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How to cite

CAROZZI, Albert V. Complex oöids from Triassic lake deposit, Virginia. In: American Journal of Science, 1964, vol. 262, n° 2, p. 231–241. doi: 10.2475/ajs.262.2.231

This publication URL: https://archive-ouverte.unige.ch/unige:137025
Publication DOI: 10.2475/ajs.262.2.231

[AMERICAN JOURNAL OF SCIENCE, VOL. 262, FEBRUARY 1964, P. 231-241]

COMPLEX OÖIDS FROM TRIASSIC LAKE DEPOSIT, VIRGINIA

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ABSTRACT. Complex reworked oöids are described from a lacustrine limestone intercalated in the Manassas formation (Late Triassic) near Culpeper, Virginia. These oöids are characterized by several sets of concentric or non-concentric rings with intercalations of an argillaceous calcilutite which also builds their nuclei and the interstitial matrix of the deposit. The nuclei are simple or compound. In the first case, they consist of an irregular pellet probably generated by a process of aggregation of aragonite needles. Compound nuclei display two to sixteen oöids embedded in a variable amount of mud. Both types of reworked oöids result from the numerous repetition of phases of oölitization, deposition in a mud where pellets were formed by aggregation, and reworking. These processes must have taken place in the immediate vicinity of each other. Such conditions are actually very common in shallow water environments, lacustrine, lagoonal, or marine.

Complex reworked oöids occur in small number in almost all oölitic limestones but have been frequently overlooked. Their abundance in the Triassic of Virginia is unusual for a carbonate rock. However it is comparable to the situation displayed in many oölitic iron ores where numerous complex oöids indicate reworking phenomena of high complexity.

INTRODUCTION

The oölitic limestone or oölite described in this paper is exposed as a layer of 6 to 9 inches thick in a sandstone quarry, operated by the Virginia Department of Highways, located along State Route 3, about 3½ miles east of Culpeper and one-quarter mile west of Stevensburg, in the north-central Virginia Piedmont.

This interesting rock, first described by Young and Edmundson (1954), is interbedded with the red sandstones and dark-gray to red shales of the Manassas formation of Late Triassic (Keuper) age.

The oölite is buff to light-brown in color. In hand specimen the texture appears medium to coarse-grained, porous, and strikingly uneven. Closer examination reveals individual bodies or oöids with complex internal structures. They are associated with flat lithic pebbles of oölite which are either imbricated or oriented parallel to bedding.

The limestone bed is moreover interrupted several times by sets of dark irregular crusts, usually parallel to bedding, and consisting of superposed layers of fibrous calcite. These crusts may be related to the minor unconformities described by Young and Edmundson (1954) that truncate in places the underlying oöids.

GENERAL MICROSCOPIC DESCRIPTION

In thin section the oölite shows an interstitial cement of microcrystalline to coarsely crystalline calcite with irregular cavities. Clay minerals appear concentrated as films or small pockets along the boundaries of the calcite crystals whereas individuals of secondary quartz and secondary pyrite are irregularly scattered. The cement results from the recrystallization of a homogeneous argillaceous calcilutite into which it grades at numerous places within a single thin section.

Abundant oöids with complex internal structures are set in this rather clear groundmass. They are commonly closely packed and without exception possess dark nuclei of homogeneous argillaceous calcilutite identical to that which forms the original interstitial matrix. Large flat pebbles consisting of a similar argillaceous calcilutite with closely packed oöids are associated with the isolated bodies.

The oöids described in this paper may be subdivided into simple and reworked (multi-cycle) types. The simple ones are either superficial (core surrounded by a single accretionary ring) or normal (core with two or more concentric rings).

The reworked types are subdivided according to the number of nuclei surrounded by the common envelope of concentric rings. They are called simple in the case of one nucleus and compound when they display two or more nuclei.

