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Art. XXII.—*Pre-Cambrian and Carboniferous Algal Deposits*; by W. H. Twenhofel.

Not very long ago the view generally prevailed that, except for their contributions to the coal series, plants played a very insignificant part in the building of sedimentary rocks. The average textbook in geology still gives the general impression that calcareous deposits indicate accumulations of coral and shell and essentially nothing is said relating to the contributions of the plants. So strong was the view intrenched that calcareous deposits are of animal origin, that plant structures, as *Spongiostroma, Sphærocodium, Cryptozoon* and others, were classed with the animals.

The work of recent years is leading to the conception that as rock-builders the plants—chiefly the algæ—are of prime importance. This work must ultimately compel a restatement of the agents of limestone formation and a general re-evaluation of the quantitative importance of the several agents concerned. At one extreme, this work relates to some of the oldest of rocks and, at the other, to sediments now accumulating on the ocean floor. In addition, considerable detailed work has been done in intermediate portions of the geologic column, particularly the Carboniferous of Great Britain and the Silurian and Ordovician of the Scandinavian countries.[1]

Walcott's explorations[2] of the Pre-Cambrian strata together with contributions relating to the same rock from other students have shown the great part that algæ

[1] An excellent review of the algal deposits of the geological column is given by Garwood, E. J.: Geol. Mag., N. S., Dec. V, vol. 6, pp. 440-446, 490-498, 545-553, 1913.

[2] Walcott, C. D.: Pre-Cambrian Algal Flora, Smithsonian Misc. Coll., vol. 64, No. 2, 1914.

have taken in the building of some divisions of the Pre-Cambrian limestones. The data have been chiefly derived from the Rocky Mountain region, but that is probably due to the fact that paleontologic studies of Pre-Cambrian rocks have been to a very great extent confined to that region. There is little doubt that algal deposits will ultimately be found to be equally abundant in all other Pre-Cambrian terranes during the formation of which conditions obtained which were adapted to the presence of algæ. Doctor C. K. Leith's photographs of some of the rocks to the east of Hudson Bay[3] show that algal deposits are abundant in some of the limestones of that region and in the paper by Doctor Grout and in this paper it will be shown that they are also extremely abundant in some Pre-Cambrian terranes of the Lake Superior country.

The contributions of the algæ to modern deposits are of great importance and in the building of the "coral reefs" they appear to have played a role that from a quantitative point of view is equal to that of any other organism. At Funafuti the relative importance of the organisms forming the reef were *Lithothamnium, Halimeda,* Foraminifera, and lastly the corals,[4] while about the Murray Island coral reef (north end of the Great Barrier reef) at 200 feet from the shore the algæ constitute 42·5% of the sediments and the corals 34·6%. At 1600 feet from the shore the algæ make 32·6% of the sediments and the corals 41·9%.[5]

In the Carboniferous rocks of Great Britain, Professor E. J. Garwood has found algal deposits in abundance in some horizons and he personally suggested to the writer that such would likely be found to be true for American Carboniferous strata.[6] In the highest Ordovician formation (Stage 5) of the Kristiania region of Norway, entire beds of limestone are composed of algal remains and in Gotland the *Spongiostroma* and *Sphaerocodium* marls and limestones receive their names from the abundance of algal material.[7]

[3] Recently described by Moore, J. C.: Jour. Geol., vol. 26, pp. 412-413, 1918.

[4] Howe, M. A.: The Building of "Coral Reefs"; Science, vol. 35, pp. 837-842, 1912.

[5] Vaughan, T. W., and Goldman, M. I.: Papers from the Dept. Marine Biology of the Carnegie Institution of Washington, vol. 9, pp. 255-258, 1918.

[6] Garwood, E. J.: Geol. Mag., Dec. VI, vol. 1, pp. 265-271, 1914.

[7] Munthe, H.: Guide Book, No. 19, XIth Internation. Geol. Cong., 1910.

