A PECULIAR OOLITE FROM BETHLEHEM, PENNSYLVANIA.

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The material here described occurs in Lerch's quarry, on the west side of Monocacy Creek, one-quarter mile north of the northwest corner of the borough of Bethlehem, and a mile and a half north of Lehigh River, near the center of the Allentown quadrangle, in Northampton County, Pennsylvania. The rock quarried is a magnesian limestone belonging to the "Allentown" formation, which represents the Upper Cambrian (Ozarkian) in this region.

A variety of geologic phenomena is exhibited at the locality. In the southern portion of the quarry the beds are thrown into a fine anticline, the north limb of which is cut by a vertical fault marked by brecciation and shearing of the rock. In the northern part the beds are steeply upturned, and show slickensides where they have slipped over one another. Tension cracks filled with secondary dolomite and quartz crystals are numerous, and a miniature cave containing tiny stalactites and beautiful twinned calcite crystals was at one time opened in the course of quarrying operations. Well-developed colonies of several types of cryptozoon, splendid ripple-marked surfaces, and strata crowded with oolite grains are also to be seen at various horizons.

In these oolitic beds the separate grains, or ooids, are usually from 1 to 1½ mm. in diameter, but occasionally attain 5 mm. They are normally spherical in shape, although elongated or irregular lumpy forms are not uncommon, especially among the larger ones. The color of the grains is usually a dark gray, and they stand out distinctly against the paler tint of the enclosing rock.

The details of their structure can best be seen when sections are examined under a low-power microscope. They sometimes show a distinct concentric arrangement of lighter and darker layers, with well-rounded grains of quartz or calcite as nuclei, but in most cases recrystallization has obliterated all traces of both nucleus and concentric rings. A carbonaceous pigment is usually visible, and minute irregular or subangular masses of limonite, probably pseudomorphous after pyrite, are dotted here and there, being especially abundant near the surfaces of the grains.

In one layer about 20 cm. in thickness, which has been removed from much of the quarry face, but is still (at time of writing) exposed in place at the extreme north end, the majority of the ooids show, when broken across, a remarkable "half-moon" aspect, being divided parallel to the bedding into a light and a dark portion, the latter being the lower. In most of them the light portion is the larger, but in rare instances the dark may occupy nearly the entire grain.

When examined under the microscope the dividing line between the two parts is found to be, as a rule, convex toward the white one, but in a few instances it is straight across, irregularly curved, or even slightly concave. The two parts are alike in crystallinity, both being much coarser than the ground-mass of the rock; the black pigment may be seen to spread in films between the individual crystals as well as to be enclosed by them. The nuclei occasionally remaining are no longer in the centers of the grains, but always well toward the bottom of the dark portions. The tiny specks of limonite are practically absent from the white portions, but are often present all the way around the dark ones.

Throughout the bed in which these "half-moon" ooids occur there are lens-shaped areas in which the grains are of the ordinary type. These lie in the centers of blocks formed by the intersection of bedding and joint planes. The ooids in them are also mostly recrystallized, but as a rule are not as coarse-grained as the divided ones.

Table of analyses.

	1.	2.	3.
CaO	33.10	30.40	......
MgO	17.84	19.71	......
FeO	0.25	0.11	......
CO_2	45.70	45.57	......
Al_2O_3	0.23	0.32	......
Fe_2O_3	1.33	1.90	......
SiO_2	0.52	0.68	......
H_2O	0.32	0.44	......
C	0.79	1.21	......
	100.08	100.34	......

Calculated mineral compositions.

	1.	2.	3.
Dolomite	81.65	89.98	73.32
Calcite	14.78	5.31	24.25
Siderite	0.40	0.18	0.62
Kaolin	0.58	0.80	0.36
Quartz	0.25	0.31	0.19
Limonite	1.55	2.21	0.89
Carbon	0.79	1.21	0.37
	100.00	100.00	100.00

1. Composition of the oolitic limestone.
2. Composition of the ooids which have weathered out.
3. Calculated composition of the matrix, assuming that the ooids make up about half the rock.

Although the rock has probably undergone some alteration since its original deposition, it seemed worth while to make an analysis of it, the results of which are given in column 1, above. This shows it to be a high-magnesian limestone. It is not possible to separate the ooids from the matrix in the fresh rock, but where slight weathering has taken place the ground-mass has become soft and sandy, and they stand out in relief and can readily be picked out. In the weathering process they have no doubt been altered slightly, so that their original composition is indeterminate, but an analysis, given in column 2, shows them to differ from the rock itself to a greater extent than can be accounted for by weathering.

