion that the magnesium content of Algonkian river and epicontinental bodies of water was not far from what it is to-day. Dr. Stuart Weller asks the question, "Are the Fossils of the Dolomites indicative of Shallow, highly Saline and Warm Seas?"[1] He compared the faunas of the dolomitic Galena formation of the upper Mississippi region with that of the Trenton limestone of the eastern or Atlantic region. He concludes that from these comparisons there is

no evidence whatever for concluding that the life conditions in the Galena sea were in any respect different from those of the basins which are now represented by purely calcareous sediments. There is no single characteristic of the fauna which would suggest that the waters were more saline, warmer, or shallower that the seas in which, for instance, the Trenton limestone of the East or the Kimmswick limestone of southern Illinois and Missouri were deposited. It is ordinarily conceded that an intensification of the salinity of sea waters produces a depauperation of the faunas, but the fauna of the Galena is notably composed of the larger and more robust forms, probably because the smaller and more delicate shells have been obliterated by secondary chemical changes in the sediments.[2]

His summary is that,[3]

in conclusion, it may be stated from the evidence of the fossils alone there seems to be no reason for assuming that our widespread dolomitic

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[1] Bull. Geol. Soc. America, Vol. 22, 1911, p. 227.

[2] Idem, pp. 229-230.

[3] Idem, p. 231.

formations of Paleozoic age have been deposited under conditions which are notably different, as regards salinity, temperature, or depth, from those under which non-magnesian formations, either argillaceous or calcareous, have been laid down. Chemical geologists are almost unanimously agreed that in general the dolomitization of limestone is a secondary process, and the paleontological evidence, so far as it is available, seems to substantiate that view. Formations now dolomite were in all probability originally deposited as limestones, and have been altered to dolomites since their original deposition, while other beds entirely similar in original condition have not been modified, but persist to the present time as true limestones.

Thus far my observations have led to practically the same conclusion for the Algonkian and Cambrian magnesian limestones. There was in all probability a small percentage of magnesian salts deposited through the agency of Bacteria and Algæ in the epicontinental Algonkian sediments, but it was a secondary process that produced the limestones with a high percentage of magnesia.

Definition of magnesian limestone and dolomite.—In response to my request Mr. E. F. Burchard, of the United States Geological Survey, sent the following note on magnesian limestone and dolomite. I think it would be well if some such classification of the magnesian rocks could be generally accepted, as the term dolomite has been very loosely used in geologic literature:

Magnesian limestone.—Magnesian limestone is limestone containing magnesium carbonate in any quantity up to 45.65 per cent. The majority of magnesian limestones carry either a small percentage or a high percentage of magnesium carbonate, although there are many deposits that are intermediate in composition.

Dolomite.—Dolomite is a mineral composed of the double carbonate of calcium and magnesium ($CaCO_3 \cdot MgCO_3$). It contains 54.35 per cent $CaCO_3$ and 45.65 per cent $MgCO_3$. In practice, magnesian limestone, containing 20 per cent or more of magnesium carbonate generally has been called dolomite, but it would be preferable if magnesian limestone could be distinguished as "low magnesian" and "high magnesian," restricting the term dolomite to rock containing nearly, if not quite, the theoretical quantity of magnesium carbonate necessary to combine with the calcium carbonate in the proportions given above, or in the ratio of 1 : 1.19. The mineral dolomite in places form rock masses, in which the crystals of dolomite can be distinguished. In some rocks these crystals make up a large proportion of the beds, and on weathering, the rock crumbles to a sand composed of dolomite crystals. Rock and sand of this character are common in southwest Wisconsin near the junction of Wisconsin and Mississippi rivers. The texture of magnesian limestone and so-called dolomite is commonly rather rough and moderately coarse on weathered surfaces.

In the formation of magnesian limestone and dolomite, magnesium carbonate is believed to have replaced calcium carbonate, either while the beds were being deposited in the sea, or after the beds become part of the land surface.

The degree of replacement is variable, and ranges from less than one per cent to 45.65 per cent, although most commonly found to be either low or high. Limestone containing a higher percentage of magnesium carbonate than true dolomite may be termed "super-magnesian" limestones, and if all the calcium carbonate is replaced by magnesium carbonate the rock becomes magnesite. This process of replacement is known as dolomitization, and is accompanied by contraction or shrinkage of about 12.3 per cent[1] of the volume of the original limestone. This contraction is believed to produce porosity in the rock under conditions where the pressure is not sufficiently great to close the pores of the rock.

THE BIOTIC RECORD

The fauna.—The biotic record and character of the Algonkian rocks included in the Grand Canyon, Llano, and Belt series of the Cordilleran region, and in formations correlated with them,[2] prove that the marine waters of the extra-continental seas very rarely had access to the epicontinental seas and lakes in Algonkian time. Such connection appears to have been established in mid-Beltian time when at least a crustacean, and a few annelids penetrated into and became adapted to the conditions of the Montana-Alberta sea, and more or less similar forms to the Arizona sea.[3] Other and different forms may have lived in these and other interior bodies of water, but as yet we have no knowledge of them.

The vertical range of the small Beltian (Algonkian) fauna is limited to a few hundred feet of strata in the Cordilleran area, a fact which tends to demonstrate that the environment was not favorable to its development and survival for any considerable period.

The most satisfactory explanation of the absence of a characteristic marine life in Algonkian deposits is the probability that all the known rocks of Algonkian time are of non-marine origin and hence could not have had the opportunity to embed a marine fauna except as few marine species gained access to the epicontinental seas and quickly disappeared.

The existence of a large and varied marine life (Lipalian) in the extra-continental pre-Cambrian seas is inferred from the occurrence of a highly organized and varied fauna in Lower Cambrian time in both the Cordilleran and Appalachian geosynclines. The worldwide distribution of the Lower Cambrian fauna also indicates the great antiquity of the fauna from which it was derived.

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[1] Van Hise, C. R., A treatise on metamorphism; U. S. Geol. Survey, Monogr. 47, 1904, p. 806.

[2] Bull. U. S. Geol. Survey, No. 350, 1909, pp. 42-46.

[3] Bull. Geol. Soc. America, Vol. 10, 1899, pp. 199-244.

The practically entire absence of the types of the Cambrian fauna from all Algonkian rocks not only on the North American continent but all continents is so significant that it is to me very strong evidence that there was no sustained connection between the great oceans swarming with a highly developed invertebrate life and the epicontinental bodies of water in which the Algonkian limestones and shales were deposited.

The fauna of the Lower ? Huronian of Steeprock Lake, western Ontario, was presumably derived from a marine fauna and possibly lived under brackish-water conditions. The principal species of the Steeprock Lake pre-Cambrian fauna, *Atikokania lawsoni*,[1] is probably a spongoid of a rather advanced stage of development, although it suggests the Archæocyathinæ. We are here given a glimpse of a fauna that existed near the base of the (Algonkian) Proterozoic and which must have had its beginnings in Archeozoic time. It further indicates the presence of a sufficient supply of calcareous matter in this inland water to form its skeleton and also a massive limestone deposit in which its remains now occur. This also implies calcareous beds in the great unknown Lipalian deposits of marine waters on the borders of the continents.

The recognized animal life includes several species of annelids and one large species of crustacean that occur in the Greyson shales just above the Newland limestone. This fauna is illustrated in plates 21 and 22 of this paper. It was described along with doubtful forms from the Grand Canyon series in 1899.[2]

Algal deposits.—The presence of an abundant algal flora is proven by thick layers formed of the remains of *Collenia* (*Cryptozoan*[3] in former reports) in the Grand Canyon section where representatives of the genus occur in limestones separated by 1500 feet (460 m.) of intervening strata. In the Camp Creek section of Montana *Collenia* was found to range up through 2,500 feet (760 m.) of strata.[4]

In the Blackfoot series the vertical range is over 2,800 feet (850 m.). In 4 of the section fine specimens of *Collenia* two feet (0.6 m.) and more in diameter occur in beds 3 feet (1 m.) thick.[5] These and beds near the Lewis and Clark Pass are reefs formed by calcareous algæ.

[1] Appendix to Memoir No. 28, Geol. Survey, Canada, 1912, p. 4.

[2] Bull. Geol. Soc. America, Vol. 10, 1899, pp. 232-239.

[3] I do not know a true Cryptozoön older than the Cambrian fauna.

[4] Bull. Geol. Soc. America, Vol. 17, 1906, pp. 4-5.

[5] Idem, p. 6.

The Newland limestone of the Belt series is about 2,000 feet (630 m.) in thickness and the algal forms are reported by Collen as occurring in it from base to summit. These include *Newlandia, Greysonia, Camasia,* etc. *Collenia* is abundant in the Spokane shales 3,000 to 4,000 feet (960 to 1200 m.) above the Newland limestone.

The preceding examples prove that the algal forms extend through several thousand feet of strata and that they are so abundant as to form reefs or banks of fossil algæ in the section.

Stratigraphic position.—As the principal groups of fossils occur in the Beltian series of formations the typical section is introduced here and the position of the genera indicated as they occur in the several formations. The section is one obtained during a reconnaissance of the Belt Mountains in 1898. The thickness assigned to the various formations is based on fairly careful reconnaissance estimates.[1]

SECTION OF BELT SERIES

Cambrian—Flathead sandstone.

	Feet	
Unconformity		
Marsh shales	300	
Helena limestone	2,400	
Empire shales	600	
Spokane shales	1,500	*Collenia undosa*
Greyson shales	3,000	*Annelid trails,* 5 spp. *Beltina danai*
Newland limestone	2,000	*Newlandia concentrica* *Newlandia frondosa* *Newlandia lamellosa* *Newlandia major* *Camasia spongiosa* *Weedia tuberosa* *Kinneyia simulans* *Greysonia basaltica* *Copperia tubiformis*
Chamberlain shales	1,500	
Neihart sandstone	700	
	12,000	

Unconformity

Archean complex

[1] Bull. Geol. Soc. America, Vol. 10, 1899, pp. 201-215.

The fauna of the Greyson shales occurs toward the base of the formation. *Collenia undosa* is found at many horizons in the Spokane shales, and the Newland limestone algæ are reported by Mr. M. Collen to occur throughout the section of that formation on the eastern slope of the Big Belt Mountains.

THE ALGAL FLORA

The algal flora of the Algonkian and the *Cryptozoon*-like species from the Cambrian and later formations are now considered to have been deposited through the agency of algæ similar in type and activity to the (Cyanophyceæ) Blue-green Algæ. No traces have been seen of the fine stems of the algæ but single cells and strings of cells have been found with a magnification of 260 diameters.

In the fresh-water lakes of the present time the Blue-green algæ form a thin felt-like layer over some object either minute or large as the case may be. As the under side of this layer dies the outer surface sends the delicate slender stems out into the water until these in turn become twisted and matted together and added to the inner layer. If there is bicarbonate of lime or magnesia in the water a portion is taken up by the algæ and deposited in the laboratory existing in the matted portion of the inner layer and added to the thin layer of calcareous matter. The result is shown in sections of " Lake Balls " illustrated by the figures on plate 4. Some genera and species of the algæ build up concentric forms like those shown on plate 4, while others build up sponge-like masses that form solid beds along the shore or in shallow portions of the lake (pl. 4, fig. 4).

The examination of a large series of the Algonkian and Cambrian algæ illustrated in this paper fails to disclose any traces of internal structure (except miroscopic cells) such as occurs in most of the marine algæ (Corallinaceæ, Characea, etc.), but nearly all have a distinct structure resulting from the deposition of calcium carbonate in certain definite forms. This may be the simple concentric lamination of *Collenia* (pl. 13), the more complicated *Newlandia* (pl. 6), or the elongate cellular pipe-like *Greysonia* (pl. 17).

Comparison of recent Blue-green algæ deposits and those of Algonkian time.—On comparing the sections of the " Water Biscuit " (pl. 4) with sections of *Collenia* (pl. 13) from the Spokane shales of the Belt series of Montana, a striking similarity in their structure is seen. Both are formed of concentric laminations without any apparent structural connection between them as the interspaces are filled in with irregular granulations without any particular method of arrangement.

The mode of growth of the recent and ancient forms has many points in common. The "Water Biscuit" are found on the muddy or sandy lake-bottom; in some places quite abundant and in others more scattered. The specimens of *Collenia* from the Spokane shales occur embedded in a very fine arenaceous shale, sometimes in great numbers. That they were formed on the muddy bottom of a body of water which was shallow, is shown by the presence of ripple marks and sun cracks at various horizons in the shales. The specimens of *Collenia* vary in size from the size of a mustard seed up to a foot or more in diameter, and usually occur with the flattened or hollow side downward. They may be scattered about singly or in groups or attached to each other so as to form a mass of calcareous nodules.

There is considerable siliceous matter occurring in the laminations of *Collenia* and also dolomitic partings between the laminations of growth although all openings in the original specimen are now filled with a dark bluish-gray limestone.