SIMPLE SUPERFICIAL AND NORMAL OÖIDS

These two types are well represented in the investigated limestone. The normal oöids may display numerous concentric layers of clear fibrous calcite and both types reach maximum sizes of 0.7 to 1.0 mm. Many superficial and normal oöids are characterized by small irregular nuclei of argillaceous calcilutite with sharp edges and straight boundaries. However, the larger nuclei are subspherical to ellipsoidal and even appear as cylindrical rods with rounded ends. This association of small angular and large rounded nuclei could result from the reworking of a calcareous mud in which lumps and pellets had been formed by a process of aggregation of aragonite needles similar to the one described by L. V. Illing (1954, p. 27 to 35) in the Bahama Banks. Eolian action should also be considered as a partial agent of transportation of the nuclei into the agitated waters where concentric coatings formed (Young and Edmundson, 1954).

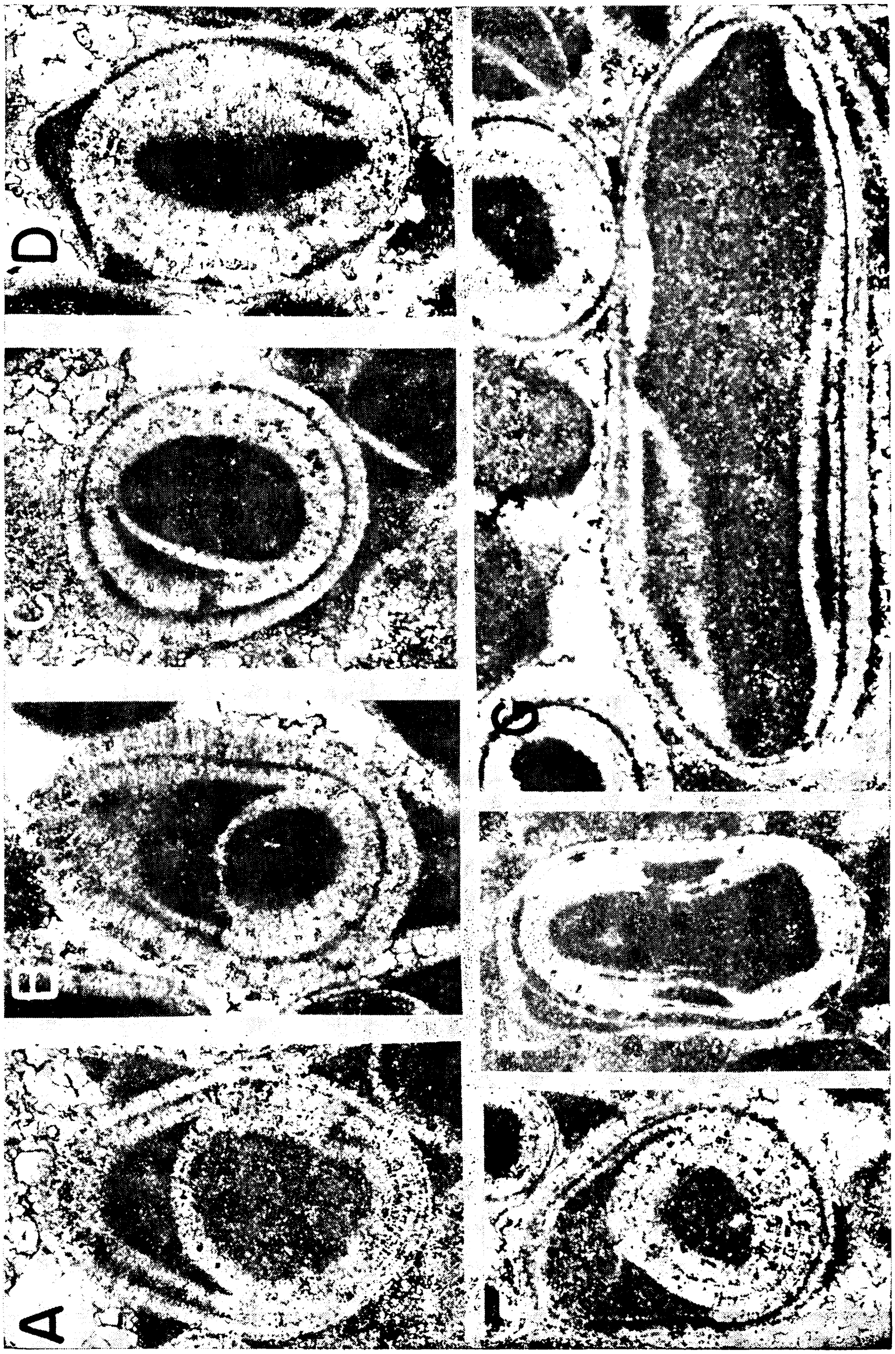
When angular nuclei are submitted to oölitization processes that tend toward the development of accretionary spheres, their irregularities tend to be smoothed out during the deposition of the first carbonate layers which are thicker and more numerous in the depressions, thinner and less numerous over the protruding areas. These conditions, which are particularly well displayed by the superficial oöids, gradually disappear with the addition of new concentric layers. Many aragonitic oöids formed today in the Great Salt Lake, Utah, around cores of irregularly shaped mineral fragments display these features very clearly (Eardley, 1938, p. 1364, pl. 9-A). The same can be said for the concentric coatings developed around shell fragments.

