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Cave ooids in a Tertiary karst shaft at Pogorzyce, southern Poland

ABSTRACT: The fossil cave ooids have first been reported from splash cups occurring in several horizons of alternating flowstone and sandy layers filling a Tertiary karst shaft at Pogorzyce, Cracow Upland. The study of the internal structure of the ooids shows the concentric laminae being primary, and the radial structure resulting from wet recrystallization.

INTRODUCTION

Cave ooids (cave pearls, cave pisoids) occur, as a rule, as loose deposits in shallow depressions (splash cups) in the floor of cave or mine galleries. Sedimentary conditions of such ooids, their morphology, internal structure and recrystallization processes have been well recognized i.a. by Baker & Frostick (1947, 1951), Kirchmayer (1963, 1964), Donahue (1965, 1969), and Gradziński & Radomski (1967). As far as the present authors know, the papers hitherto published deal only with Holocene cave ooids. The finding in a fossil karst shaft at Pogorzyce in the Cracow Upland, southern Poland, permits comparisons between the fossil and Recent cave ooids, especially concerning their recrystallization processes.

Acknowledgements. Docent K. Bogacz helped to find the ooids, Docent M. Krysowska-Iwaszkiewicz studied the heavy minerals, Docent A. Manecki made X-ray analyses, Docent F. Szymakowska drew the figures, and finally, Dr. E. Turnau, Docent S. Gąsiorowski and Dr. G. Haczewski read the final draft of this paper. The authors are greatly indebted to all these persons.

GEOLOGICAL SETTING

The Pogorzyce quarry is situated in the western part of the Cracow Upland, 4 km south of Chrzanów (Fig. 1). The rocks worked there are limestones of the Gogolin Formation (lowermost Middle Trias), thin, medium and thick bedded. The quarry is situated in the northern slopes of the Płaza hills, which correspond to a horst of a Miocene age (*cf.* Siedlecki 1952, Bogacz 1967). The upper part of the horst consists mainly of Middle Triassic limestones (locally secondarily dolomitized), up to 50 m thick (Fig. 2). They are underlain by Lower Triassic and Stephanian deposits. The Quaternary of the Płaza hills is represented by fluvioglacial sands and by loess.

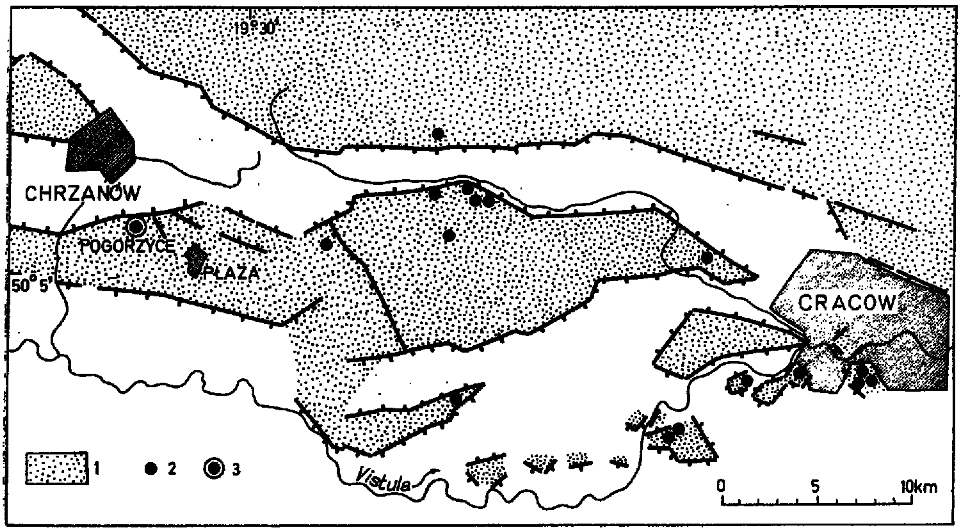

Fig. 1. Geologic sketch-map of the area between Cracow and Chrzanów
1 more important Miocene horsts, *2* karst shafts with Palaeogene filling of redeposited Cretaceous sands, *3* Pogorzyce karst shaft