Another case of resemblance between a deposit made by Blue-green algæ and the Algonkian fossil algæ is seen by comparing a section of a fragment of a large deposit in a fresh-water lake in Michigan (pl. 4, fig. 4) with a section from the Belt terrane that I have named *Camasia spongiosa* (pl. 12).

From the fact that the recent laminated lake balls and layer deposits were largely deposited through the agency of Blue-green algæ, it is probable that the same simple types of algæ were the active agents in depositing the forms described in this paper under the generic names of *Collenia, Newlandia, Camasia, Kinneyia, Weedia, Greysonia,* and *Copperia.* The finding of single cells and chains of cells with *Camasia spongiosa* is a most important factor in establishing the presence of the (Cyanophyceæ) Blue-green algæ-like forms in connection with the Algonkian forms listed above.

Mode of growth.—In the absence of sticks of wood, stones and other solid objects upon which to start their growth, as do the modern Blue-green algæ, the Algonkian forms evidently started and built up their structures on bits of hardened mud and often on fragments of algal deposit broken up by current or wave action. Most of the forms spread out along the surface of the muddy bottom until they were buried beneath an influx of ooze or mud that filled all the cavities and channels in the algal deposits. In the Newland limestone specimens the filler was a fine calcareous mud, and in those from the Spokane shale an argillaceous mud. One of the undecided questions is the stopping of growth at the top of each layer of limestone. Why some of the stronger forms did not extend above the level top surface of the layer in which they are found, it is difficult to conjecture. It may be that a strong current swept away the smaller pieces and filled in the interspaces among the larger forms. It is planned to give attention during the field season of 1914 to the occurrence of the large masses in the Newland limestone with special reference to their mode of growth.

Mineral composition.—A compact specimen of *Camasia spongiosa* with very small opening into which the calcareous mud could penetrate gave the following result as determined by Dr. Edgar T. Wherry of the United States National Museum:

Oxides	
CaO	40.52
MgO	1.15
$CO_2 + H_2O$	33.38
$Fe_2O_3 + Al_2O_3$	3.72
SiO_2	21.08
	99.85

An analysis of a second specimen from which the calcareous matter deposited within the cellular openings had been removed by solution in hydrochloric acid gave the following:

Oxides	
CaO	10.88
MgO	0.27
$CO_2 + H_2O$	10.20
$Fe_2O_3 + Al_2O_3$	10.22
SiO_2	68.32
	99.89

The second analysis may be taken as indicating the present mineral composition of the deposit made by the algæ. What its original composition was cannot well be determined as there has evidently been a large replacement by silica unless there was some unrecognized siliceous sponge associated with it that furnished the silicia.

Microscopic structure.—Being fairly well convinced from the comparison of "Lake Balls" and other recent massive calcareous fresh water deposits with *Newlandia, Camasia, Collenia* and *Cryptozoon,* that water plants similar to the Blue-green algæ were the agents that built up the fossil algal flora of the Algonkian, I asked my friend Dr. Albert Mann, the microscopist, if he would not study thin sections of the rock in which the specimens occur, also the residual mud resulting from the dissolving of the algal limestone by hydrochloric acid. He very kindly consented, and soon found in the residual material many single cells and groups of cells such as occur in the recent Chroococcaceæ (pl. 20, fig. 5) and rows of cells similar to those of the recent Nostocaceæ.

A row or chain of cells derived from *Camasia spongiosa* is shown by figures 2-4, plate 20. Figure 4 is from an untouched photograph (x 350). Owing to the chain or filament not being in the same plane from end to end many of the cells are not in focus in figure 4. In order to correct this the entire series of cells have been outlined in figure 2, and in figure 3 this is further enlarged so as to show the outline of the cells. The same conditions exist in a chain of cells in a filament of a recent Blue-green alga, *Schizothrix,* from the surface of a calcareous deposit in Green Lake, New York. Figure 8 is from an untouched photograph, and figure 8*a* shows the full length of the chain. The chain represented by figures 2-4 is embedded in a very thin plate of opal-like silica.

Figure 5 represents a cluster of round cells (x 350) with their outline strengthened, and figure 5*a* as they appear in the untouched photograph. A group of longitudinally arranged cells is shown by figure 6*a,* and in the untouched photograph represented by figure 6. A group or chain of cells of a recent, calcareous depositing Blue-green alga is shown by figure 7 (x 1,200). This may be compared with figure 3 from *Camasia spongiosa* of the Newland limestone.

A number of very thin opal-like siliceous plates show minute tubes such as are illustrated by figure 1. These appear to be of organic origin and may represent minute tubes similar to those found in some genera of Blue-green algæ.

Bacteria.—Although the existence of Bacteria in Algonkian time has not been demonstrated from the observations already given (pp. 92-94) ; it is quite probable that the Bacteria were a most important factor in the deposition of the Algonkian limestones.

Classification.—For the purpose of grouping the various forms of the algal flora of the Algonkian the following classification is made from external form.

Massive—Cellular—*Camasia spongiosa*

Semisphærical	*Cryptozoon* and its allies ? *Newlandia concentrica* *Weedia tuberosa* *Collenia undosa* *Collenia compacta*
Flabelliform	*Newlandia frondosa* *Newlandia lamellosa* *Newlandia major* *Kinneyia simulans*
Tubiform	*Greysonia basaltica* *Copperia tubiformis*

All of the genera and species are based on the variation in form, as it is impossible with the data now available to determine the genera or species of the Cyanophyceæ that built up the widely differing forms described in this paper. They all agree in not having the structure of the higher algæ, Corallinaceæ, etc. All appear to have been deposited as successive layers, the inner and older layers serving as a foundation on which the younger filaments grew in variously arranged forms. In the absence of the identification of the actual algæ that built up the structure found in the fossil state, a purely artificial classification has been adopted that includes a number of new generic and specific names as given above.

DESCRIPTION OF GENERA AND SPECIES

NEWLANDIA, new genus

More or less irregular semispherical or frondlike forms built up of concentric, subparallel, subequidistant thin layers that may be connected by very irregular, broken partitions.

Genotype.—*Newlandia frondosa,* new species.

Stratigraphic range.—Lower portion of Newland limestone.

Geographic distribution.—Eastern slope of Big Belt Mountains, Montana.

Observations.—The compact, semispherical forms of *Newlandia* have regular concentric laminations that recall the laminated structure of some forms of *Collenia* and *Cryptozoon*. They differ in having more regular and broader interspaces devoid of the fine laminations so characteristic of *Cryptozoon*. It is not improbable that *Newlandia concentrica* (pl. 5, figs. 2, 3) may ultimately be found to be identical with the concentric forms of *N. frondosa* (pl. 5, fig. 4; pl. 6, figs. 1, 2; pl. 7), but with the specimens now available for study the semispherical forms are considered as representing a distinct species. *Newlandia frondosa* (pl. 6) illustrates both the laminated and coarsely cellular form of growth. Some of its fronds are two feet (60 cm.) or more in diameter with a thickness of 4 inches (10 cm.) or more.

The species referred to *Newlandia* are:

Newlandia concentrica Walcott (pl. 5, figs. 2, 3)
Newlandia frondosa Walcott (pl. 5, fig. 4; pls. 6-8)
Newlandia lamellosa Walcott (pl. 10, figs. 1, 2)
Newlandia major Walcott (pl. 9, fig. 3)

NEWLANDIA CONCENTRICA, new species

Plate 5, figs. 2, 3

Semisphærical bodies, built up of concentric layers of irregular thickness that appear to be attached at the base of each cup-shaped concentric layer, and also by irregular projections from the surface of the layers. The layers are perforated to a greater or less extent by irregularly shaped and located small openings. The thickness of the layers varies from 0.5 cm. or less to 2 or 3 mm. The largest individual specimen has a transverse diameter of 9 cm. with a depth of 1.5 cm. A smaller specimen has a depth of 3 cm. These measurements are not very important as the specimens have evidently been somewhat crushed down.

Observations.—The concentric form of growth of this species is much like the concentrically arranged layers of the nucleus of some of the specimens of *N. frondosa.* It differs in having interspaces between the layers and in its more regular form.

The growth appears to have been about a nucleus around the base of which successive layers were built up. It is anticipated that future collections will afford the material for a more detailed description.

Formation and Locality.—(400c) Algonkian, Beltian series; Newland limestone; eastern slope of Big Belt Mountains, 8 miles (12.8 km.) west of White Sulphur Springs, at forks of Birch Creek, Meagher County, Montana.

NEWLANDIA FRONDOSA, new species

Plate 5, fig. 4; plate 6, figs. 1-3; plate 7, figs. 1, 2; plate 8, figs. 1-3

Large frond-like forms built up of thin layers that may have a laminated arrangement (pl. 7) or a combined coarse cellular and laminated structure (pl. 6). The large fronds appear to have started from a central section and increased in size by the addition of thin layers that are more or less parallel to each other. The number of layers may also increase by intercalating layers that are attached at their points of origin to one of the adjoining layers. The lower side of the frond-like forms usually has an irregular skin-like layer that served as a base for the coarse, sponge-like and laminated growth above. The additions to the base and to the body above were made in more or less irregular, concentric lines. An imperfect series of connecting radial structure is shown by figs. 1 and 2, plate 7, and fig. 1, plate 8.

How the various forms grew by accretion and why their upward growth was limited is discussed in the introduction under Mode of Growth (p. 101).

Specimens of this form attain a large size. Some in the collection indicate a diameter for the entire body of from 2 to 3 feet (60 to 80 cm.) with a thickness of 4 inches (10 cm.) or more.

Formation and locality.—(400c) Algonkian, Beltian series: Newland limestone; eastern slope of Big Belt Mountains, 8 miles (12.8 km.) west of White Sulphur Springs, at forks of Birch Creek, Meagher County, Montana.

NEWLANDIA LAMELLOSA, new species

Plate 10, figs. 1, 2

Layers forming the body and interspaces much narrower and more regular than those of *N. frondosa*. The form of growth in flat, frond-like bodies was much like that of *N. frondosa*. The largest fragment in the collection has a length of 23 cm. and a thickness of 3.5 cm.

This form differs from *Kinneyia simulans* in the greater regularity of its layers, and from other species of *Newlandia* by the fine, closely arranged layers.

Formation and locality.—(400c) Algonkian, Beltian series: Newland limestone; eastern slope of Big Belt Mountains, 8 miles (12.8 km.) west of White Sulphur Springs, at forks of Birch Creek, Meagher County, Montana.

NEWLANDIA MAJOR, new species

Plate 9, fig. 3

This species is founded on a fragment of a large frond-like body. It has a length of 27 cm. and a depth of 8 cm. The layers forming the body are very thin and separated by interspaces much wider than in other species. The two fragments known indicate a greater diameter and thickness than for any other species of the genus.

Formation and locality.—(400c) Algonkian, Beltian series: Newland limestone; eastern slope of Big Belt Mountains, 8 miles (12.8 km.) west of White Sulphur Springs, at forks of Birch Creek, Meagher County, Montana.

KINNEYIA, new genus

Body built up of thin, subparallel layers separated by narrow intervals that are not much greater than the thickness of the layers forming the body.

This form differs from *Newlandia* in its finely laminated arrangement of its layers and interspaces and the marked bifurcation of the layers forming the body.

Genotype.—Kinneyia simulans, new species.

As far as known the geographic distribution and the stratigraphic range are the same as for *Newlandia*.

KINNEYIA SIMULANS, new species

Plate 11, fig. 3

There are several specimens of this species that have the characters shown by fig. 3, of plate 11, which is the upper etched surface of a block 22 mm. in thickness down through which the layers forming the body extend almost vertically. The layers of some of the specimens are a little coarser than those represented by fig. 3, plate 11, but they have the same character.

The mode of growth was probably much like that of *Newlandia frondosa.*

Formation and locality.—(400c) Algonkian, Beltian series: Newland limestone; eastern slope of Big Belt Mountains, 8 miles (12.8 km.) west of White Sulphur Mountains, at forks of Birch Creek, Meagher County, Montana.

WEEDIA, new genus

Irregular, encrusting, and solid deposits that gathered as tubercles, ridges, and many irregular forms on the bed of the body of water in which the algæ forming them lived. The specimens suggest a secondary siliceous deposit in the limestones, but the concentric laminated structure of the tubercles points more strongly to an origin similar to that of the encrustations made through the agency of the Blue-green algæ (Cyanophyceæ).

Genotype.—*Weedia tuberosa*, new species.

Stratigraphic range.—Upper part of the Altyn limestone series interbedded with siliceous and cherty layers.

Geographic distribution.—Above Gunsight Pass, Glacier National Park, Montana. This will probably be found to be a widely distributed form in the Algonkian formations. Heretofore such forms have been passed over as of concretionary origin or as of secondary siliceous deposits.

Observations.—The generic name is given in recognition of the work of Dr. Walter H. Weed among the Algonkian formations of the Belt Mountains of Montana.

WEEDIA TUBEROSA, new species

Plate 11, figs. 1, 2

The external characters of this species are well shown by figure 2, plate 11. Also the structure of the tubercles as they have been cut into by erosion so as to expose the irregular laminations and in figure 1 the hollow interior, a feature so often seen in recent "Lake Balls," plate 4. The main portion of the specimens represented by figure 2 is a thin encrustation on the upper surface of a layer of limestone.