SIMPLE REWORKED OÖIDS

Reworked oöids display between sets of concentric or non-concentric rings continuous and discontinuous residues of the sediment in which they were temporarily deposited between episodes of reworking. By analogy with the situation described in the Bahama Banks the oöids could be visualized as rolled around alternately in an environment where aragonite needles were aggregating into mud clumps and alternately in an environment where concentric coatings were formed.

In this particular limestone, the residues systematically consist of argillaceous calcilutite indicating that the oöids were repeatedly deposited and re-

PLATE 1



Simple reworked oöids. Nicols not crossed. X 83.

worked out of essentially the same type of mud. The simple reworked oöids show a wide range of shapes and reach a maximum size of 1.3 mm. The best developed commonly display elongated nuclei whose irregularities tend to be smoothed by the initial concentric coatings. Two to three distinct sets of argillaceous calcilutite residues may be present separating the concentric rings belonging to three or four distinct phases of oölitization (pl. 1).

The residues of argillaceous calcilutite are particularly thick in the depressions of the surface of the particular concentric layer underlying them. This indicates that abrasion due to the reworking processes tends to smooth out the contours of the small bodies. Therefore two smoothing processes alternate, one by abrasion during reworking, the other by accretion during oölitization.

Each phase of coating is represented either by one rather thin ring of fibrous calcite or by a thicker one consisting of two or three distinct layers directly superposed over one another. Because of the general environment suggested before, these layers were most certainly aragonitic when first deposited.