These facts relating to algal deposits are of immense importance in connection with the formation of limestone and they become of greater significance when it is remembered that many marine algæ thrive almost as well in cold waters as in warm and that in some cold waters their deposits constitute a large percentage of the sediments.

It would seem that in the Pre-Cambrian periods the algæ would have been likely to have had a greater absolute importance than in later times. Before the advent of the manifold variety of bottom animal life, they had the entire submerged area at their disposal where they dwelt undisturbed by competitors or enemies. When the bottom animals appeared in abundance the algæ furnished food for many of them and had to compete with them for space and this must have brought about some decrease in their absolute and certainly in their relative importance.

In this paper are described the occurrence of algal deposits in the Lower Huronian of Michigan and in the Pennsylvanian and Permian of Kansas and Oklahoma. For the opportunity of studying the field distribution of the Kansas and Oklahoma occurrences the writer is indebted to Mr. B. E. LaDow of Fredonia, Kansas; for the opportunity of seeing the Huronian occurrence he is indebted to Doctor C. K. Leith.

Method of Origin of Algal Deposits of the Type Considered.

The algal deposits considered in this paper are of the incrusting or laminated type and one of them is quite similar to the "water biscuits" of modern lakes. These are thought to develop as a consequence of the absorption of the carbon dioxide in the water and the release of oxygen by the plant to the water.[8] These changes in the gaseous content of the water surrounding the plant lessen the capacity of the water to hold the dissolved calcium carbonate and this is precipitated about the bases of the algæ and upon their thalli. The precipitated material has a laminated structure which probably results from variations in the rate of precipitation and interruptions thereof. The process is not one wherein the lime carbonate enters into the tissues of the plant and hence the precipitated material may develop little or no internal

[8] Davis, C. A.: Geol. Surv. Mich., vol. 8, pt. 3, p. 69, 1903.

structure which resembles the structure of the plant. It is possible that the filaments and thalli of the algæ may leave molds within the precipitated material.

Terminology and Principle of Classification.

The terms employed for the lime carbonate structures which are formed in the manner outlined above are not uniform. Garwood, Howe and others use the term thallus, but that term had better be limited to its original significance. It is true that in some cases the precipitated lime carbonate may have the same general shape as the thalli, but even in those cases there is considerable doubt as to the propriety of calling the precipitated material by the same name as the leaf-like structures of the plant. Some writers have called these structures algæ, but to so term them has about the same application as calling a worm boring a worm. Howe and others use the term thallium with a suitable prefix for certain parts of these structures, as hypothallium, perithallium, etc. While appropriate, that term, however, has already been used as the name of an element. As a suitable name for these algal structures appears to be lacking and as one is certainly needed, the writer proposes the word, *cœnoplase,* from *koinos,* common, and *plasis,* formation. This term is used in the present article.

A cœnoplase from the very nature of its origin may, or may not, show anything of the structure and characteristics of the plants which are responsible for its development and algæ giving rise to cœnoplases quite similar in shape may be widely different in appearance and general make-up. On the other hand it appears to be reasonable to believe that algæ belonging to the same genus would develop cœnoplases of so similar a form and structure that little distinction could be made between the deposits of different species and deposits of closely related genera might also be apt to be quite similar in general appearance. If these assumptions be correct, it follows that small constant differences in the shape, size and structure of cœnoplases are to be given a far greater importance than would be the case were one dealing with essential structures of animals and plants. It is on this basis that the Carboniferous algæ described in this paper are referred to different genera.

Algal Deposits of the Kona Dolomite.