Formation and locality.—(**400**) Algonkian: Siyeh limestone; above Lake McDonald, south side of Gunsight Pass, Glacial National Park, Montana.

GREYSONIA, new genus

Irregular, cylindrical or tubular growth with relatively thin walls except at the union of three or more tubes, where the walls are thickened as shown by figure 2, plate 17, and figure 1, plate 18. The tubes are large, irregularly rhomboidal or pentagonal in section with the interior now filled in with a dark bluish-grey limestone. The walls or partitions represent the deposit made by the algæ and are now a buff-colored and grey magnesian limestone.

The ends of a group of the tubes filled in with the limestone appear like a group of miniature basaltic columns (pl. 17, fig. 2), and the base or lower side of the same tubes has irregularly oval and round, concentrically marked forms that appear to be the filling of the ends of the tubes. The walls of the tubes surrounding the ovals and the basal ends are shown by figure 2, plate 18, and the broken upper ends by figure 2, plate 17. The walls are arranged in echelon and the fillings break out as plates of columns (fig. 1, pl. 17).

Mode of growth.—As far as indicated by the specimens collected by Mr. M. Collen the cellular structure grew with the tubes more or less parallel to the bottom and in some instances upright or at right angles to the bottom. The section illustrated by figure 1, plate 18, shows that it was formed of four rows of tubes parallel to the under and upper surface of the layer of limestone. The specimen represented in part by figure 2, plate 17, and figure 1, plate 18, is 36 cm. in length, with a depth of 18 cm. It has 12 rows of tubes, and it is evidently part of a much larger mass. The tubes vary from 1 to 2 cm. in diameter.

Genotype.—*Greysonia basaltica*, new species.

Stratigraphic range.—Lower portion of Newland limestone.

Geographic distribution.—Eastern slope of Big Belt Mountains, Montana.

Observations.—It is difficult to conceive of the tubular structure of *Greysonia* as a deposit made by algæ, but with the example of the varied forms of recent deposits made by the Blue-green algæ (Cyanophyceæ) and the other fossil forms described in this paper we are prepared to consider *Greysonia* as of algal origin. There is evidently much yet to be learned of its mode of growth, but that is a matter of further field study.

GREYSONIA BASALTICA, new species

Plate 17, figs. 1, 2; plate 18, figs. 1, 2

The generic description contains what is known of this species from the material now in the collection.

Formation and locality.—(400c) Algonkian, Beltian series: Newland limestone; eastern slope of Big Belt Mountains, 8 miles (12.8 km.) west of White Sulphur Springs, at forks of Birch Creek, Meagher County, Montana.

COPPERIA, new genus

A tubular structure formed of thin partition walls that are thickened at the junction of three or more tubes. The tubes are in echelon arrangement and break out in plates as shown by figure 2, plate 19.

In the specimen illustrated by figure 3, plate 19, the four lower layers of tubes were formed in a horizontal position and above them the growth was irregular, the tubes curving and also bending up to the surface of the layer.

The tubes are nearly circular in outline and probably grew in a large frond on the bed of the body of water in which the algæ lived. The tubes are now filled with dark greyish-blue limestone.

Genotype.—*Copperia tubiformis,* new species.

Stratigraphic range.—Lower portion of Newland limestone

Geographic distribution.—Eastern slope of Big Belt Mountains, Montana.

Observations.—At first I was inclined to place this form under *Greysonia,* but from the form of the tubes and the irregular habit of growth concluded to give it a distinct generic designation.

COPPERIA TUBIFORMIS, new species

Plate 19, figs. 1-3

The principal characters of the species are given under the generic description. The largest fragment in the collection has a length of 15 cm. The tubes are from 7 to 10 mm. in diameter and the thickness of the layer made up of layers of the tubes is 6 cm.

Formation and locality.—(400c) Algonkian, Beltian series: Newland limestone; eastern slope of Big Belt Mountains, 8 miles (12.8 km.) west of White Sulphur Springs, at forks of Birch Creek, Meagher County, Montana.

COLLENIA, new genus

More or less irregular dome-shaped, turbinate or massive, laminated bodies that grew with the arched surface uppermost. The growth appears to have been by the addition of external layers or lamellæ of varying thickness with interspaces that vary greatly even in the same specimen.

Genotype.—*Collenia undosa,* new species.

Stratigraphic range.—The type species occurs in the Spokane shales of the Big Belt series of Montana.

Collenia compacta, new species, is from the Siyeh limestone and several thousand feet above the horizon of *Collenia undosa.*

Collenia occidentale (Dawson) is from the Chuar terrane of the Grand Canyon, where it ranges through 1,500 feet (460 m.) of strata.

Geographic distribution.—Eastern slope of the Big Belt Mountains, south of White Sulphur Springs, Meagher County, Montana. Gunsight Pass, Glacial National Park, Montana. Chuar Valley in the Grand Canyon, Arizona.

Observations.—The resemblance between the structure of *Collenia* and *Cryptozoon* Hall[1] is marked in hand specimens as may be seen by comparing illustrations of the two forms. Both have a laminated appearance in sections, the concentric lamellæ varying in thickness and in the width of their interspaces, but when we compare the mode of growth we find that *Collenia* has an encrusting-like growth that forms a dome-shaped body with the edges of the lamellæ pointing downward (pl. 13, fig. 1), while *Cryptozoon* grows in a cup-shaped form with the edges of the lamellæ on the upper surface (pl. 16).

Specimens of *Collenia* are usually small, although they attain a diameter of 12 inches (32.7 cm.) or more.

The *Collenia*-like turbinate form that I found in the Algonkian series of the Grand Canyon in 1882, and sent to Sir William Dawson in 1897, had the same manner of growth as *Collenia undosa* except that owing to its being crowded together it grew to a greater height from a narrow base (pl. 15, figs. 5, 6).

Collenia compacta (pl. 15, fig. 7) grew in part like *C. occidentale,* but it also developed a laminated growth that filled the interspaces between the more individual club-shaped forms.

The species now referred to *Collenia* from the Algonkian group are:

Collenia compacta Walcott (pl. 15, fig. 7)
Collenia ? frequens (Walcott)[2] (pl. 10, fig. 3)
Collenia occidentale (Dawson) (pl. 15, figs. 1-6)
Collenia undosa Walcott (pl. 13, figs. 1, 2; pl. 14, figs. 1, 2)
Collenia ? sp. undt.

Dr. J. G. Bornemann described under the name *Zonatrichites* an algal form from the Mesozoic rocks as follows:[3]

> A calcareous alga, with radially arranged filaments, forming hemispherical or kidney-shaped layers, growing on or enclosing other bodies. Parallel or concentric zones are seen in cross-section, formed by the periodic growth of the alga, the older and dead layers serving as a foundation on which the young filaments grow in radially arranged groups.

Mr. A. C. Seward comments upon the form as follows:[4]

> The nodules which are apparently formed by species of this genus occur in various sizes and shapes; Bornemann describes one hemispherical mass 8

[1] Thirty-second Ann. Rept., New York State Mus., Nat. Hist., 1883, Description of pl. 6.

[2] Bull. Geol. Soc. America, Vol. 17, 1906, pl. 11.

[3] Geologische Algenstudien, Jahrb. k. preuss. geol. Landesanst. Berkakad., 1886, p. 126, pls. 5 and 6.

[4] Fossil Plant, Cambridge Press, Vol. 1, 1898, pp. 129, 130.

cm. broad and 4 cm. thick. In some cases the organism has given rise to oölitic spherules, which in radial section exhibit the branched tubular cells spreading in fan-shaped groups from the centre of the oölitic grain. The section parallel to the surface of a nodule presents the appearance of a number of circular or elliptical tubes cut across transversely or more or less obliquely. The resemblance between the fossil and a specimen of the recent species *Zonatrichia calcivora* Braun, is certainly very close, but it is very difficult, in the absence of material exhibiting more detailed structure than is shown in the specimens described by Bornemann, to decide with any certainty the true position of the fossil. The figures do not enable us to recognize any trace of cells in the radiating tubes. It is possible that we have in *Zonatrichites* an example of a Cyanophyceous genus in which only the sheaths of the filaments have been preserved. In any case it is probable that this Mesozoic species affords another instance of a fossil alga which has been responsible for certain oölitic or other structures in limestone rocks.

I refer to *Zonatrichites* as in external form and section it closely resembles *Collenia*.

Dr. A. C. Peale, in describing the limestones of the lower part of the Algonkian section as exposed at the south end of the Madison Range, Montana, on the south side of the Gallatin Valley, mentions the occurrence of so-called concretions that had been mistaken for fossil turtles by the people living in the region.[1] He describes the concretions as very large, often measuring several feet in diameter and from 6 to 12 inches (15 to 30 cm.) in thickness, averaging about 6 inches to a foot in diameter, with a thickness of only 3 to 4 inches (7.5 to 10 cm.).

The above description strongly suggests that the so-called concretions are a form of *Collenia*, or possibly *Cryptozoon*. It is anticipated that the locality will be visited, and study made of their occurrence and character, during the season of 1914 (pp. 116-117).

COLLENIA COMPACTA, new species

Plate 15, fig. 7

This species has a turbinate growth, also in the solid layers of limestone a massive laminated growth that is irregular and compact. The two forms of growth are well shown by plate 15, figure 7. The finer lamellæ occur in bands outlined by coarser lamellæ.

Where the specimens in the collection were found they occurred in a layer 9 cm. thick. The layer appeared to be made up of the turbinate forms and intervening laminations and broken fragments.

[1] Bull. U. S. Geol. Survey, No. 110, 1893, p. 17.

Formation and locality.—Algonkian: (400a) Siyeh limestone; Continental Divide at head of Kipps Creek, a branch of Mineral Creek, east of Flat-top Mountain, Glacial National Park, Montana (C. D. Walcott, 1908).

COLLENIA ? FREQUENS (Walcott)

Plate 10, fig. 3

Cryptozoan frequens Walcott, 1906, Bull. Geol. Soc. America, Vol. 17, pl. 11. (Species figured.)

This form has an upright, irregular cylindrical growth, that appears like paving blocks fitted closely together. The individual bodies vary from 2 inches (5 cm.) in diameter up to 15 inches (38 cm.) or more. In the great limestone block illustrated the depth of the cylindrical growth is about 16 inches (43 cm.).

I hope to obtain during the season of 1914 much more information about this form.

Formation and locality.—Algonkian: Siyeh limestone; Little Kootna Creek, Chief Mountain quadrangle, Montana.

COLLENIA UNDOSA, new species

Plate 13, figs. 1, 2; plate 14, figs. 1, 2

More or less irregularly dome-shaped, semisphæroidal, sometimes roughly sphæroidal, laminated bodies that are usually roughly concavo-convex. They appear very much as though the under side had been dug out or that the first encrusting calcareous deposit was made over a lump of mud. The interior of the body is made up of alternating fine and coarse laminations subparallel to the upper and lower surfaces of the body.

Individual specimens occur scattered in reddish silico-argillaceous shale and sometimes in groups of irregular forms as shown by figures 1 and 2, plate 14. In some instances thin layers of somewhat siliceous or magnesian limestone are nearly filled with broken and more or less entire specimens, as shown by figure 1 on plate 13. In sections of the roughly sphæroidal forms it appears as though a high dome-shaped specimen had been rolled over during growth and a new growth started that covered the hollow under side so as to enclose fragments of other specimens in the interior of the mass (pl. 13, fig. 2).

The outer surface is often botryoidal as indicated by the structure in the upper part of the section illustrated by figure 2, plate 13. The greater number of specimens are from 3 to 4 inches (7.6

to 10 cm.) in diameter, but some are a foot (32.7 cm.) or more across.

Formation and locality.—Algonkian: (400b) Beltian series; Spokane shales; 8 miles (12.8 km.) west of White Sulphur Springs at forks of Birch Creek, Meagher County, Montana (M. Collen, 1906).

COLLENIA ? species undetermined

The late Professor N. H. Winchell recently sent me, a few days before his death, photographs of a specimen that suggests *Collenia*. It is made up of 28 vertical columnar bodies which show on the top a roughly hexagonal section. Their average size is about 1 cm. The columns are made up of concentric lamellæ, somewhat like those of *Atikokania* from the Steeprock series in Canada.

I have not seen the specimen nor is its origin known. It was found in a ballast gravel of the railroad that came from glacial drift, near St. Paul, Minnesota.

ARCHÆOZOAN ACADIENSE Matthew

Archæozoan acadiense Matthew, 1901, Bull. Nat. Hist. Soc., New Brunswick, No. 9, Presidential Address, p. 32; also pp. 38-41.