In the Palaeogene, a vast peneplain was formed in the investigated region (Klimaszewski 1958), which was later faulted, particularly at the south (Dżułyński 1953, Bogacz 1967). The top surface of the Płaza hills seems to be a fragment of a Palaeogene peneplain, little changed in the Neogene and Quaternary. The whole area between Chrzanów and Cracow (*cf.* Fig. 1) was covered by marine Tortonian clays (*cf.* Radwański 1968), subsequently eroded away on horts and now preserved mainly in grabens.

KARST SHAFT

The fossil karst shaft with cave ooids was exposed in the southern wall of the lower exploitation level (*cf.* Fig. 2). The authors studied the shaft as exploitation advanced in 1963–1967. The upper part of the shaft was destroyed before any observations were made; according to the information received at the quarry, it was steeply inclined southward and also completely filled with deposits, mainly sands.

The part of the shaft accessible to the authors was almost vertical, suboval in transverse section, 2—3 m in diameter. Within the deposits filling the shaft (*cf.* Fig. 3), two main generations may be distinguished: an older one, represented by calcite flowstones on the walls and by a club-shaped stalagmite; and a younger one, represented by deposits gradually filling the shaft. The latter consist, from bottom to top, of loose sands containing a layer somewhat cemented with calcium carbonate, a laminated layer (described in detail below) with ooids and a thick flowstone layer with sporadic sandy laminae.

The sand deposited in the shaft is generally fine- to very fine-grained, with local admixtures of coarser grains, exceptionally up to 4 mm in diameter; the sand is well to moderately sorted.

Heavy minerals were studied by Docent M. Krysowska-Iwaszkiewicz, according to whom the poor assemblage (with zirkone predominating and subordinate rutile) indicates that the source rocks were neither Quaternary nor Cretaceous deposits, but rather the Kwaczała Formation (Stephanian) or the Buntsandstein.

Though it is not possible to date exactly the deposits in the shaft, a Palaeogene — Early Miocene age may be suggested (*cf.* Gradziński 1962). Similar vertical shafts filled mainly with sands occur in the same region in the Jurassic limestones to the east of Pogorzyce (*cf.* Fig. 1). These shafts extending downwards from the Palaeogene peneplain surface are filled with redeposited Cretaceous sediments, and belong to a phase of karstification prior to the Miocene faulting (Gradziński 1962, Głazek & al. 1972). Different provenance of the clastic material in the Pogorzyce shaft may be explained by the erosional limit of the Cretaceous deposits situated east of Pogorzyce at the close of the Palaeogene (*cf.* Alexandrowicz 1969).

THE OOID-BEARING LAYER

The layer with ooids, 1.6 m thick, consits of generally horizontal laminae, a fraction of millimeter to 2 mm thick. Sets of laminae consisting of sand cemented with calcium carbonate alternate with those of calcitic flowstone laminae. Particular sets are usually a few milimeters thick. Throughout the layer, there occur numerous small depressions (3—8 cm in diameter), their depth being usually four to six times less than the diameter. The depressions are developed mainly in the sandy laminae and are, as a rule, covered by a thin flowstone layer (Fig. 4). The maximum density of depressions in a single horizon is 40 per 1 sq m. Commonly, the depressions are developed one above the other in successive horizons, but this is not a rule.

The depressions appear to be typical splash cups, such as known in the Recent caves. The depressions are usually filled with sand somewhat coarser than that in the neighbouring laminae and frequently also with small fragments of crushed calcitic laminae. The ooids occur in several depressions, two to twenty specimens in one depression (Pl. 1). Sporadic single ooids were found outside depressions, presumably displaced from the nests by strong water dripping.