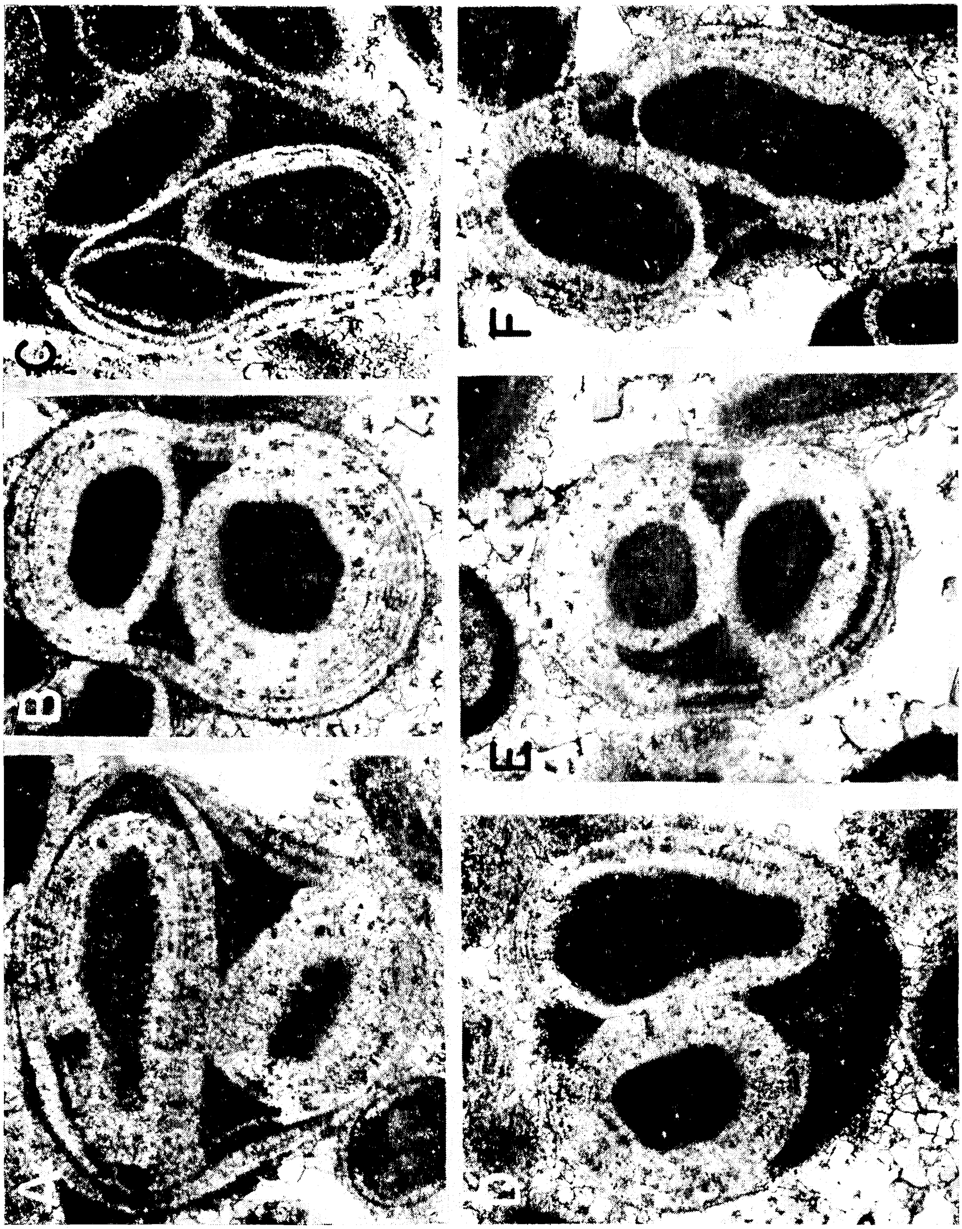
The varieties of sections through simple reworked oöids are better shown by illustrations (pl. 1) than described by words and can be readily explained by the random intersection of accretionary bodies developed around irregularly elongated nuclei. However, the strongly non-concentric appearance of many of these oöids, due to rather large and irregular residues of argillaceous calcilutite, should be pointed out.

Simple reworked oöids display interesting features of recrystallization which result from their peculiar internal structure of alternating layers of calcilutite and fibrous concentric coatings. The main effect of the recrystallization is an extension of the fibrous crystals of the concentric rings into the intercalated calcilutite residues resulting into large radial crystals with single optical orientation across the entire succession of layers.

This process can take place only where the concentric layers are closely spaced and parallel to each other, as soon as they diverge appreciably the growth of optically continuous crystals is no longer possible. Therefore, some radial segments of a given oöid will be entirely converted into fibro-radiated calcite crystals with faint traces of concentric structure. The areas of incomplete recrystallization often show radially aligned patches of the intercalated argillaceous calcilutite whereas other segments have remained unaffected (pl. 1-A, E). The completion of the recrystallization may entirely destroy the reworked character of any of these oöids.