Dr. G. F. Matthew describes a "reef of limestone" of pre-Cambrian age containing numerous fragments of a concretionary structure which he regarded as of organic origin. He says:[1]

> The reef began its growth on a bottom of fine sand, now converted into a quartzite rock which forms an important member of the Upper Series. There the objects consist of a multitude of small, short, closely-set columns, which grew tier upon tier, with, at first, more or less of sand between the tiers.
>
> It may be observed also that these crowded clusters of columns were often cut off over considerable areas, by thin horizontal layers of mineral matter, perhaps indicative of the incursion of sand or other sediment, but the growth was almost immediately renewed by a new set of columns, occupying the fresh surface of mud that covered the old ones. . . . .
>
> This reef of calcareous columns was about one hundred and fifty feet deep. . . . .

He compares these forms with *Eozoan canadense*. The mode of growth also suggests *Collenia occidentale* and *C. compacta*. I hope to have specimens for study in the fall of 1914 that will possibly determine the origin of these problematical fossils. My present impression is that they are of algal origin.

Formation and locality.—"Laurentian" limestone: St. John River, near St. John, New Brunswick.

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[1] Bull. Nat. Hist. Soc., New Brunswick, No. 9, 1901, pp. 38, 39.

CAMASIA, new genus

Compact layer-like growth with numerous irregular tube-like openings that give a spongoid appearance in cross sections of the tubes (pl. 12, figs. 1 and 2). The openings or tubes are smallest at the base, increasing inside toward the summit of the layer. In the specimen illustrated by figure 2, plate 9, they are very small and all are inclined in one general direction. In another large specimen (pl. 12, fig. 2) the irregular tubes and openings extend obliquely to the left about one-third of the way and then very irregularly in an oblique direction to the right to near the top of the layer.

A row or chain of cells derived from *Camasia spongiosa* is shown by figures 2-4, plate 20, and a cluster of round cells by figure 5. These cells are of essentially the same character as those found in the filaments of the recent Blue-green Algæ.

Genotype.—*Camasia spongiosa,* new species.

Stratigraphic range.—Lower portion of Newland limestone.

Geographic distribution.—Eastern slope of Big Belt Mountains, Montana.

Observations.—As far as now known this species is represented by one species that forms layers varying in thickness and extent. The largest specimen in the collection has a thickness of 7 cm., with a length of 21 cm. It is apparently a fragment of a large mass that extended over a much larger area.

The microscopic cells illustrated on plate 20 were obtained by treating the specimen with hydrochloric acid and examining the residual matter. All of the chains of cells thus far seen occur in thin opal-like plates such as are found abundantly in the recent calcareous lake deposits formed by Blue-green Algæ.

The only species yet referred to the genus is *Camasia spongiosa.*

CAMASIA SPONGIOSA, new species

Plate 9, figs. 1, 2; plate 12, figs. 1, 2; plate 20, figs. 2-6, 6*a*

The general form of this species is shown by the illustrations on plates 9 and 12. It resembles in some respects the recent growth deposited by Blue-green Algæ as represented by figure 4 on plate 4.

It evidently grew in extended masses on the bottom. The few specimens in the collection are only fragments, and none of them show indications of having come from near the outer margin of the mass of which they formed a part.

The microscopic structure is referred to on page 103 and illustrated on plate 20, figures 2-6.

An attempt will be made during the field season of 1914 to discover the mode of growth and the extent of this species. It is unusually interesting owing to its resemblance to the deposit made by the Blue-green Algæ in the fresh-water lakes of New York, Michigan, and elsewhere.

Formation and locality.—Algonkian: (400c) Beltian series: Newland limestone; 8 miles (12.8 km.) west of White Sulphur Springs at forks of Birch Creek, Meagher County, Montana (M. Collen, 1906.)

GALLATINIA, new genus

As there is but one species of the genus known the generic and specific description is united for the present in the description of the species.

Genotype.—*Gallatinia pertexa*, new species.

Stratigraphic range.—As far as known it is limited to a few layers of limestone in the central portion of the Algonkian section of the Gallatin Valley.

Geographic distribution.—North side of Gallatin and East Gallatin Rivers, between Gallatin Station and Dry Creek, Gallatin County, Montana.

GALLATINIA PERTEXA, new species

Plate 23, figs. 1, 2

External form discoid, circular, flattened. In a specimen 21 cm. in diameter there is an outer border about 3 cm. in width and 4 cm. in depth that extends from the base to the upper surface of the specimen. This outer ring is united to the center by seven ray-like arms arranged in a more or less irregular manner. The outer border ring is formed of fine, irregular lamellæ that slope inward more or less from the base to the upper surface. The radiating arms are formed of a series of V-shaped lamellæ that extend down into the mass of the specimen a distance equal to about their width at their upper surface. The border ring and arms are connected by a mass of vesicular lamellæ that fill the interior of the specimen. At the upper surface between the radiating arms the vesicular lamellæ form more or less concentric lines about the center.

The photographs of the specimen show the details of structure fairly well.

The specimen is formed of a siliceous, buff-weathering material with a filling in all interspaces of dark, bluish-gray limestone that is readily removed in solution by weak hydrochloric acid.

Observations.—Recently when reading an account by Dr. A. C. Peale of the pre-Cambrian rocks of the region between the Missouri River and Dry Creek, a tributary of the East Gallatin River, Gallatin County, Montana, I noted that he described the occurrence of numerous flattened concretions in an Algonkian limestone[1] which the people in the vicinity called fossil turtles. On inquiring of Dr. Peale he told me that there was a specimen in the United States National Museum. Upon examining it there was very little to indicate that it was more than an ordinary septaria-like concretion. Cutting a cross section on one side and treating it with acid the wonderful interior and exterior structure was developed that is shown in the accompanying illustrations. Dr. Peale states that the "concretions" measure several feet in diameter and from 6 to 12 inches (15.4 to 31 cm.) in thickness, and that they occur in a limestone.

An examination of the residual sediment resulting from dissolving some of the limestone matrix shows microscopic cells much like those found with *Cryptozoon* and *Collenia*.

I anticipate visiting the locality where Dr. Peale collected the specimen described and hope to be able to give a much fuller account of the occurrence and character of this remarkable addition to the Algonkian algal flora.

Formation and locality.—Algonkian: (400j) Belt terrane; north side of Gallatin and East Gallatin Rivers, north of Bartons Bridge, west of Hillsdale Postoffice, Gallatin County, Montana (A. C. Peale, 1885).

After this paper was in page proof I received from Dr. G. R. Wieland a copy of his paper on "Further Notes on Ozarkian Seaweeds and Oölites"[2] in which he discusses the various forms that have been referred to *Cryptozoon*. This important contribution to the subject of fossil algæ will be referred to in any future study I may make of the pre-Cambrian fossil algæ.

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[1] Bull. U. S. Geol. Survey, No. 110, 1893, p. 17.

[2] Bull. American Museum Nat. Hist., Vol. 33, pp. 237-260.

DESCRIPTION OF PLATE 4

PAGE

Lake Balls formed by Blue-green algæ. (See pl. 5) 100

Fig. 1. (× 2.) Exterior surface of pear-shaped specimen. U. S. National Museum, Catalogue No. 60690.

2. (× 2.) Transverse section of an ovel-shaped ball, showing concentrically laminated structure. U. S. National Museum Catalogue No. 60691.

These lake balls were in the process of formation by filamentous algæ when taken from the lake.

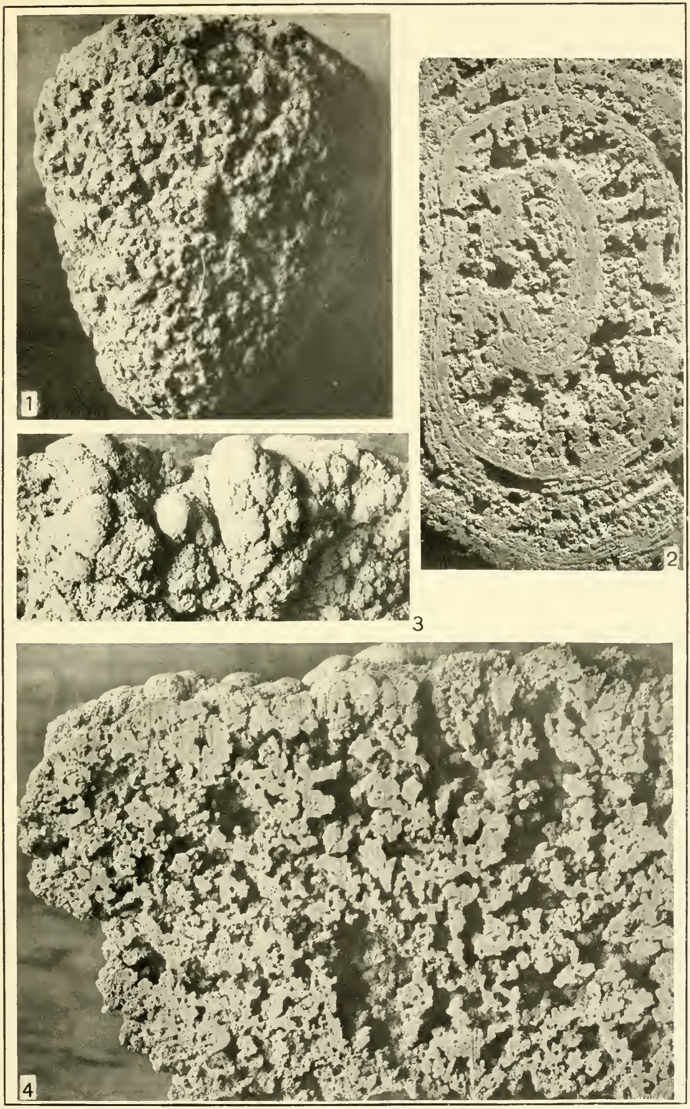
Locality: Squaw Island, Canandaigua Lake, New York.

Layer deposit by Blue-green algæ 100

Fig. 3. (Natural size.) Botryoidal outer surface of specimen represented in section by figure 4. The same occurs in *Collenia undosa* (pl. 13, fig. 2). U. S. National Museum, Catalogue No. 60692.

4. (Natural size.) Vertical section through a layer 7.5 cm. thick. Compare with the section of *Camasia spongiosa* (pl. 12, fig. 1). U. S. National Museum, Catalogue No. 60692.

The specimen illustrated by figs. 3 and 4 is from Green Lake, 2 miles (3.2 km.) southwest of Kirkville, Onondaga County, New York.



LAKE BALLS AND LAYERS, FORMED BY RECENT BLUE-GREEN ALGÆ

DESCRIPTION OF PLATE 5

PAGE

Section of *Lake Ball* formed by Blue-green algæ. (See pl. 4) 100

Fig. 1. (× 4.) Transverse section of an elongated ball, showing laminated structure and the presence of several nuclei toward the center of the section. U. S. National Museum, Catalogue No. 60693.

Locality Squaw Island, Canandaigua Lake, N. Y.

Newlandia concentrica Walcott 105

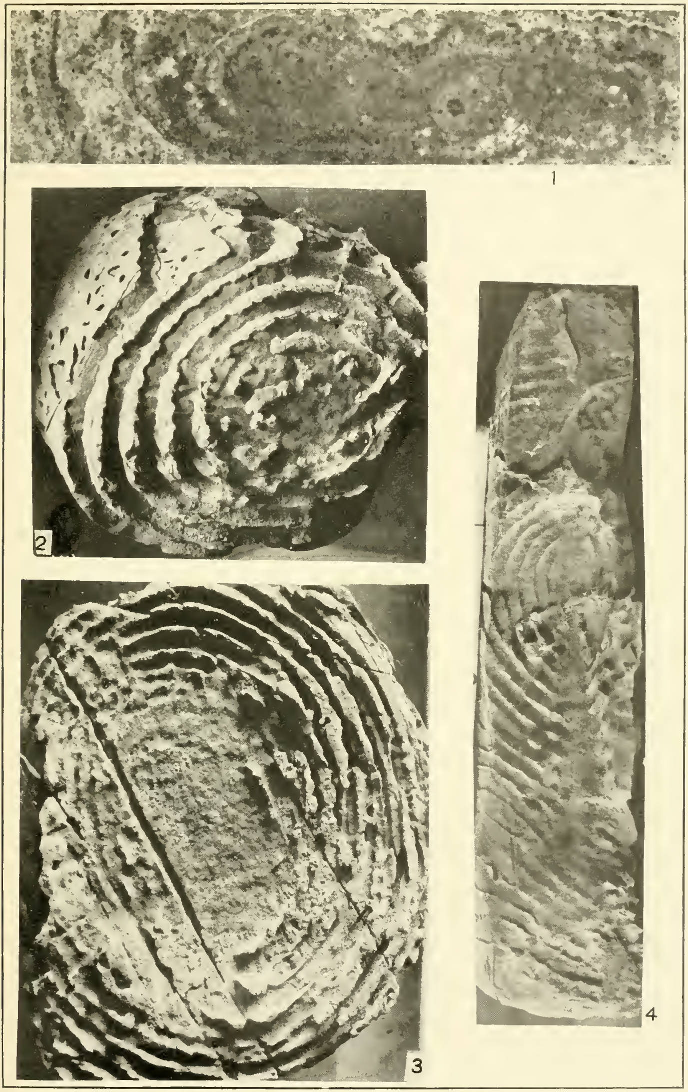
Fig. 2. (Natural size.) View of upper portion of concentrically arranged laminations as exposed by natural weathering, U. S. National Museum, Catalogue No. 60694.