The maximum diameter of the ooids is 16 mm, but specimens of a few milimeters in diameter prevail. The surface is, as a rule, smooth but not shiny (Pl. 2, Fig. 1). Only few specimens have a cauliflower structures on parts of their surface (Pl. 2, Fig. 2). Most ooids are spherical. The X-ray analyses have shown that both ooids and flowstone laminae are calcitic.

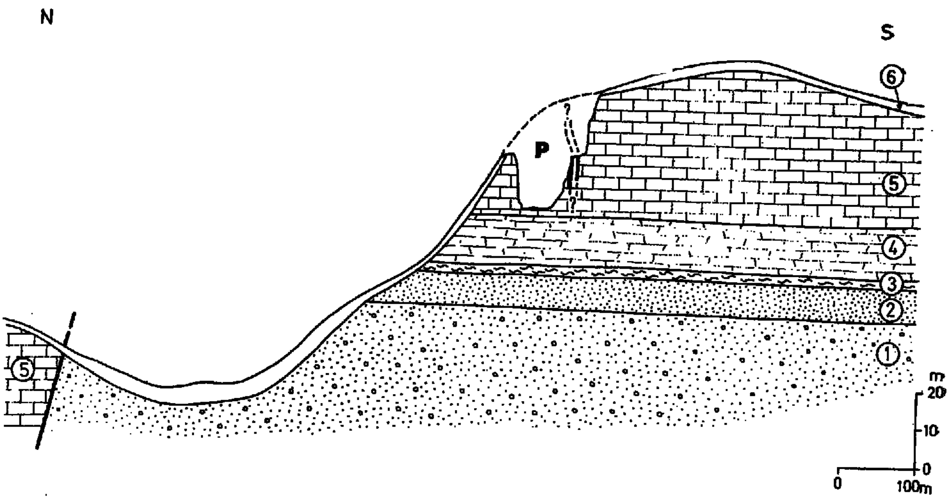

Fig. 2. Section of the northern edge of the Płaza horst, at the Pogorzyce quarry (*P*) in which the karst shaft is exposed
1 sands and sandstones of the Kwaczała Formation (Stephanian); *2*—*4* Lower Triassic: *2* sands, *3* clays, *4* dolomitic marls; *5* Middle Triassic limestones; *6* Quaternary

INTERNAL STRUCTURE OF OOIDS

The nuclei consist of micritic calcite, dark due both to very small dimensions of crystals and to impurities. The nucleus/cortex boundary is not sharp. In some cases, in the innermost cortex there is no concentric lamination and it consists of microspar due probably to recrystallization (Pl. 2, Fig. 3).

The remaining part of the cortex exhibits a concentric-radial fabric. Concentrical laminae are composed of light ("pure") calcite and of dark alternating layers. The dark laminae mark the successive stages of the ooid growth. They are generally thinner than the light ones. Some dark laminae contain micrite but usually they represent concentrations of impurities accumulated at the discontinuity surfaces when calcium carbonate deposition lagged, or are residues formed during recrystallization of micritic laminae.

The concentric laminae, particularly the light ones, are constant in thickness and usually extend parallelly to the substrate following its uneven surface. Inside the ooids no indications of erosion of the laminae were observed. The partial or more rarely complete lack of lamination in some parts of ooids is caused by recrystallization.