Another effect is to make the recrystallized segments appear at first glance thicker than the nonrecrystallized ones as if the oöids had developed preferentially along the former radii. However, this is an illusion because single concentric rings may be traced unchanged from one zone to the other (pl. 1-A, E, and F). Broken and recoated oöids as well as distorted ones described in many carbonate and ferruginous deposits in association with reworking phenomena (Carozzi, 1961a,b) are very rare in this limestone. Berg (1944, p. 14) pointed out that such oöids appear often ruptured along radial lines indicating an almost instantaneous recrystallization from a concentric structure into a predominantly radial one much weaker upon impact. The rarity of broken oöids

PLATE 2



Compound reworked oöids with two nuclei. Nicols not crossed. X 75.

in the described limestone indicates a strong resistance of the complex oöids to mechanical rupture. This situation results from the absence of general recrystallization due to their internal structure of concentric rings separated by thick zones of argillaceous calcilutite.

COMPOUND REWORKED OÖIDS WITH TWO NUCLEI

In such bodies two oöids, superficial, normal, or themselves compound are surrounded by common sets of concentric rings separated by continuous or discontinuous residues of argillaceous calcilutite. The two oöids forming the cores of the compound bodies, usually in reciprocal contact, are of variable shape and size. They are surrounded by a variable but quite large amount of interstitial calcilutite which builds the remaining portion of the reworked fragment but may be missing over the protruding oöids as a result of abrasion. Apparently the oöids were originally deposited in the argillaceous calcilutite in sufficient number to be predominantly in reciprocal contact. Then irregular fragments containing two oöids (or more in other cases) were isolated, reworked, and abraded to a variable extent before undergoing their new phase of oölitization.

The common envelope consists usually of two to three sets of layers of fibrous calcite separated by one to two rather thin intercalations of argillaceous calcilutite continuous or limited to the depressions of the particular accretionary surface underlying them (pl. 2). As in the preceding types, each phase of oölitization is represented either by one rather thin ring of fibrous calcite or by a thicker one consisting of two to three distinct layers directly superposed over one another.

If one of the oöids forming the nucleus is itself compound with two nuclei for instance, the generation of the final body has required at least five periods of oölitization separated by as many phases of deposition in a argillaceous calcilutite and of reworking out of it.

The oöids forming the nuclei of this type of compound reworked bodies are usually small because the maximum size of the latter which varies between 0.5 and 1 mm with a maximum frequency between 0.7 and 0.8 mm is not very much larger than that of the simple reworked types. This indicates a size-limit above which oöids could not be set in motion in that particular environment (Carozzi. 1960, p. 240 to 244).

The recrystallization of these compound oöids generates large radiating crystals of calcite in the portions where the concentric rings of the oöids forming the core are close enough and parallel to those of the common envelope. Such a situation is present mostly at the two opposed extremities of the compound bodies, and consequently the two oöids of the nucleus give the appearance of having grown preferentially away from each other (pl. 2-B, E).

COMPOUND REWORKED OÖIDS WITH THREE NUCLEI

These oöids display a greater variety of shapes than the preceding type because of the geometrical possibilities afforded by three bodies under a common envelope of concentric rings. The oöids forming the nuclei, in most cases in reciprocal contact, may be superficial, normal, and simple reworked. The compound types are rare or absent because these oöids are rather small as a