3. (Natural size.) Upper surface showing concentric laminations exposed by the removing of the limestone by acid. U. S. National Museum, Catalogue No. 60695.

Newlandia frondosa Walcott (See pls. 6-8) 105

Fig. 4. (Natural size.) This specimen illustrates a concentric structure toward the center with laminations to the right and left that are cut off at top and bottom by the surface of the layer of limestone in which they occur. U. S. National Museum, Catalogue No. 60696.

The specimens represented by figs. 2-4 are from locality 400c: Algonkian; Newland limestone; 8 miles (12.8 km.) west of White Sulphur Springs, Meagher County, Montana.



1. LAKE BALL
2, 3. NEWLANDIA CONCENTRICA Walcott
4. NEWLANDIA FRONDOSA Walcott

DESCRIPTION OF PLATE 6

Fig. 1. (Natural size.) Portion of the upper surface of a large frond. 3 cm. in thickness, as shown by fig. 3. U. S. National Museum, Catalogue No. 60697.

2. (Natural size.) Lower surface of the specimen represented by fig. 1.

3. (Natural size.) Vertical section through the edge of the specimen represented by figs. 1 and 2. The laminated structure is toward the upper surface, the cellular structure forming the lower half.

The specimen represented by figs. 1-3 is a portion of a large frond that was 48 cm. or more in diameter, with an average thickness of 2.5 to 3 cm.

Locality 400c: Algonkian: Newland limestone; 8 miles (12.8 km.) west of White Sulphur Springs, Meagher County, Montana.

NEWLANDIA FRONDOSA Walcott

DESCRIPTION OF PLATE 7

FIG. 1. (Natural size.) Oblique view of the vertical section of a large frond with a central concentric arrangement of the lamellæ in which there is almost no development of the coarse cellular structure shown by the illustrations on plate 6. U. S. National Museum, Catalogue No. 60698.

2. (Natural size.) View of a portion of the upper laminated surface of the specimen represented by fig. 1.

The specimen represented by figs. 1 and 2 is from locality 400c: Algonkian: Newland limestone; 8 miles (12.8 km.) west of White Sulphur Springs, Meagher County, Montana.

NEWLANDIA FRONDOSA Walcott

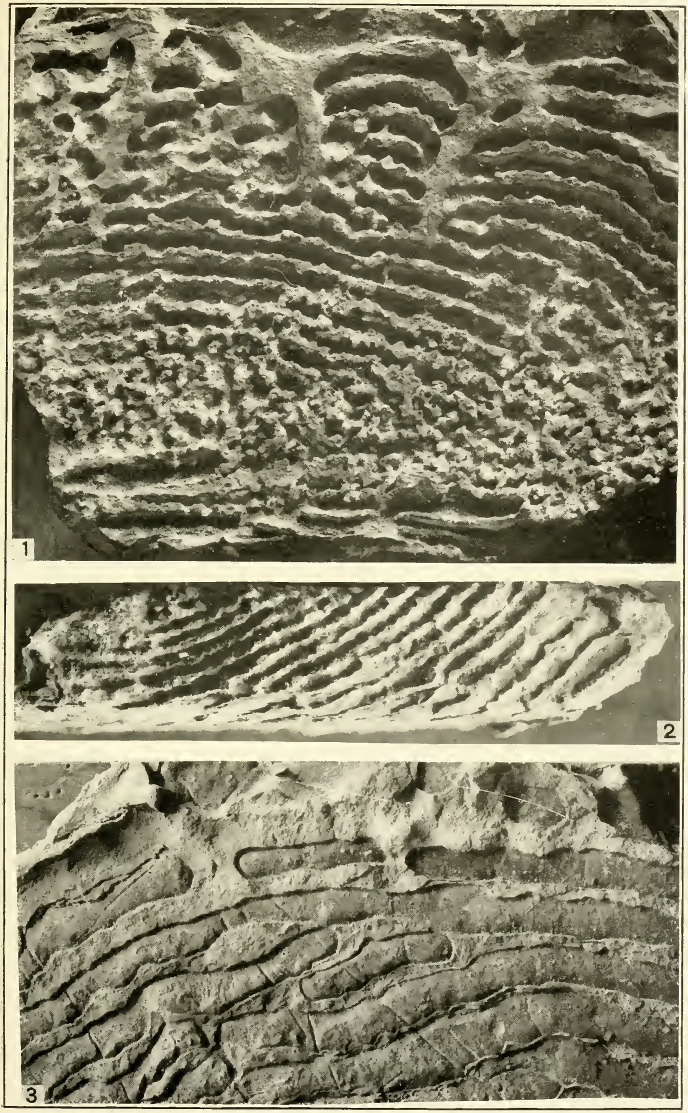
DESCRIPTION OF PLATE 8

PAGE

Newlandia frondosa Walcott. (See pls. 5-7) 105

FIGS. 1, 2, 3. (Natural size.) Views of the upper, vertical, and lower faces of a specimen showing somewhat different structure from that illustrated on plates 6 and 7. U. S. National Museum, Catalogue No. 60699.

The specimen represented by figs. 1-3 is from locality 400c: Algonkian: Newland limestone; 8 miles (12.8 km.) west of White Sulphur Springs, Meagher County, Montana.



NEWLANDIA FRONDOSA Walcott

5

DESCRIPTION OF PLATE 9

PAGE

Camasia spongiosa Walcott. (See pl. 12) 115

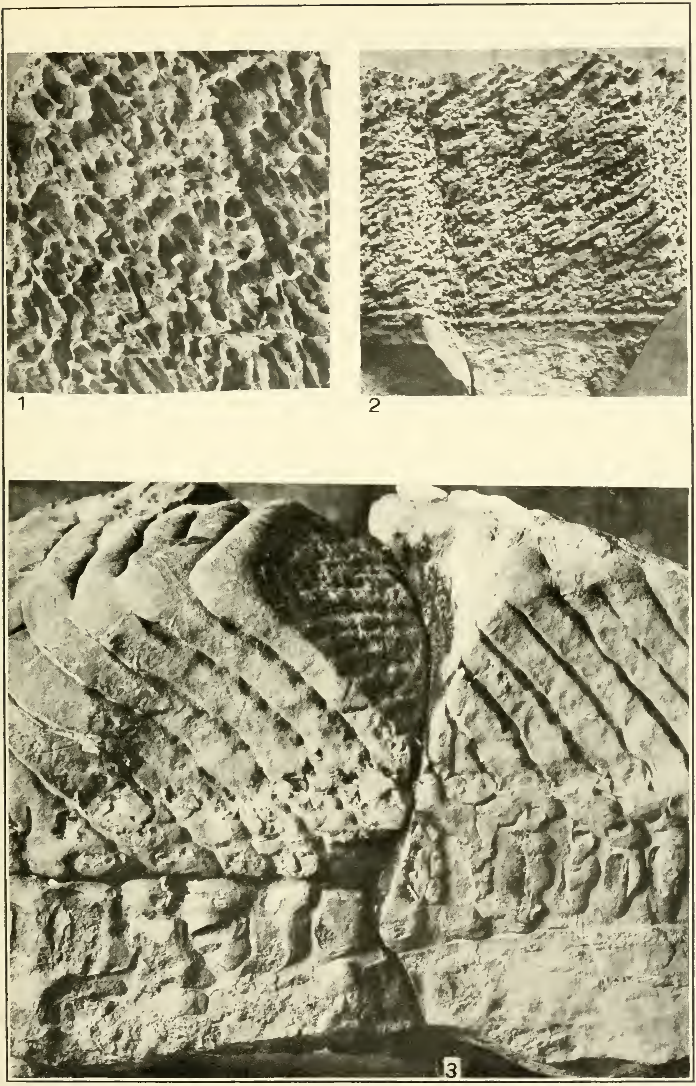
FIG. 1. (Natural size.) View of upper surface, showing the somewhat open cellular structure. U. S. National Museum, Catalogue No. 60700.

2. (Natural size.) Vertical view through the specimen represented by fig. 1, showing sponge-like growth and the thickness of the specimen, which has at its base a thin layer of limestone.

Newlandia major Walcott... 105

FIG. 3. (Natural size.) Vertical section of a specimen in which the lamellæ are interrupted in their growth toward the bottom and then continue up through to the upper surface of the layer. U. S. National Museum, Catalogue No. 60701.

The specimens represented by figs. 1-3 are from locality **400c**; Algonkian: Newland limestone; 8 miles (12.8 km.) west of White Sulphur Springs, Meagher County, Montana.



1, 2. CAMASIA SPONGIOSA Walcott

3. NEWLANDIA MAJOR Walcott

DESCRIPTION OF PLATE 10.

PAGE

Newlandia lamellosa Walcott.. 106

FIG. 1. (Natural size.) Vertical section of a specimen having very finely laminated structure. U. S. National Museum, Catalogue No. 60702.

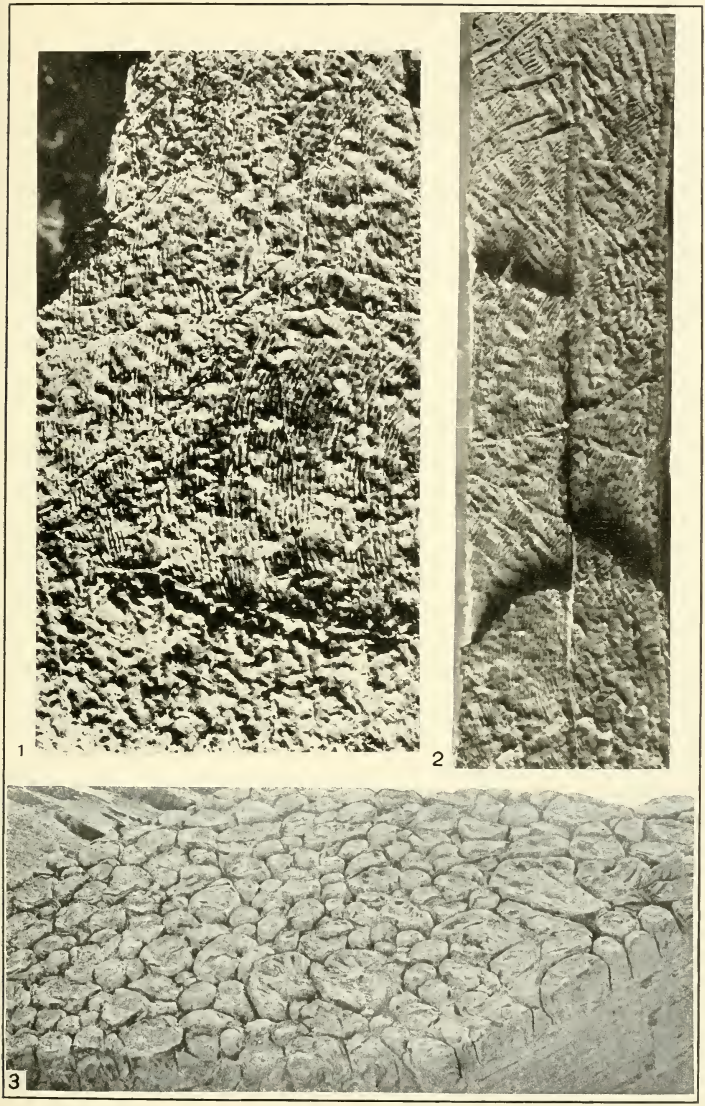
2. (Natural size.) Upper surface of the specimen represented by fig. 1.

The specimen represented by figs. 1 and 2 is from locality 400c: Algonkian: Newland limestone; 8 miles (12.8 km.) west of White Sulphur Springs, Meagher County, Montana.

Collenia ? frequens (Walcott).. 113

FIG. 3. (About one-thirtieth of natural size.) Upper surface and section of a group of cylindrical forms. After photograph by Bailey Willis.

Locality: Algonkian: Siyeh limestone; Little Kootna Creek, Chief Mountain quadrangle, Montana.



1, 2. NEWLANDIA LAMELLOSA Walcott
3. COLLENIA ? FREQUENS (Walcott)

DESCRIPTION OF PLATE 11

PAGE

Weedia tuberosa Walcott 108

FIG. 1. (Natural size.) View of a weathered section of one of the large sphæroidal tubercles, showing something of the laminated structure. U. S. National Museum, Catalogue No. 60703.