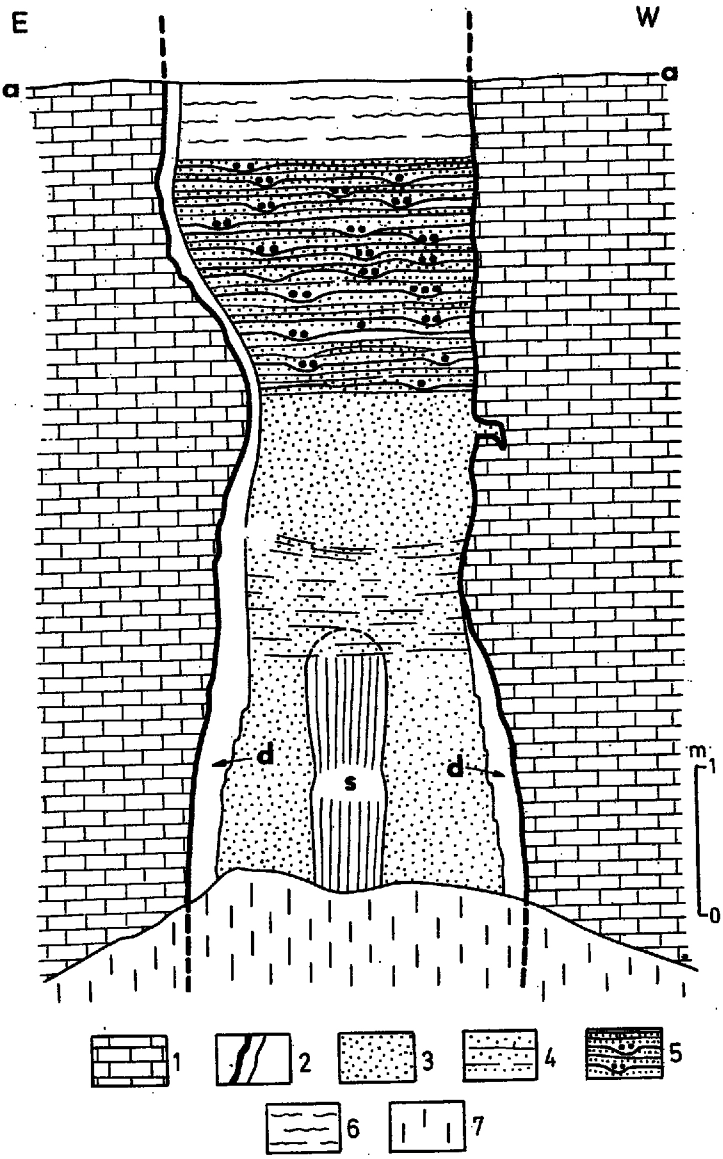

Fig. 3. Karst shaft in the Pogorzyce quarry

1 limestones of the Gogolin Formation, 2 flowstone on the shaft walls, 3 loose sand, 4 layered sand, 5 alternating layers of sandstone and calcitic flowstone containing ooids, 6 calcite floor formation, 7 scree

d draperies, *a—a* bottom of the upper exploitation level (*cf.* Text-fig. 2), *s* stalagmite

The recrystallization has more or less obliterated the primary structure of the ooids, resulting in radial structures consisting of elongate crystals perpendicular to the primary concentric laminae.

In the least altered parts of ooids the light laminae consist of a very fine fibrous calcite. The fibres are perpendicular to the substrate and mostly do not extend beyond the laminae. It seems that this is a primary structure or most closely approximating it. One cannot be sure because in some laminae there occur also some structures due to incipient recrystallization. Some neighbouring fibres join to form needle-like crystals extending beyond the dark laminae and absorbing the fibres in the adjoining light laminae.

This process seems to have continued, and only for the sake of simplicity, it may be divided into two stages. The first stage consisted in growth of the radial crystals which became wider and, first of all, longer. The particular needles recognized by a uniform extinction in crossed nicols extend through several concentric laminae. Simultaneously, the dark laminae are partly or completely resorbed (Pl. 2, Fig. 4). In the second stage, a radial mosaic was formed consisting of triangular zones with bases becoming shorter towards the center of the ooid. At this stage, there persisted only the thicker laminae as ghost lines, the other laminae disappeared almost completely (Pl. 2, Fig. 4).