Comparison of columns 2 and 3 in the table shows the ooids to be higher in dolomite, quartz, kaolin, limonite, and carbon, and lower in calcite and siderite than the matrix.

That quartz and kaolin should be higher is to be expected, for grains of these minerals acted as nuclei for the formation of the ooids in the first place. That carbon should be higher is also normal, for low forms of life no doubt took part in the deposition of the concentric coats of the carbonates.

The greater amount of limonite is probably to be correlated with that of carbon, for the former has been produced by the decomposition of pyrite, precipitated from circulating iron sulphate solutions by the carbonaceous matter. The reason for the greater amount of dolomite and smaller of siderite is discussed later.

The significance of practically all of the above-described features becomes evident when the probable mode of formation of the "half-moon" oolite is considered. When the ooids were first formed they no doubt consisted of aragonite, whereas the matrix was dolomite-mud. Mixed with the aragonite, in varying amounts in the different concentric layers, was the carbonaceous pigment. After the solidification of the sediment into rock and the development of joint cracks (but before the uptilting of the beds) waters penetrated along these cracks and along the bedding planes. Since aragonite is more soluble than the dolomite of the matrix, it dissolved away, leaving behind the carbon and the nuclei—sand grains and bits of kaolin—in some cases stripped of all concentrically deposited aragonite, in others still retaining a few layers. These settled to the bottom of the cavities in heaps, the shapes of which varied with the sizes of the nuclei and the stage in the solution process at which they fell into the masses of carbon powder.

At some later period water again traversed the rock, but this time conditions were favorable to deposition instead of solution, and secondary dolomite filled up all openings in the rock, tension and joint cracks as well as the holes left by the removal of the ooids. As is usual in the recrystallization of carbonate rocks this secondary material tended to approach the normal dolomite ratio, although as the analysis shows, a slight isomorphous admixture of calcium and ferrous carbonates still remained. The secondary crystallization took place so slowly and quietly that the heaps of carbonaceous dust were not disturbed, but merely enclosed by the crystal grains, and their shapes preserved.

The deposition of pyrite took place at still a later time. Migrating solutions brought in ferrous sulphate, which was reduced to sulphide by the carbon near the surface of the normal ooids, and around the black part of the divided ones. Apparently the rearrangement of the carbon particles in the latter rendered them more readily attacked, for both microscopic examination and the analysis show them to be the higher in limonite, which now takes the place of the pyrite. This last change, which represents the latest chapter in the history of the rock, was evidently brought about by the action of oxygen-bearing rain water.

Ooids exhibiting all stages of these various processes are shown in the figures, examination of which will leave no doubt that this rock, which at first sight appears so remarkable, has had the comparatively simple origin here outlined.

EXPLANATION OF PLATES.

Plate 40.

Fig. 1. A cross section of the oolite rock, natural size. Shows division of ooids into black and white portions, and lens-shaped patch in which many are unchanged, in the left-center. Cat. No. 88448, U.S.N.M.

2. The central portion of the same specimen, enlarged 5 times. Shows coarse crystallization of ooids, variable though usually convex dividing line between black and white portions, nuclei central in unchanged grains, but dropped into black portions in the divided ones.

Plate 41.

All enlarged 40 times.

Fig. 1. Ooid showing nucleus but little displaced from center.