The Kona dolomite is a Lower Huronian formation of the Marquette region of northern Michigan. It consists of "a cherty dolomite interstratified with layers of slate, graywacke, and quartzite, with all gradations between the various mechanical sediments and between these and the pure dolomites. The texture varies from quite fine to very coarse and the color from a white to a dark-brown. The dolomite does not appear to constitute more than a half of the formation and the beds vary from a few inches to many feet."[9] The thickness varies from 200 to 700 feet.[10]

In the spring of 1917 the writer had the good fortune to accompany Doctor C. K. Leith and his party of students on the field trip which constitutes a part of the course in "Lake Superior Geology." Among other things geological, the Kona dolomite was studied in one of its best exposures, this being situated on the shore of Lake Superior just south of the city of Marquette.

The most striking feature of the dolomite in this exposure is the abundance and large size of the algal cœnoplases which compose it. So far as could be observed, the entire mass of dolomite developed through the progressive plastering of one layer of algal material upon another, the only material of other origin which was observed consisting of insignificant streaks of silt between the algal masses. With the assistance of Doctor W. O. Hotchkiss a group of colonies having a continuous growth from base to summit was measured. It was found to have a thickness of 22 feet with neither base nor summit exposed and a width of 55 feet with neither end shown. This is the extent of the exposure and the actual dimensions must be much greater. Since the dimensions given are of "coral reef" proportions, it can not be doubted that reefs of algæ existed in the Lower Huronian sea of this region.

So far as the writer has been able to learn, the algal growths are not coextensive with the distribution of the Kona dolomite, this being the only place where they have been observed in the formation.[11] In Huronian times

[9] Van Hise, Bayley and Smith: U. S. Geol. Surv., Mon. 28, p. 244, 1897.
[10] Van Hise and Leith: U. S. Geol. Surv., Mon. 52, p. 258, 1911.
[11] Hotchkiss, W. O.: Personal communication.

algæ were probably related to light in their distribution just as they are to-day, and this factor would have confined them to the shallows about the margins of the lands which they would have reefed just as the corals and algæ reef tropical lands at the present time. Places where clastic sediments were being deposited in the Huronian

FIG. 1.

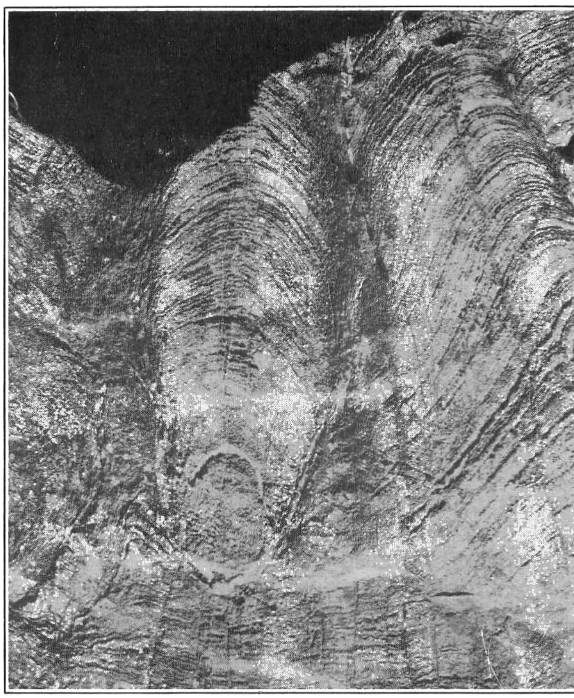

FIG. 1. *Collenia kona* n. sp. Cross section of a single colony, Kona dolomite, Marquette, Mich. Photograph by Dr. W. O. Hotchkiss.

sea or were being transported along the shore would have been free from algæ. Their places of abundant growth would have been found in clear and shallow waters. This fact of distribution probably explains their general absence from this dolomite formation. It is quite likely, however, that some of the dolomite which shows no evidence of algal origin may have so originated; but have lost all traces of its origin in the process of recrystallization.

The character of the water can hardly be determined from the algæ. These organisms at the present time thrive in cold as well as in warm waters, illustrated by the fact that in the cold waters of some localities of northern Newfoundland *Lithothamnium* covers everything in the shallows, and about the "coral reefs" it is one of the most abundant organisms precipitating lime carbonate. The algæ do not even prove that the waters were salty,

FIG. 2.