A secondary origin of the radial structure is indicated by:

(1) radial crystals crossing several concentric laminae which correspond to successive stages of growth (Pl. 2, Fig. 4; Pl. 3, Figs 1—2),

(2) relics of fibrous laminae in the coarse radial mosaic (Pl. 3, Fig. 3),

(3) ghosts of dark laminae in the more intensely recrystallized parts of ooids (Pl. 2, Fig. 4; Pl. 3, Fig. 1),

(4) saw tooth boundaries of crystals in coarse radial mosaic (Pl. 3, Fig. 4),

(5) ghost lines after needle crystals in coarse radial mosaic crystals (Pl. 4, Fig. 1),

(6) wavy extinction visible in larger crystals of coarse grained mosaic (*cf.* Bathurst 1964).

The crystals of the coarse radial mosaic cluster sometimes in fan-like bundles. This is expressed at the surface of the ooid by gentle convexities (Pl. 3, Figs. 2—3). In the bundles, the preserved dark laminae are clearly more curved. At the base of fans there occurs usually a small convexity of the underlying lamina, *e.g.* a larger crystal protruding above the then existing surface of the ooid or the accumulation of impurities. The successive laminae followed the shape of the substrate, becoming successively less curved. Presumably, these laminae consisted of fibrous or acicular calcite, with fibres at any place perpendicular to the growth surface. As during recrystallization the fibres grew mainly along the longer axes, in the closing stage fans of triangular crystals were formed.

STRUCTURE OF THE OOID-BEARING LAYER

The thin layered ooid-bearing deposit (*cf.* Fig. 4) consists of alternating sandy-calcareous and calcitic layers devoid of detritic material. The quartz grains in the sandy layers are poorly rounded or angular and are enclosed in an abundant microspar matrix. Such layers (sets of laminae) pass gradually upwards into calcitic layers where there are no sand grains and there appear, in microspar mass, somewhat lighter laminae of fibrous calcite.

The structure of the calcitic layers is identical to that of the ooid cortex (Pl. 4, Figs 2—4). Both consist of light laminae of fibrous calcite

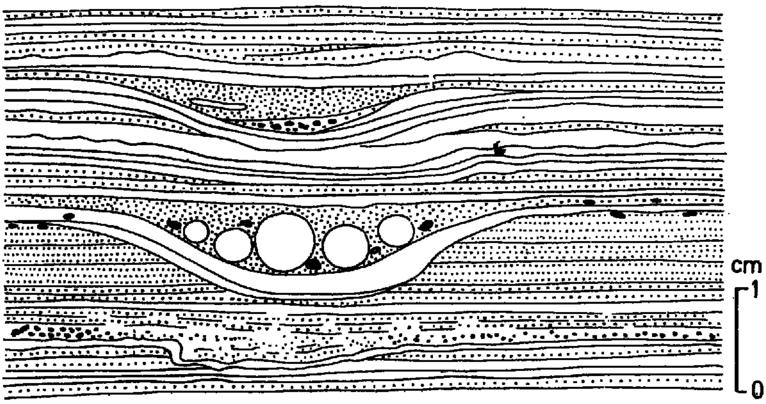

Fig. 4. Section of the shaft deposits containing ooids: calcitic flowstone laminae (*blank*), and sandy laminae (*stippled*)

and very thin dark laminae. If the transitional zone is absent or very thin, the laminae follow the uneven top surface of the underlying sandy layer, their course being then wavy or quite irregular. Forms due to recrystallization are identical to those in the ooid cortex. The upper surfaces of calcitic layers are clear and their course corresponds to that of the laminae they consist of.

GROWTH AND RECRYSTALLIZATION OF OOIDS

The investigated ooids and the mode of their occurrence show that in the Pogorzyce shaft the ooids developed in splash cups (*cf.* Gradziński & Radomski 1967, Donahue 1969).

The succession of the shaft deposits implies that following the first speleothem generation there was an intense filling with sand most probably water carried. Later, this process slowed down and became intermittent. In such conditions alternating thin layers of lamined sand and of lamined flowstone were formed. At the same time, water dripped from the inclined shaft walls. Presumably the rate of growth of the deposits was high, as suggested by a stable position of several points of dripping water and a relatively great thickness of the whole layer of a uniform character. A high rate of the formation of cave ooids is confirmed by the data from mines (*cf.* Gradziński & Radomski, 1967, pp. 248–249). The accumulation of the entire layer with ooids at Pogorzyce might have lasted a few thousand years.