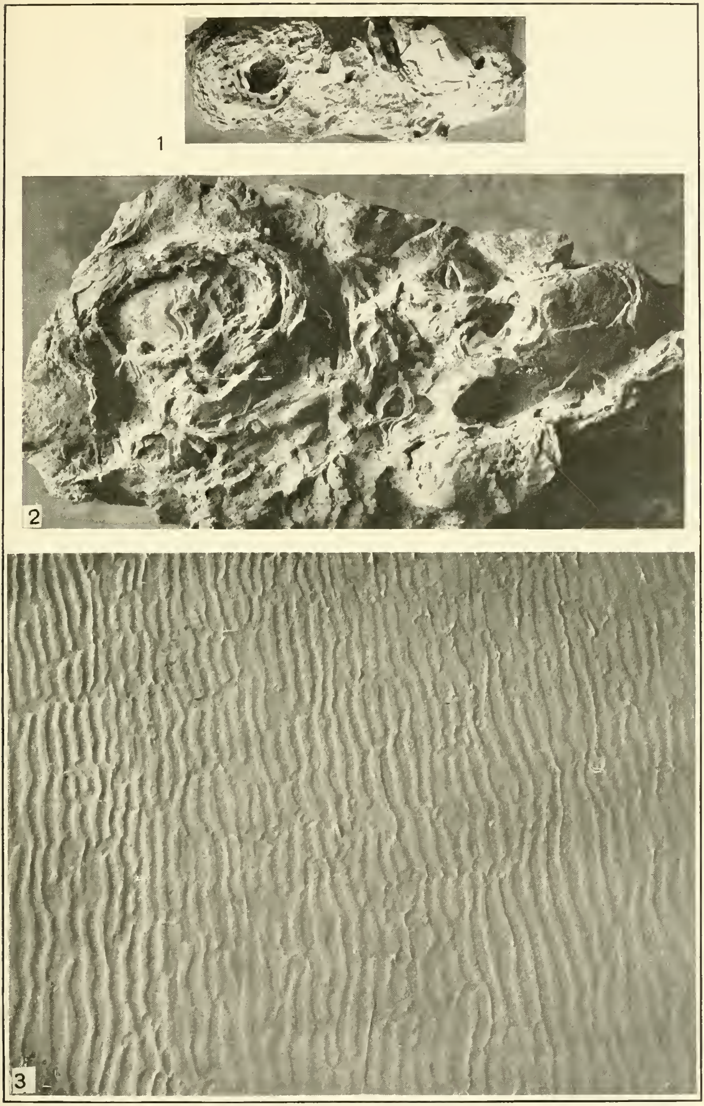
2. (Natural size.) View of the weathered surface of a group of large tubercles on the upper surface of a layer of limestone. U. S. National Museum, Catalogue No. 60704.

The specimens represented by figs. 1 and 2 are from locality **400**: Algonkian: Siyeh limestone; south side of Gunsight Pass, Glacial National Park, Montana.

Kinneyia simulans Walcott 107

FIG. 3. (Natural size.) View of upper surface of a specimen in which the irregular lamellæ extend almost vertically through the layer. U. S. National Museum, Catalogue No. 60705.

The specimen represented by fig. 3 is from locality **400c**: Algonkian: Newland limestone; 8 miles (12.8 km.) west of White Sulphur Springs, Meagher County, Montana.



1, 2. WEEDIA TUBEROSA Walcott

3. KINNEYIA SIMULANS Walcott

DESCRIPTION OF PLATE 12

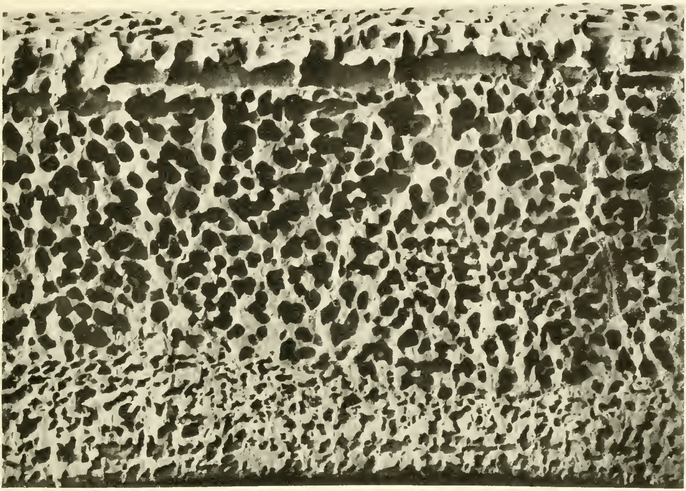
PAGE

Camasia spongiosa Walcott. (See pl. 9) 115

Fig. 1. (Natural size.) Vertical section through the side of a large block showing the vesicular character of the specimen. U. S. National Museum, Catalogue No. 60706.

2. (Natural size.) Vertical section of the same specimen as shown by fig. 1, at right angles to the section shown by fig. 1. The tubular openings are very irregular.

The specimen represented by figs. 1 and 2 is from locality 400c: Algonkian: Newland limestone; 8 miles (12.8 km.) west of White Sulphur Springs, Meagher County, Montana.



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2

CAMASIA SPONGIOSA Walcott

DESCRIPTION OF PLATE 13

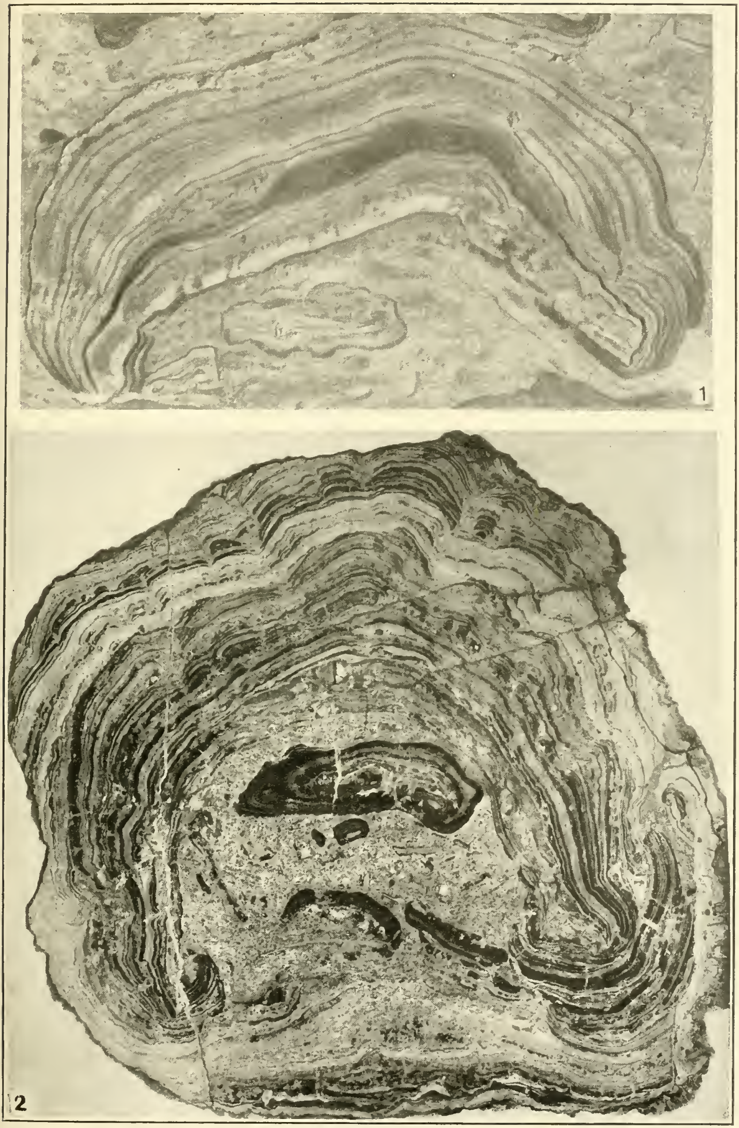
PAGE

Collenia undosa Walcott. (See pl. 14) 113

Fig. 1. (Natural size.) Vertical polished section through a layer in which numerous specimens are embedded. U. S. National Museum, Catalogue No. 60707.

Fig. 2. (Natural size.) Photograph of thin section of a subspherical specimen, showing the original growth as a dome and then a second growth that apparently occurred after the specimen had been rolled over. U. S. National Museum, Catalogue No. 60708.

The specimens represented by figs. 1 and 2 are from locality **400b**: Algonkian: Spokane shales; 8 miles (12.8 km.) west of White Sulphur Springs at forks of Birch Creek, Meagher County, Montana.



COLLENIA UNDOSA Walcott

DESCRIPTION OF PLATE 14

PAGE

Collenia undosa Walcott. (See pl. 13) 113

FIGS. 1 and 2. (0.5 natural size.) Side and top view of a group of specimens that have apparently grown together, forming a solid mass. They are embedded in the red Spokane shales. U. S. National Museum, Catalogue No. 60709.

Locality **400b**: Algonkian: Spokane shales; 8 miles (12.8 km.) west of White Sulphur Springs, Meagher County, Montana.

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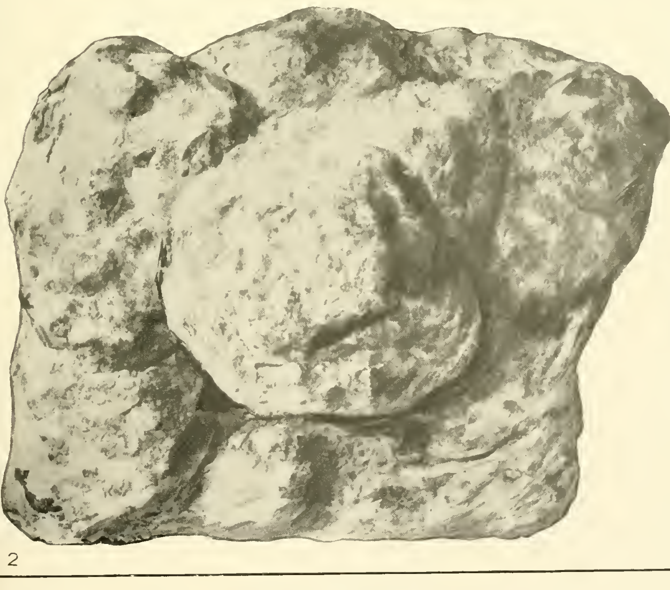


2

COLLENIA UNDOSA Walcott

DESCRIPTION OF PLATE 15

PAGE

Collenia occidentale (Dawson) 111

FIG. 1. (Natural size.) Photograph of a thin-section showing portions of two fragments. U. S. National Museum, Catalogue No. 33799.

2. (× 8.) Enlargement of the lower, smaller fragment in fig. 1.

3, 4. (Natural size.) Photographs of two thin-sections occurring in the same stratum of rock as that represented by fig. 1. U. S. National Museum, Catalogue No. 33799.

5, 6. (Natural size.) Natural sections through two turbinate forms of growth. U. S. National Museum, Catalogue Nos. 60710, 60711.

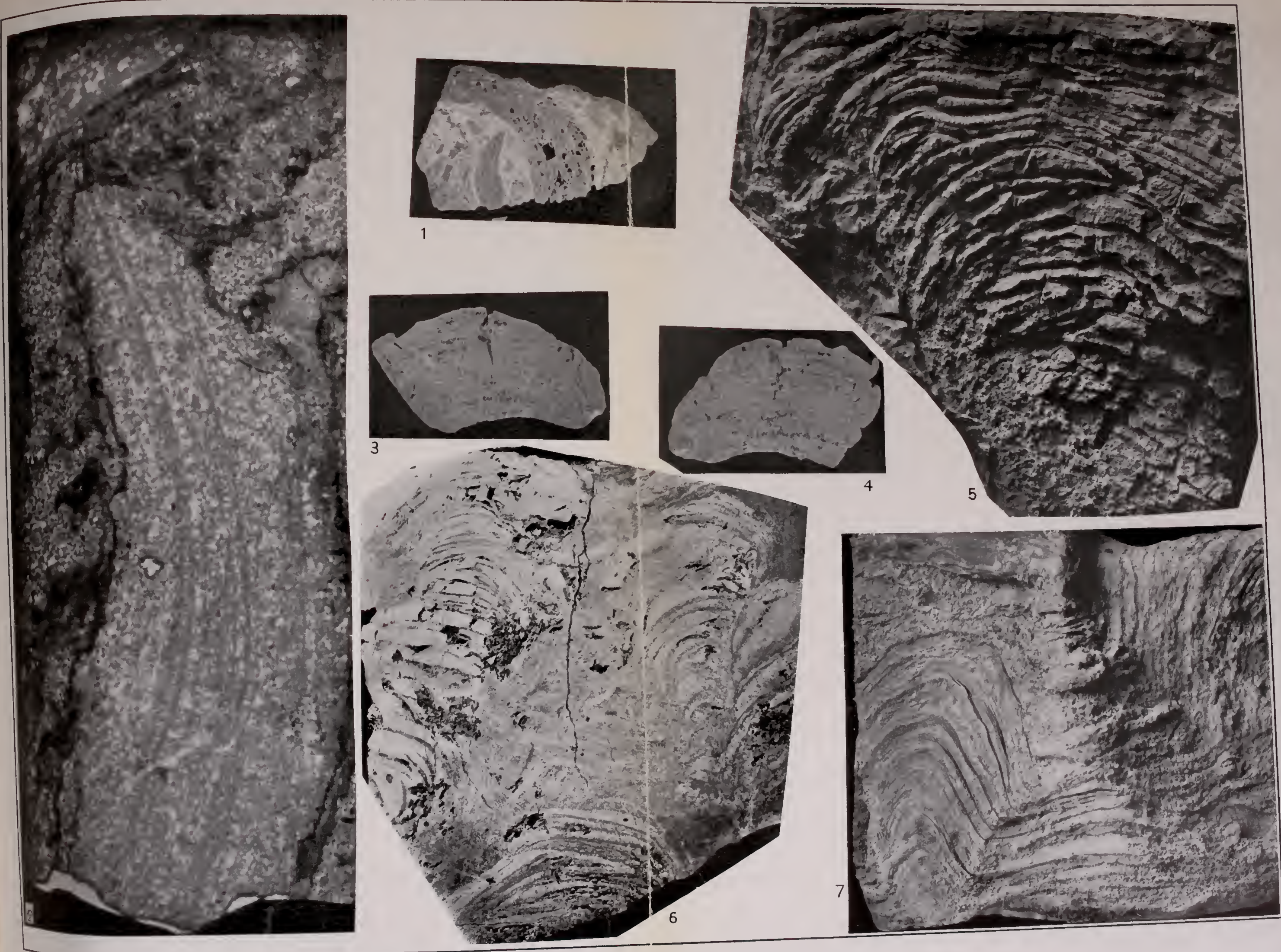
The specimens represented by figs. 1-6 are from the Algonkian: Chuar terrane; Grand Canyon, Arizona.