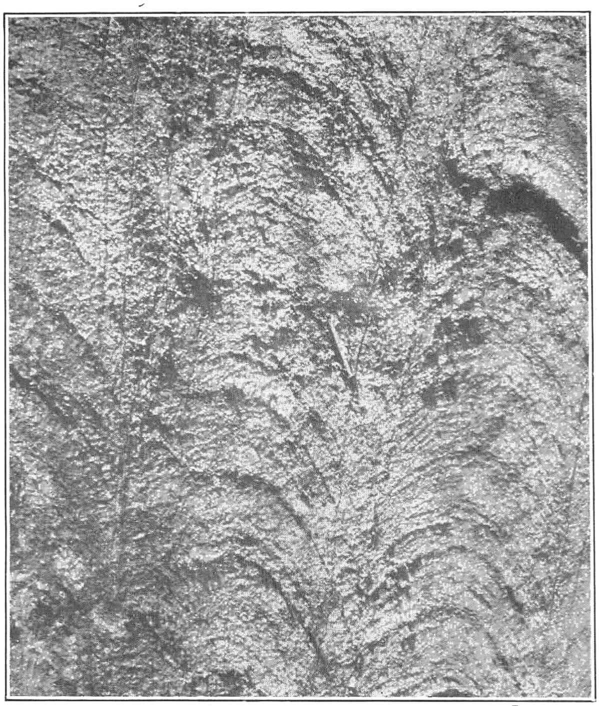

FIG. 2. *Collenia kona* n. sp. Cross section of two colonies, Kona dolomite, Marquette, Mich. The hammer is 18 inches long. Photograph by Dr. W. O. Hotchkiss.

as lime-precipitating algæ thrive in both fresh and salt waters, but the tremendous growth of the Kona algæ suggest marine conditions.

The upper surface of the Kona reef was irregular from the presence of elevations which are dome-shaped in cross section. Some of these elevations appear to have been as great as 10 feet across. Small secondary domes are superimposed upon the larger ones. Most of the domes are from 6 inches to 2 feet in diameter. The relief arising from these elevations appears to have been about a foot.

Each dome seems to have represented a more or less separate colony which was separated from neighboring elevations by V-shaped depressions in the apices of which small quantities of silt collected and as the reef grew upward both the separating hollows and the domes appear to have held about the same relative positions. As a consequence, each dome continues downward into the reef as a cylindrical structure which in some cases terminates at the base in a round-apexed cone. Some of these cylindrical structures attained lengths of 7 to 10 feet.

The structure of the reef material is laminated, growth having taken place through the deposition of laminæ over the external surface of the dome-shaped masses. The structure and general features of the cœnoplases appear to be similar to those occurring in the genus *Collenia* Walcott of which genus this is considered a new species.

Collenia kona new species.

Growths of large size; dome-shaped on the upper surface; diameters varying, but mostly 2 feet or less; structure consisting of superimposed laminæ parallel to the upper surface and hence convex upward. The laminæ vary in thickness from one to several millimeters. They are wrinkled and in cross section appear as small anticlines and synclines of 3 to 5 millimeters amplitude. A part of this wrinkling may have arisen from the pressures to which the rock has been subjected, but probably very little of it did so arise. A colony probably began as an incrustation over some other substance; but after covering the bottom, more rapid growth in one place than in another gave rise to domal shapes which by growth upward in the same position led to cylindrical structures. The upper surface of the algal reef appears to have had a somewhat large-featured botryoidal aspect.

Horizon and locality. Kona dolomite, Lower Huronian, near Marquette, Michigan.

The holotype and paratype are in the collections of the Department of Geology, University of Wisconsin.

Algal Deposits of the Bad River and Ironwood Formations.