The described fossil ooids show an advanced recrystallization process. However, the degree of its development does not exceed that known to the authors from the Cuban caves (Gradziński & Radomski 1967). To the contrary, some Recent cave ooids from Cuban caves are more intensively recrystallized than the fossil ones dealt with here.

This may imply that recrystallization might be interrupted at some stage, the forms then persisting up to now. Interruption of recrystallization is presumably connected with environmental conditions. In the case of the cave ooids, the essential change might be the disappearance of a humid microclimate which is a condition of their development, followed by a dry regime (drying of splash cups, shifting of "larmes" pointes etc.). It seems that at this time not only the ooid growth is inhibited, but also recrystallization processes stop. An additional evidence may be very weak recrystallization of the Cuban ooids occurring in the "pisolitic fields" (Gradziński & Radomski 1967), only seasonally flowed and dry most of the year. The above agrees with Bathurst's (1971) view concerning the formation of radial-fibrous structures in the course of wet recrystallization.

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R. GRADZIŃSKI i A. RADOMSKI

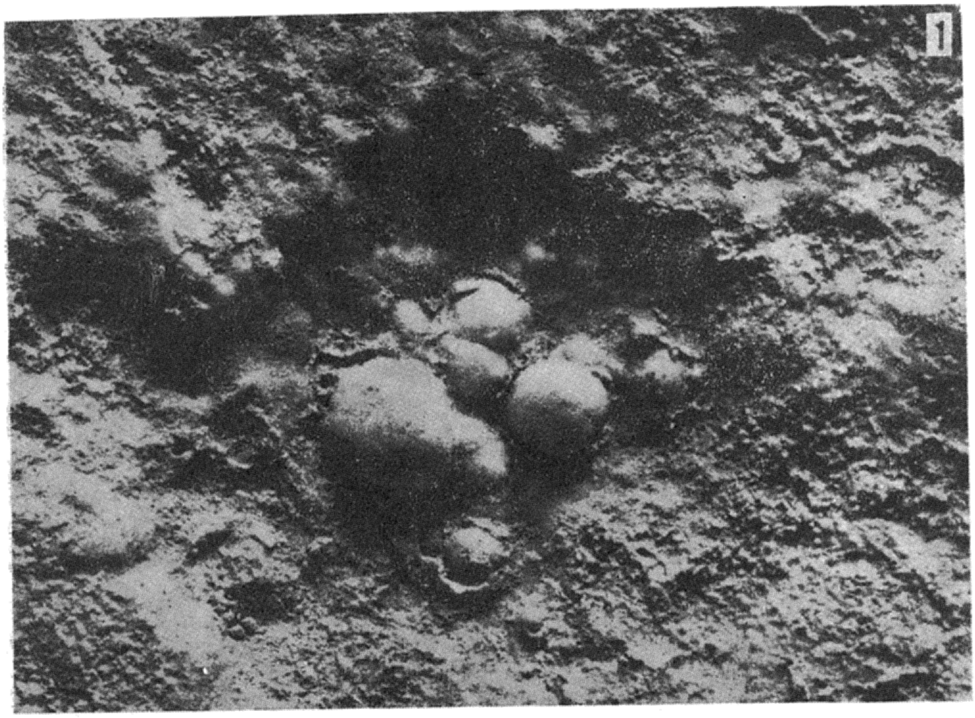
TRZECIORZĘDOWE OOIDY JASKINIOWE Z KOPALNEJ STUDNI KRASOWEJ W POGORZYCACH KOŁO PŁAZY