These figures (1-4) were published as figs. 1-4, plate 23, Bull. Geol. Soc. America, Vol. 10, 1898, Walcott: Pre-Cambrian fossiliferous formations.

Collenia compacta Walcott 112

FIG. 7. (Natural size.) Natural weathered vertical section showing the club-shaped growth on the left with the irregular lamellæ about it on the right. U. S. National Museum, Catalogue No. 60712.

From locality 400a: Algonkian: Siyeh limestone; Continental Divide at head of Kipps Creek, Glacial National Park, Montana.



COLLENIA

DESCRIPTION OF PLATE 16

Fig. 1. Glaciated exposure of one of the *Cryptozoan* reef beds of the Hoyt limestone, by the roadside near the Hoyt quarry, northwest of Saratoga, New York. Original locality of Hall's figure of the species.

This plate is published here through the courtesy of Dr. John M. Clarke, Director of the New York State Museum. It is plate 3 of Bulletin 169, 1914, of the Museum.

Cryptozoon proliferum is illustrated and referred to in my paper on the "New York Potsdam-Hoyt Fauna." Smithsonian Misc. Coll., Vol. 57, 1912, p. 258, pl. 37.

CRYPTOZOON PROLIFERUM Hall

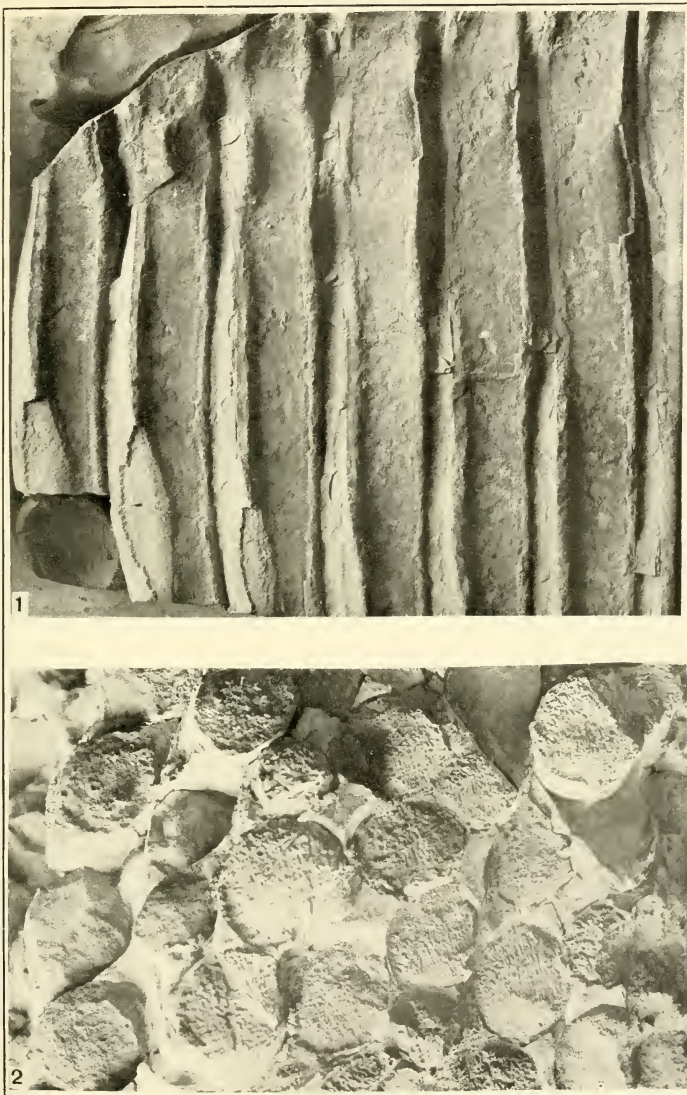
DESCRIPTION OF PLATE 17

FIG. 1. (Natural size.) Section of a mass of the basaltic-like columns obtained by splitting off a group of the tubes. U. S. National Museum, Catalogue No. 60713.

2. (Natural size.) View of the end of the basaltic-like tubes. U. S. National Museum, Catalogue No. 60714.

The algæ form the interspaces between the tubes that are now filled with limestone.

The specimen represented by figs. 1 and 2 is from locality 400c: Algonkian: Newland limestone; 8 miles (12.8 km.) west of White Sulphur Springs, Meagher County, Montana.



GREYSONIA BASALTICA Walcott

DESCRIPTION OF PLATE 18

PAGE

Greysonia basaltica Walcott. (See pl. 17) 109

FIG. 1. (Natural size.) Vertical section of a group of tubes forming a layer 5 cm. in thickness. U. S. National Museum, Catalogue No. 60715.

The tubes are filled with a bluish-black limestone and the algæ are represented by gray to grayish-yellow magnesian limestone.

The tubes were formed in a horizontal position, presumably as portions of a large frond.

2. (Natural size.) Lower surface of a specimen of which the upper surface is represented by fig. 2, pl. 17. U. S. National Museum, Catalogue No. 60714.

The tubes of this specimen appear to have grown in a vertical position, and have a length in the portions preserved of 18 cm.

The specimens represented by figs. 1 and 2 are from locality 400c: Algonkian: Newland limestone; 8 miles (12.8 km.) west of White Sulphur Springs, Meagher County, Montana.

GREYSONIA BASALTICA Walcott

DESCRIPTION OF PLATE 19

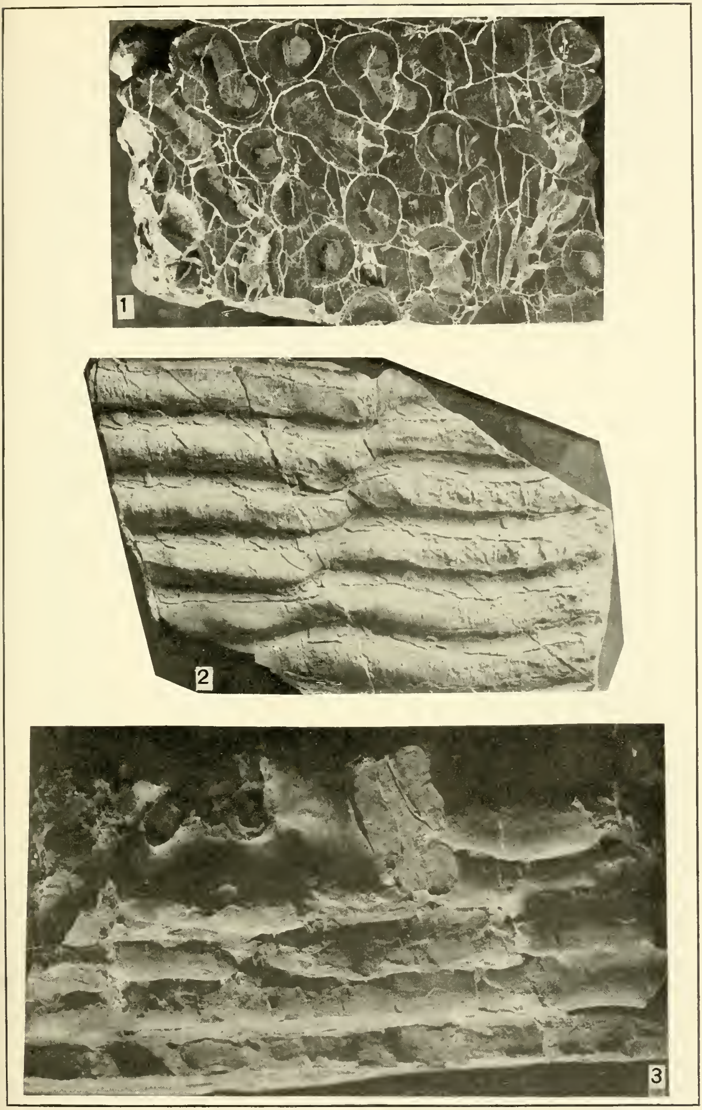
FIG. 1. (Natural size.) Polished vertical section of a group of more or less irregular tubes that form a layer 5.5 cm. thick. U. S. National Museum, Catalogue No. 60716.

2. (Natural size.) Surface of a group of tubes that were formed in a horizontal position. U. S. National Museum, Catalogue No. 60717.

3. (Natural size.) View of a natural section of a layer 5 cm. in thickness in which the three lower layers of tubes are fairly regular, while the upper layers show irregular growth. U. S. National Museum, Catalogue No. 60718.

This form occurs in layers or tubes that are more or less parallel to the bedding of the layer.

The specimens represented by figs. 1-3 are from locality **400c**: Algonkian: Newland limestone; 8 miles (12.8 km.) west of White Sulphur Springs, Meagher County, Montana.



COPPERIA TUBIFORMIS Walcott

DESCRIPTION OF PLATE 20

PAGE

Newlandia frondosa Walcott. (See pls. 6, 7, 8) 105

FIG. 1. (× 500.) Drawing of a plate of opal-like silica containing numerous slender tubes, some of which have irregularly spaced partitions that have a distinct upper and lower surface that probably indicates organic origin. This type is not uncommon in material obtained by treating specimens of this species with hydrochloric acid. U. S. National Museum, Catalogue No. 60719.

Camasia spongiosa Walcott. (See pls. 9, 12) 101

FIG. 2. (× 350.) Chain of cells as photographed and partly outlined. The untouched micrograph is shown by fig. 4, where about half of the cells are in the focal plane. U. S. National Museum, Catalogue No. 60720.

3. (About × 1400.) Outline sketch of the chain shown by figs. 2 and 4.

4. (× 350.) Micrograph of a portion of the fragment of opal-like silica containing the chain of cells represented by figs. 2 and 3. There are also present numerous minute tubes similar to those illustrated by fig. 1.

5, 5*a* (× 350.) A group of seven supposedly round cells as they occur free from the matrix. Similar bodies occur in the opal-like silica both singly and in groups. The untouched micrograph is shown by fig. 5*a*. U. S. National Museum, Catalogue No. 60722.

6, 6*a*. (× 350.) Untouched micrograph of an irregular chain-like group of round cells that are free from the matrix. The round cell-like bodies are outlined in fig. 6*a* as they appear when examined under the microscope. U. S. National Museum, Catalogue No. 60723.