The Bad River dolomite (Lower Huronian) and the Ironwood formation (Upper Huronian) of the Gogebic Range contain algal deposits. These from the latter formation are composed of chert and form a bed which is 5 to 6 inches thick.[12] The structure is laminated with the conspicuous divisions between laminæ from a half to a millimeter apart. The laminæ and the upper surface are domed, with the domes not more than an inch across. The material which the writer had for examination is hardly sufficient for detailed description. The writer has not seen the algal material from the Bad River dolomite. According to Doctor Hotchkiss they do not form colonies, but occur as isolated individuals in the dolomite. They are of domed shape and vary from 3 to 6 inches in diameter.

Pennsylvanian and Permian Algal Deposits.

In southeastern Cowley County, Kansas, the beds belonging to the Crouse limestone member of the Permian system contain an abundance of algal cœnoplases of the "water biscuit" type. A section illustrating the occurrence is as follows:

25. Wreford limestone member (summit of the section).
24. Largely concealed, partly red gritty shale 40 to 50 feet.
23. Brown, medium-grained sandstone ....3 feet.
22. Mostly concealed, some red shale and brown sandstone... 9 feet.
21. Gray semi-crystalline limestone ....4 to 5 inches.
20. Mostly concealed, some shale and brown sandstone ..... 9 feet.
19. Wave ripple-marked, gray weathering semi-crystalline limestone; rarely seen in position, generally occurring as slabs on slopes ....12 inches.
18. Mostly concealed, but some shale and thin limestone..... 11 feet.
17. Two beds of fine-grained gray limestone, weathers full of round vertical holes, rings when struck ....16 to 18 inches.
16. One bed of gray, semi-crystalline limestone, poorly fossiliferous, weathers full of round vertical holes ......12 inches.
15. One bed of gray limestone filled with *Fusulina* 6 inches.
14. Thin-bedded limestone, bedding poorly defined, contains many *Fusulina* and other fossils, many being thinly incrusted with calcareous material which is probably of algal origin...... 15 inches.

[12] Hotchkiss, W. O.: personal communication.

13. Nodular, gray shaly limestone with numerous fragments of fossils. Bedding irregular. Contains many cœnoplases of *Lithothamnium*-like algæ ....2 feet 5 inches.

12. Gray nodular limestone, weathers yellow. Very fossiliferous, containing *Derbya, Bellerophon, Productus,* bryozoa, cœnoplases of *Lithothamnium*-like algæ and other fossils[13]...... 8 inches.

11. Concealed, probably shale ....15 feet.

10. One bed of thin, fine-grained gray limestone............ 4 to 6 inches.

9. Concealed ....6·5 feet.

8. One bed of gray limestone, generally seen as slabs on the slopes ....8 to 10 inches.

7. Concealed, supposedly shale ....16 feet.

6. One bed of gray limestone ....12 to 14 inches.

5. Gray limestone with poorly defined bedding .....3 feet.

4. Mostly concealed, presumably shale, but contains a little limestone ....15 feet.

3. Brittle gray limestone, irregularly bedded ......4 feet.

2. Gray limestone, irregularly bedded and full of *Fusulina* 1 foot.

1. Shaly, nodular gray limestone ....2 feet exposed.

The algal deposits were not seen elsewhere than in the zones in which they have been noted and their occurrence may be coextensive with the distribution of these zones, but because of the weakness of the rocks of which they are composed, exposures are rather uncommon so that the algal material was not seen in very many places.

Only a single species of alga appears to be represented, and it apparently belongs to an undescribed genus. The incrustations about the fossils of zone 14 probably belong to the same species.

Ottonosia new genus.

Irregularly shaped cœnoplases which begin as incrustations around other substances and increase in size through the deposition of material over and around that already deposited. The diameters vary up to about 85 millimeters. Most of the cœnoplases are biscuit-shaped; a few are spherical. In small specimens the shapes appear to have been determined by the shapes of the nuclei. One specimen which has the convex valve of a *Derbya* for a nucleus still retains that shape, the shell being covered with about one eighth inch thickness of

[13] Zones 12 to 17 constitute the Crouse limestone.

algal material. The exteriors are irregular through the presence of little cylindrical-sided domes and their separating depressions. The elevations arise from one another and there is great irregularity in shapes, sizes and degrees of divergence.