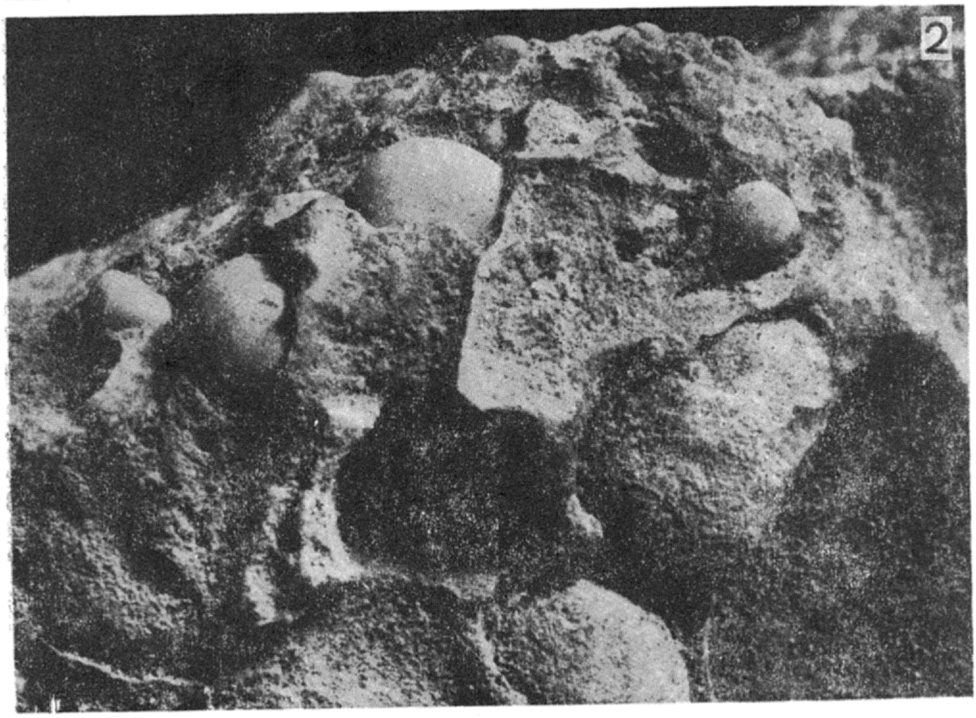
(Streszczenie)

W kamieniołomie wapieni warstw gogolińskich w Pogorzycach koło Płazy (fig. 1—2) znaleziona została studnia krasowa (fig. 3) wypełniona osadami (paleogen— wczesny miocen, *por.* Gradziński 1962), wśród których występują ooidy kalcytowe w obrębie warstwy złożonej z naprzemianległych zespołów lamin piaszczystych scementowanych węglanem wapnia oraz lamin kalcytowego nacieku. Ooidy występują tu w licznych, miseczkowatych zagłębieniach (fig. 4; pl. 1 oraz pl. 2, fig. 1—2), tworzonych pierwotnie na dnie przez skapującą wodę.