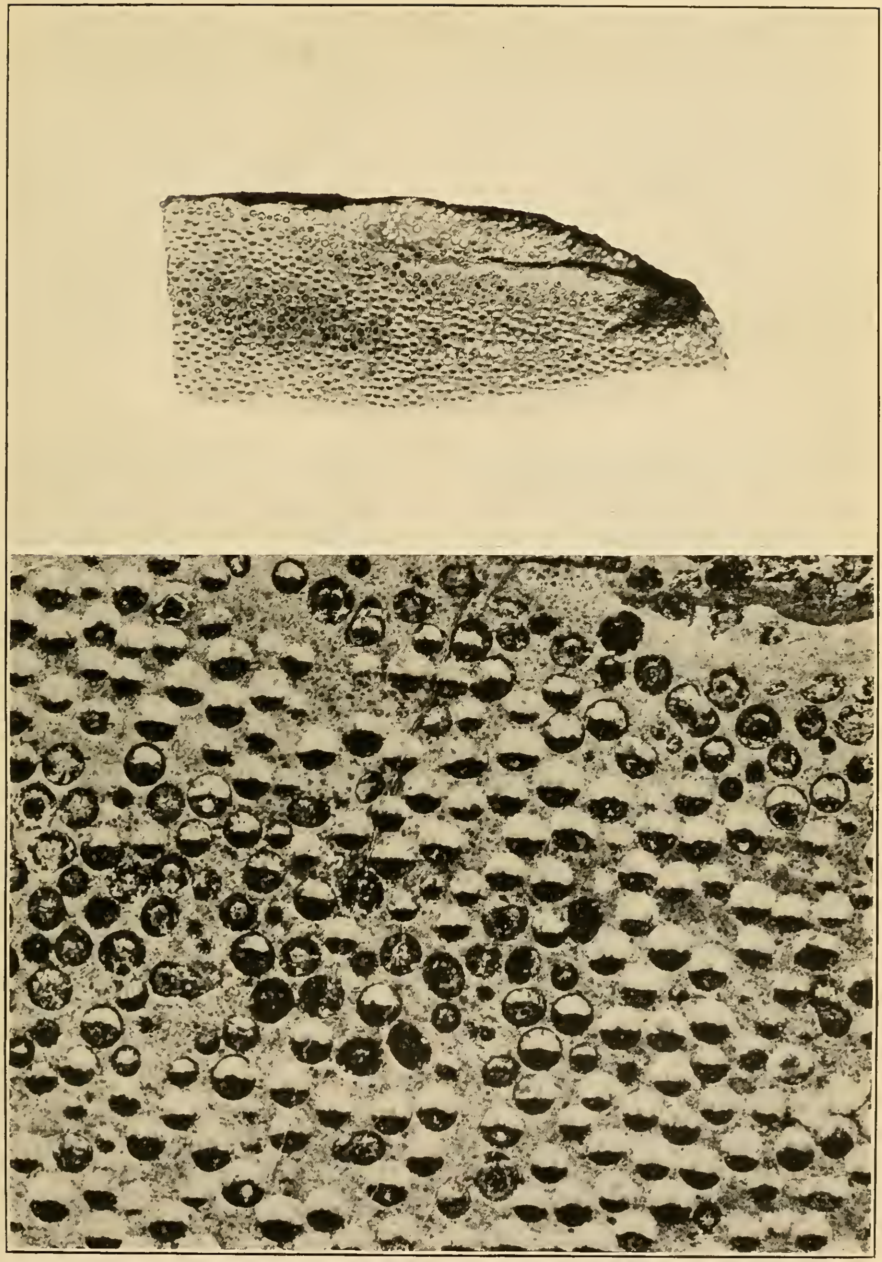
2. Nucleus, retaining several concentric coats, sunk in dark portion of ooid, the dark material being heaped up over it.

3. Nucleus, deprived of concentric coats, sunk in dark portion of ooid with less heaping up of material; specks of limonite surrounding dark portion prominent.

4. Nucleus entirely dissolved away, and line between dark and light portions of ooid straight.

5. An elongated ooid, with its nucleus of corresponding shape; the latter sunk in dark portion, which was, however, too viscous for it to fall flat.

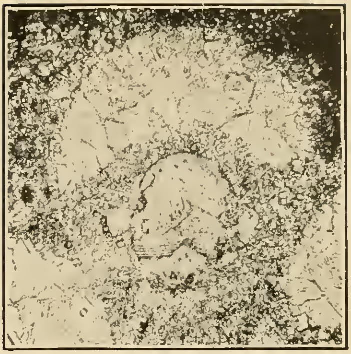
6. An ooid with two nuclei.



CROSS SECTIONS OF OOLITE ROCK FROM BETHLEHEM, PA.

FOR EXPLANATION OF PLATE SEE PAGE 156.

1



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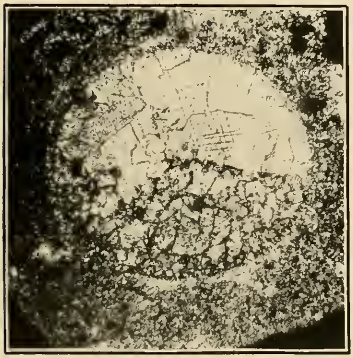

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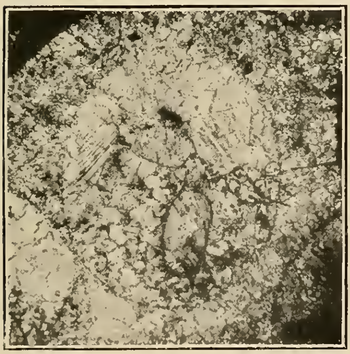

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6

SECTIONS SHOWING STRUCTURAL DETAILS IN OOLITE FROM BETHLEHEM, PA.

FOR EXPLANATION OF PLATE SEE PAGE 156.