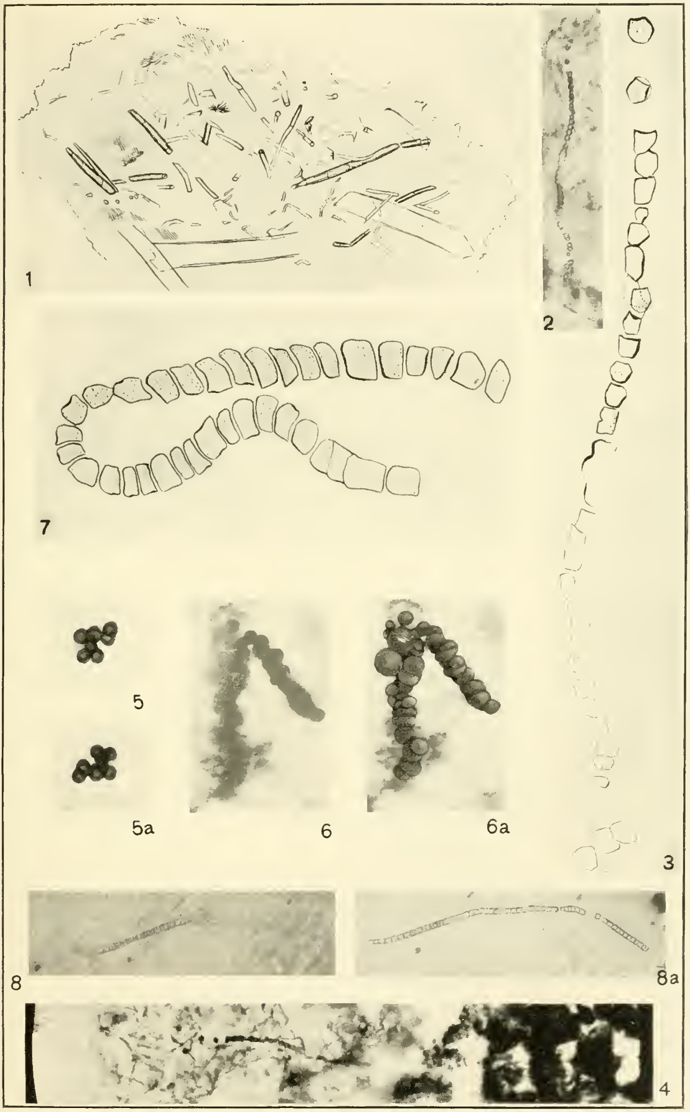
Blue-green algæ cells (*Schizothrix ?*) 100

FIG. 7. (About × 1200.) Outline drawing of a chain of cells obtained by treating a recent Blue-green algal calcareous deposit with hydrochloric acid. U. S. National Museum, Catalogue No. 60724.

8. (× 350.) Untouched photograph of a chain of cells obtained by treating a Blue-green calcareous deposit from Green Lake, Onondaga County, New York, with dilute hydrochloric acid.

8*a*. The same as fig. 8, with all the cells of the chain outlined. The chain is free except where entangled with diatoms and bits of opal-like silica. U. S. National Museum, Catalogue No. 60725.

The slides represented by figs. 7 and 8 were sent to me by Dr. Charles A. Davis. The material containing the cells represented by fig. 7 is from North Lake, Waukesha County, Wisconsin, 27 miles (43 km.) west-northwest of St. Paul, and that by fig. 8 from Green Lake, Onondaga County, New York.



MICROSCOPIC CELLS FROM RECENT BLUE-GREEN ALGÆ AND THEIR ALGONKIAN REPRESENTATIVES

DESCRIPTION OF PLATE 21

Annelid Trails on Greyson Shales

PAGE

Helminthoidichnites ? neihartensis Walcott.............................. 98

Fig. 1. (Natural size.) Two nearly parallel trails, with many small, dark, thin, flattened, usually circular concretions attached to them. U. S. National Museum, Catalogue No. 33795.

2. (Natural size.) Apparently a single trail made by the animal turning about and finally returning nearly on the line of the first trail. There are not as many concretions as in fig. 1. U. S. National Museum, Catalogue No. 33795.

3. (About × 10.) Enlargements of one of the small disc-like concretions associated with figs. 1 and 2. U. S. National Museum, Catalogue No. 33795.

4. (Natural size.) Same as figs. 1 and 2, but with many convolutions. This form is less common than the straight and partly curved trails shown by figs. 1 and 2. U. S. National Museum, Catalogue No. 33795.

Helminthoidichnites ? spiralis Walcott.............................. 98

Figs. 5. 6. (Natural size.) Two figures illustrating the typical form of trail made by this curious species. U. S. National Museum, Catalogue No. 33794.

Helminthoidichnites meeki Walcott.............................. 98

Fig. 7. (Natural size.) Illustration of the type specimen of the species. U. S. National Museum, Catalogue No. 33793.

The specimens represented by figs. 1-7 are from the Algonkian: Belt (Greyson shales) terrane; Deep Creek Canyon and Sawmill Canyon, Belt Mountains, Montana.

Planolites corrugatus Walcott.............................. 98

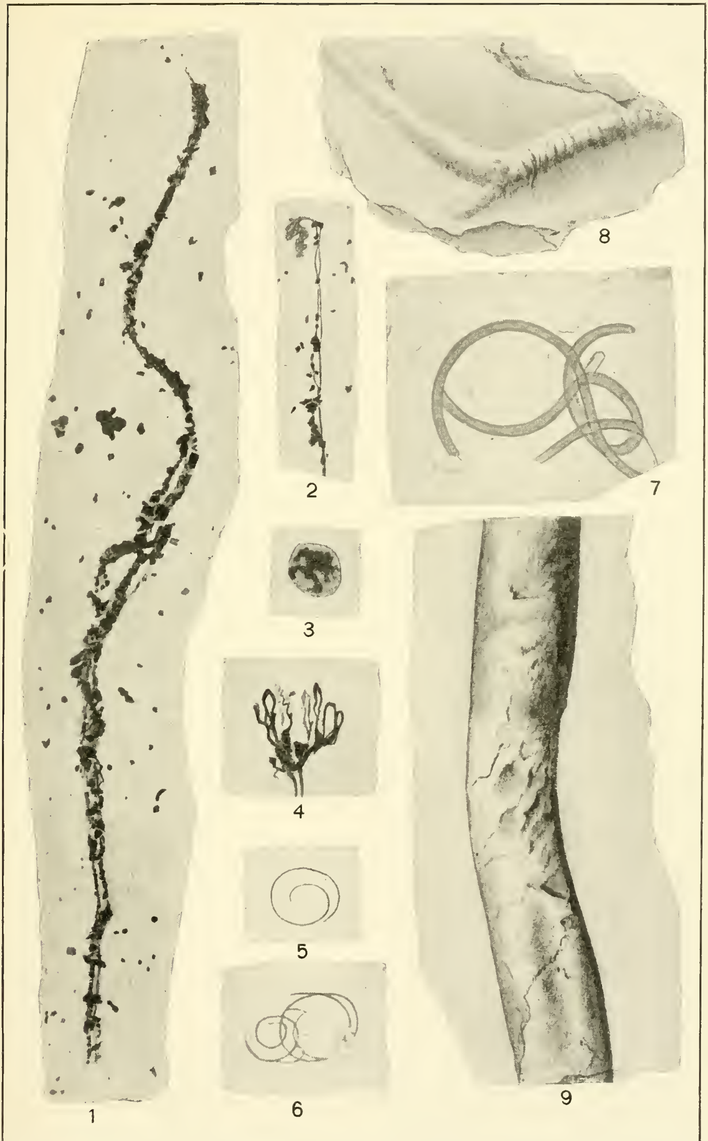
Fig. 8. (Natural size.) Exterior cast of the burrow made by medium-sized annelid in siliceous mud now forming the shales carrying *Beltina danai* Walcott. U. S. National Museum, Catlogue No. 33796.

Planolites superbus Walcott.............................. 98

Fig. 9. (Natural size.) A portion of the cast of a long burrow occurring in a sandy shale interbedded in the *Beltina danai* shales. U. S. National Museum, Catalogue No. 33797.

The specimens represented by figs. 8 and 9 are from the Algonkian: Greyson shales; Sawmill Canyon, 4 miles (6.4 km.) above Neihart, Cascade County, Montana.

This plate was published as plate 24, Bull. Geol. Soc. America, Vol. 10, 1898, Walcott: Pre-Cambrian Fossiliferous Formations.



ANNELID TRAILS

DESCRIPTION OF PLATE 22

Crustacean Remains from Greyson shales

PAGE

Beltina danai Walcott.. 98

FIGS. 1, 2. (Natural size.) Specimen which appears to represent the head. Fig. 2 is greatly compressed and distorted in front and probably belongs to another species. U. S. National Museum, Catalogue No. 33790.

3. (Natural size.) A segment of the body. U. S. National Museum, Catalogue No. 33790.

4. (× 3.) Portion of an appendage with four joints indicated. U. S. National Museum, Catalogue No. 33790.

5. (× 4.) An unidentified fragment with a small terminal curved spine. U. S. National Museum, Catalogue No. 33790.

6. (× 2.) An appendage with two large basal ? joints and two smaller terminal joints. U. S. National Museum, Catalogue No. 33790.

7. (Natural size.) Appendage with a large basal ? joint and four smaller joints indicated. U. S. National Museum, Catalogue No. 33790.

8. (Natural size.) Appendage with very large basal ? joint and several small joints. U. S. National Museum, Catalogue No. 33790.

9. (× 2.) Appendage with fragment of large basal ? joint and several small joints. U. S. National Museum, Catalogue No. 33790.

10. (Natural size.) Two appendages that are apparently attached to a single basal ? joint. U. S. National Museum, Catalogue No. 33790.

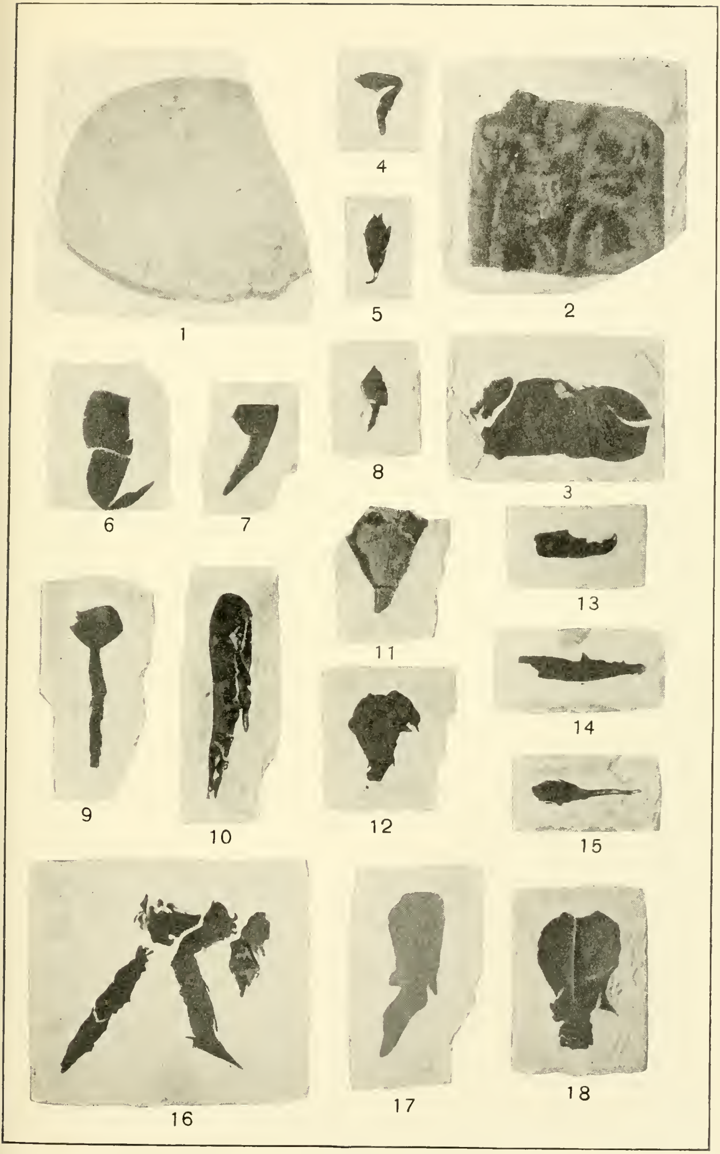
11. (Natural size.) Appendage with a broad basal ? joint. U. S. National Museum, Catalogue No. 33790.

12. (× 3.) Appendage with a broad basal ? joint. Several fine setæ or spines are attached to it. U. S. National Museum, Catalogue No. 33790.

13. (Natural size.) Movable ramus of a chelate appendage, with traces of teeth. U. S. National Museum, Catalogue No. 33790.

14. (Natural size.) Broken fixed portion of a chelate appendage, with traces of teeth. U. S. National Museum, Catalogue No. 33790.

15. (Natural size.) Several specimens of this character occur in the collection. U. S. National Museum, Catalogue No. 33790.



BELT TERRANE FOSSILS

Beltina danai Walcott—Continued.

FIG. 16. (Natural size.) Jointed appendages very much compressed and distorted. U. S. National Museum, Catalogue No. 33790.

17. (Natural size.) Jointed appendage. U. S. National Museum, Catalogue No. 33790.

18. (Natural size.) Telson preserving a central ridge. U. S. National Museum, Catalogue No. 33790.

The specimens represented on this plate are from the Algonkian: Greyson shales; Deep Creek Canyon, near Glenwood, and Sawmill Canyon, 4 miles (6.4 km.) above Neihart, Cascade County, Montana.

This plate was published as plate 25, Bull. Geol. Soc. America, Vol. 10, 1898, Walcott: Pre-Cambrian Fossiliferous Formations.

DESCRIPTION OF PLATE 23

PAGE

Gallatinia pertexa Walcott.. 116

FIG. 1. (Natural size.) View of upper surface of type specimen. U. S. National Museum, Catalogue No. 60730.

2. (Natural size.) Vertical section through specimen represented by fig. 1.

The specimen illustrated is from locality 400j: Algonkian: Belt terrane; north of Bartons Bridge on the Gallatin River, Montana.

1

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GALLATINIA PERTEXA, Walcott