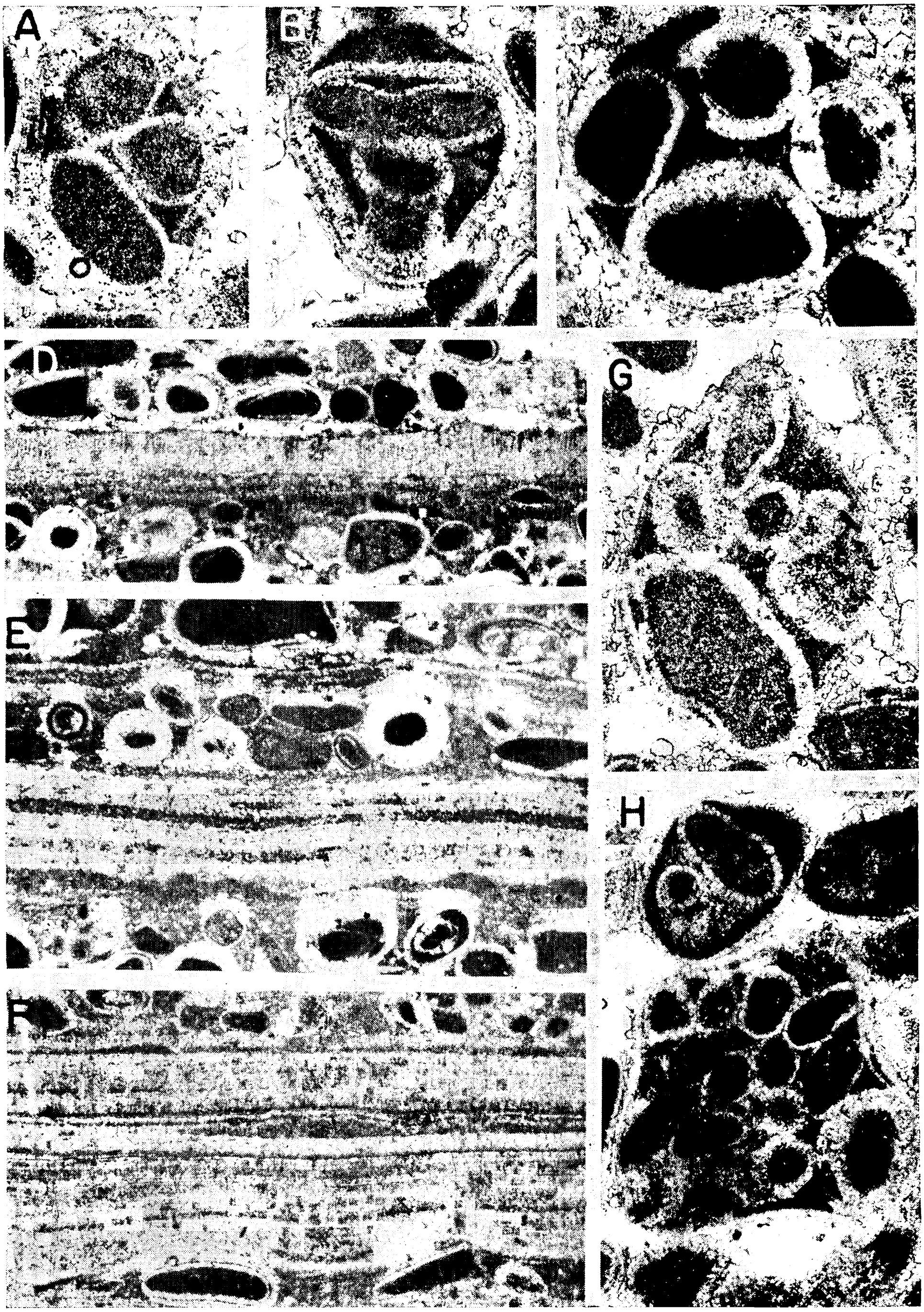


PLATE 3

Compound reworked oöids with three nuclei (A and B), with four or more (C, G, and H). Curtis of fibrous calcite (D, E, and F). Nicols not crossed. X 58, except D, E, and F, X 23.

result of the fact that the maximum size of the compound bodies (0.55 to 1.3 mm, with a maximum frequency between 0.7 and 0.9 mm) is not appreciably larger than that of the oöids with two nuclei.

Large amounts of interstitial argillaceous calcilutite have been preserved by the abrasion related to the first phase of reworking in order to build a body of reasonably regular shape (pl. 3-A, B).

The common envelope consists usually of two to three (exceptionally four) layers of fibrous calcite separated by one to two rather thin intercalations of argillaceous calcilutite, sometimes strikingly continuous in spite of their thinness. As in the preceding cases, each phase of oölitization is represented by one thin ring of fibrous calcite or by a thicker one consisting of several distinct layers directly superposed to one another. The recrystallization of these compound bodies offers identical aspects to those of the preceding types.