The interior structure consists of very thin and closely placed concentric laminæ and these repeat the irregularities of the exteriors. A depression on the surface is apt to be continued into the interior by small lines or streaks of fine sand and mud. These streaks are interpreted as arising from small quantities of mud and sand becoming

FIG. 3.

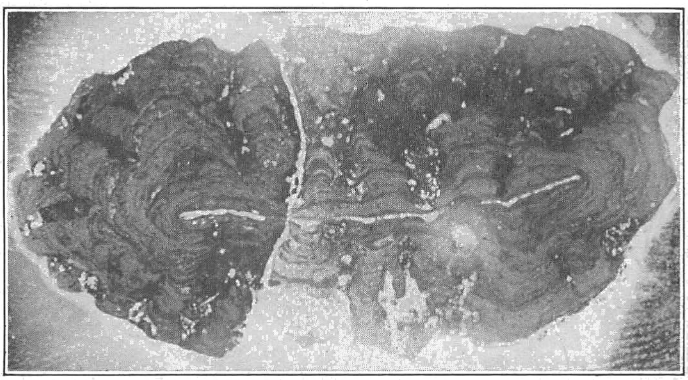

FIG. 3. *Ottonosia laminata* n. sp. X 2. Microphotograph of section of the holotype. The white streak across the middle is a cross section of the shell nucleus. Crouse limestone, near Otto, Kans.

lodged in the depressions between the domes. Some tube-like structures which penetrate portions of the interior may have been produced by the boring of annelids or mollusks, or they may be molds of the thalli or algæ. These are also filled with fine sand and mud. The laminæ vary in thickness; at one place eight were distinguished in a thickness of five millimeters; at another place only five laminæ are present in the same thickness.

Relationships.—In general appearance the cœnoplases of this genus resemble those of *Sphaerocodium* Rothpletz from the Silurian of Gotland, but differ in the general absence of a spherical form and in the nature of the irregularities of the surface. Internally, *Sphaerocodium* is said to have concentric tubes around the nucleus; such are not present in this form. It differs from *Girvanella* Nicholson and Etheridge Jun. in the same respect. The internal structure of the genus *Ortonella* Garwood from the Lower Carboniferous of England is characterized by decided dichotomous, radial tubes, none of which has been observed in this genus. It differs from *Solenopora* Dybowski in the same way. Except for the "water biscuits" of modern lakes and *Lithothamnium,* there are no other genera with which it may be compared and its resemblance to neither of these is very close.

FIG. 4.

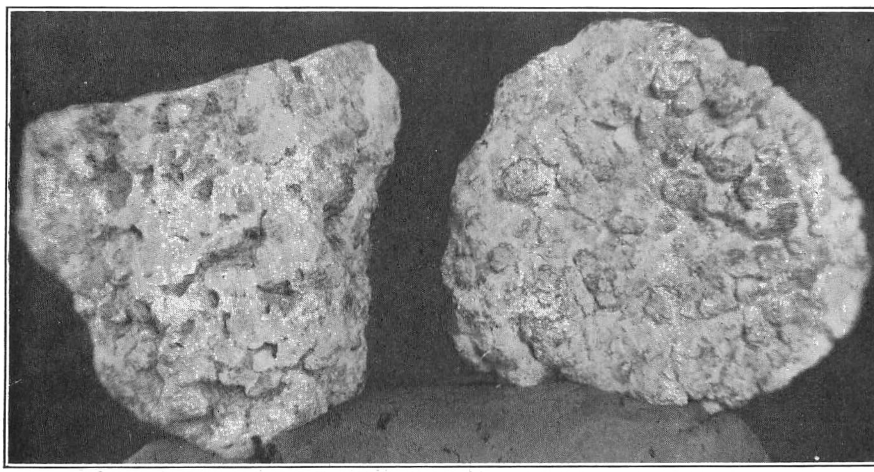

FIG. 4. *Ottonosia laminata* n. sp. Natural size. The thin section was made from the specimen on the left. The specimen on the right shows the irregularities of the surface. Crouse limestone, near Otto, Kans.