COMPOUND REWORKED OÖIDS WITH FOUR OR MORE NUCLEI

These oöids are not very abundant in the investigated limestone. Their shape is quite irregular and their maximum size which varies between 0.65 and 1.3 mm with a maximum frequency between 0.9 and 1.1 mm is slightly larger than that of the other kinds of compound bodies. Consequently the oöids forming their core, which range in number from four to sixteen, are quite small, superficial, normal, and simple reworked but compound types were not observed (pl. 3-C, G, and H).

The common accretionary envelope is rather thin and consists of one to two layers, occasionally three. The intercalations of argillaceous calcilutite are very thin, continuous or discontinuous (pl. 3-C, G, and H). Each phase of oölitization appears to be represented only by one thin layer of fibrous calcite as may be anticipated from the relatively large size of the compound bodies, probably very close to the lifting power of the agitated waters.

FLAT PEBBLES OF OÖLITIC ARGILLACEOUS CALCILUTITE

Associated with the above-mentioned types of oöids are abundant flat pebbles of oölitic argillaceous calcilutite which are either imbricated or oriented parallel to bedding.

These pebbles are actually irregularly shaped sheets which reach a surface of 3 to 4 cm^2 but a thickness of only 0.5 to 1.5 mm. They correspond often to one layer of oöids some of which may even protrude from the boundaries but are rarely truncated. The flat pebbles are the largest products of reworking, and their limits seem to correspond to cracks parallel and perpendicular to potential bedding planes. Some of them show one layer of accretionary calcite, often discontinuous and limited to the depressions of their surface which would make them compound superficial oöids, but in most instances, they were too large to be coated.

IRREGULAR CRUSTS OF FIBROUS CALCITE

The investigated oölite repeatedly displays a banded appearance due to the presence of irregular crusts of fibrous calcite.

These crusts vary in thickness from 0.30 to 0.50 mm and consist of numerous thin layers of fibrous calcite directly superposed or separated from each other by thin intercalations of argillaceous calcilutite usually devoid of oöids. The crusts seem to follow potential bedding planes. They are either isolated or associated into thicker units reaching 1.5 to 2 cm in which they are parallel or intersect each other along acute angles isolating lenticular portions of argillaceous calcilutite with oöids (pl. 3-E, F).

The lower boundary of each individual crust is very irregular and apparently follows an erosional surface cut into the underlying argillaceous calcilutite. Along that surface, single oöids may protrude to a variable extent or even be truncated in the same manner as along the minor unconformities described by Young and Edmundson (1954). The upper boundary of each individual crust is a smooth and slightly undulated surface occasionally coated with a film of argillaceous material (pl. 3-D). No reworked fragments of these crusts have been observed in spite of their being immediately overlain by large complex oöids. The identity in composition, structure, and thickness (0.03 to 0.05 mm) of the layers of fibrous calcite and the concentric rings of the oöids indicates that the crusts were generated in quiet conditions by widespread precipitation on the upper surface of freshly deposited argillaceous calcilutite with oöids. A comparison with algal mats forming today in the Great Salt Lake, Utah (Carozzi, 1962) does not suggest an organic participation in the genesis of these crusts.

Similar crusts were described by De Lapparent (1922, p. 1304-5 pl. 39, figs. 2 to 4) in some oölites of the Carboniferous of Belgium and interpreted in the same manner as in this paper. However, both occurrences are different from the crusts formed today in the Great Salt Lake, Utah, by the precipitation of aragonite during quiet periods over the upper surface of freshly deposited oölitic sands. Indeed, these crusts contain numerous oöids that were cemented together when the precipitate filled their interstitial spaces. Moreover, they are frequently broken by storms and tossed on the beaches as flat pebbles called hydrogenic shingles (Eardley, 1938, p. 1387-88, pl. 13).

CONCLUSIONS

It may be concluded with Young and Edmundson (1954) that the investigated oölite represents deposition in a shallow lake whose level fluctuated under climatic control. The nonmarine nature of the deposit is indicated by the complete absence of marine fossils. The presence of plant remains, coal seams, and dinosaur footprints in nearby Triassic rocks confirm this environmental interpretation. However, it is not excluded that this lake might have been as salty as the present Great Salt Lake in Utah.

The microscopic study reveals that the complex reworked oöids result from numerous repetitions of four distinct phases as follows:

1. Formation of concentric rings around irregular nuclei which probably originated from the reworking of a calcareo-argillaceous mud in which pellets had been generated by a process of aggregation of aragonite needles.

2. Transportation and deposition of these oöids in the calcareo-argillaceous mud from which their nuclei originated.

3. Reworking of some of the oöids with attached residues of the mud and redeposition into the environment where concentric rings were formed.

4. Temporary interruption of this succession of events by minor unconformities and deposition of crusts of fibrous calcite.

The repetition of these phases implies that the processes of oölitization, reworking, transportation, and deposition must have taken place in the immediate vicinity of each other. These conditions are actually very common in shallow water environments, lacustrine, lagoonal, or marine. Complex oöids are rarely so abundant as in the investigated limestone. In most of the cases they appear dispersed among normal oöids and therefore have been frequently overlooked in spite of the critical information they afford on the small-scale mechanisms of sedimentation.

DISCUSSION

Excellent descriptions of complex reworked oöids in the Triassic of Northern Germany were given by Kalkowsky (1908, pl. IV, fig. 6; pl. V, figs. 3, 4). He considered these bodies to result from the activity of organisms related to stromatolites, an opinion which is no longer accepted at the present time.

Similar complex oöids with intercalated zones of argillaceous calcilutite have been described by Bradley (1929, p. 221-222, pl. 48, fig. A) and by Schoff (1937, p. 167-169, figs. 1, 2) in the Green River Formation of central Utah. However, the first author postulated a growth essentially in place on the bottom or in partial suspension in the silty mud during which the oöids occasionally moved by storms would incorporate appreciable amounts of the silt stirred up into suspension. The second author held similar views. He considered the two or three oöids forming the nuclei of the compound bodies as distinct centers of growth which eventually interfered and which should demonstrate the genesis of the oöids in place in a non-agitated environment.

L. Cayeux was among the first to consider the complex oöids as the products of intraformational reworking and to realize the basic importance of this process in the genesis of oölitic iron ores. He described (1922, p. 758 and 908, pl. XXIX, fig. 63) complex reworked oöids particularly from the Callovian of France which displayed up to six oöids surrounded by a simple or double envelope of concentric rings. Similar forms were illustrated and discussed by Berg (1944, p. 15, figs. 8 to 14) in the Jurassic iron ores of Germany.

As a result of his experience of oölitic iron ores, Cayeux realized clearly the significance of complex reworked oöids in carbonate rocks. He insisted on the fact that the role of reworking processes had been underestimated in the genesis of oölites (1935, p. 225-226). He described (1935, p. 243 to 246, pl. 17, fig. 66) an oölite of lagoonal origin intercalated in the green marls of the Sannoisian near Melun (Seine-et-Marne), France, which is almost identical to the limestone in the Triassic of Virginia. It contains simple and compound reworked oöids in a cement of microgranular calcite, locally porous, which originated from the recrystallization of an argillaceous calcilutite. The latter also builds the irregular and sub-rectangular nuclei of all the types of oöids. Many of them display initial concentric coatings with variable thicknesses followed by well developed rings which may be separated by up to three intercalations of argillaceous calcilutite. These oöids present features of recrystallization identical to those described in this paper.

ACKNOWLEDGMENTS

The collaboration of R. S. Edmundson and R. S. Young of the University of Virginia who supplied the investigated samples is deeply appreciated. The writer is grateful to J. E. Sanders for critical reading of the manuscript and for suggesting the comparison with the environment of the Bahama Banks.

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