The generic name is based on the name of the village near which the type species occurs in abundance. The genotype is *Ottonosia laminata* n. sp.

Ottonosia laminata new species.

FIGS. 3 and 4.

The characters of the species are given in the generic description. The specific name is derived from the laminated structure of the interior.

Horizon and locality. Occurs in considerable abundance in the Crouse limestone member of the Permian in northern Osage County, Oklahoma, and Cowley County, Kansas. It is particularly abundant just north of the little village of Otto, Kansas. It also occurs in the Florena shale at Grand Summit, Kansas.

The holotypes and paratypes are in the collections of the writer.

Osagia new genus.

The Foraker limestone (Pennsylvanian) of southeastern Cowley County, Kansas and Osage County, Oklahoma, particularly in some of the Ekler Canyon exposures, in some horizons contains an abundance of

FIG. 5.

FIG. 5. *Osagia incrustata* n. sp. X 5. Camera lucida drawing of thin section. The light colored areas within the dark represent nuclei. Circular dark areas are cut perpendicular to the long diameters of the cœnoplases. From type locality, Ekler Canyon, about 7 miles southwest of Cedarvale, Kans.

algal cœnoplases of small size. The shapes are such that on casual examination they are apt to be mistaken for *Fusulina*. It is possible that these cœnoplases may represent a new species of *Ottonosia;* but as none attains a large size and the concentric laminæ do not appear to be wrinkled, they are considered the type of a new genus. This view is strengthened by the tendency to develop a fusiform shape. Thin beds of limestone are almost wholly composed of these algal remains.

When first discovered it was thought that possibly these structures might have developed through the chemical inorganic precipitation of material around nuclei. This led to a search for oolite and pisolite. None has been found and it is quite certain that they do not occur in association. This fact, considered in connection with the additional fact that no matter what the nucleus may be, a fusiform shape tends to be developed, makes it quite certain that they are of organic origin.

The cœnoplases are about the shape and size of Fusulina, but are generally a little larger and more robust. Each has a small fragment of rock or shell for a nucleus. In one observed instance the nucleus consists of a small pellet of fine-grained sand and mud. It is probable that anything would serve. Dimensions range to a length of about 7 millimeters and a thickness of about 4 millimeters. The exteriors are imbedded in the rock, but they appear to be smooth or only slightly irregular. The interior structure consists of thin concentric laminæ of which there are from 4 to 6 to a millimeter. No radial structures of any kind were observed.

All of the specimens are so discolored by limonite that it was not possible to photograph them in thin section. The greater part of the limonite occurs within the cœnoplases, the surrounding matrix generally being composed of quite clear calcite. It is considered quite certain that the limonite was precipitated in the cœnoplase at the time it was formed and that there is some genetic connection between the limonite and the algæ which were responsible for the cœnoplases.

Relationships.—In method of development the cœnoplase of this genus resembles all others of concentric laminated structure. The small size, the general absence of a wrinkled exterior and the tendency to assume a fusiform shape are rather marked features of difference.

The generic name is taken from Osage County, Oklahoma, on the northern border of which the cœnoplases occur in abundance. The genotype is *Osagia incrustata* n. sp.

Osagia incrustata new species.

FIG. 5.

The generic description gives the characters of the species, the specific name calls attention to the incrusting habit.

Horizon and locality. Foraker limestone, Pennsylvanian, Ekler Canyon, southern Cowley County, Kansas and northern Osage County, Oklahoma.

The holotype and the paratypes are in the collection of the writer.

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