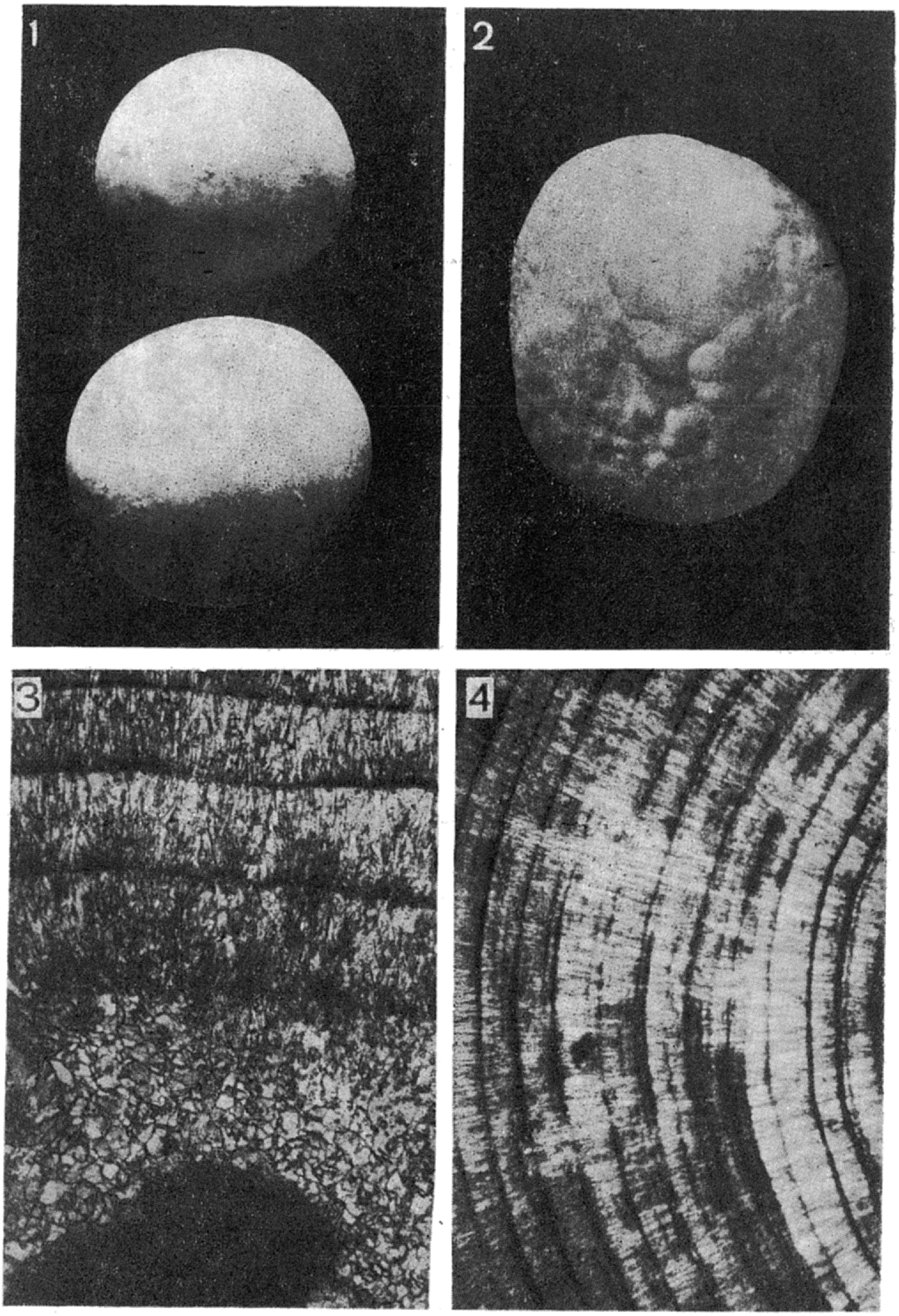
Analiza budowy znalezionych ooidów (*por.* pl. 2, fig. 3—4; pl. 3—4) wskazuje, że pierwotnie tekstura ich była koncentryczna, zaś tekstura promienista jest rezultatem procesów rekrystalizacyjnych.

Stopień zaawansowania procesów rekrystalizacyjnych w badanych ooidach nie jest większy niż w ooidach współczesnych występujących w jaskiniach Kuby (*por.* Gradziński & Radomski 1967). Można z tego wnosić, że przebieg procesów rekrystalizacyjnych w badanych ooidach został stosunkowo szybko przerwany. Zatrzymanie procesów rekrystalizacyjnych było tutaj zapewne rezultatem zmiany warunków, polegającej na przekształceniu mikrośrodowiska wilgotnego, w którym powstawały ooidy, w środowisko suche.





1 — Small splash cup with ooids exposed at a parting surface, seen from above; × 3.
2 — Part of the deposit in a splash cup: ooids enclosed in sandy matrix, × 4.5.

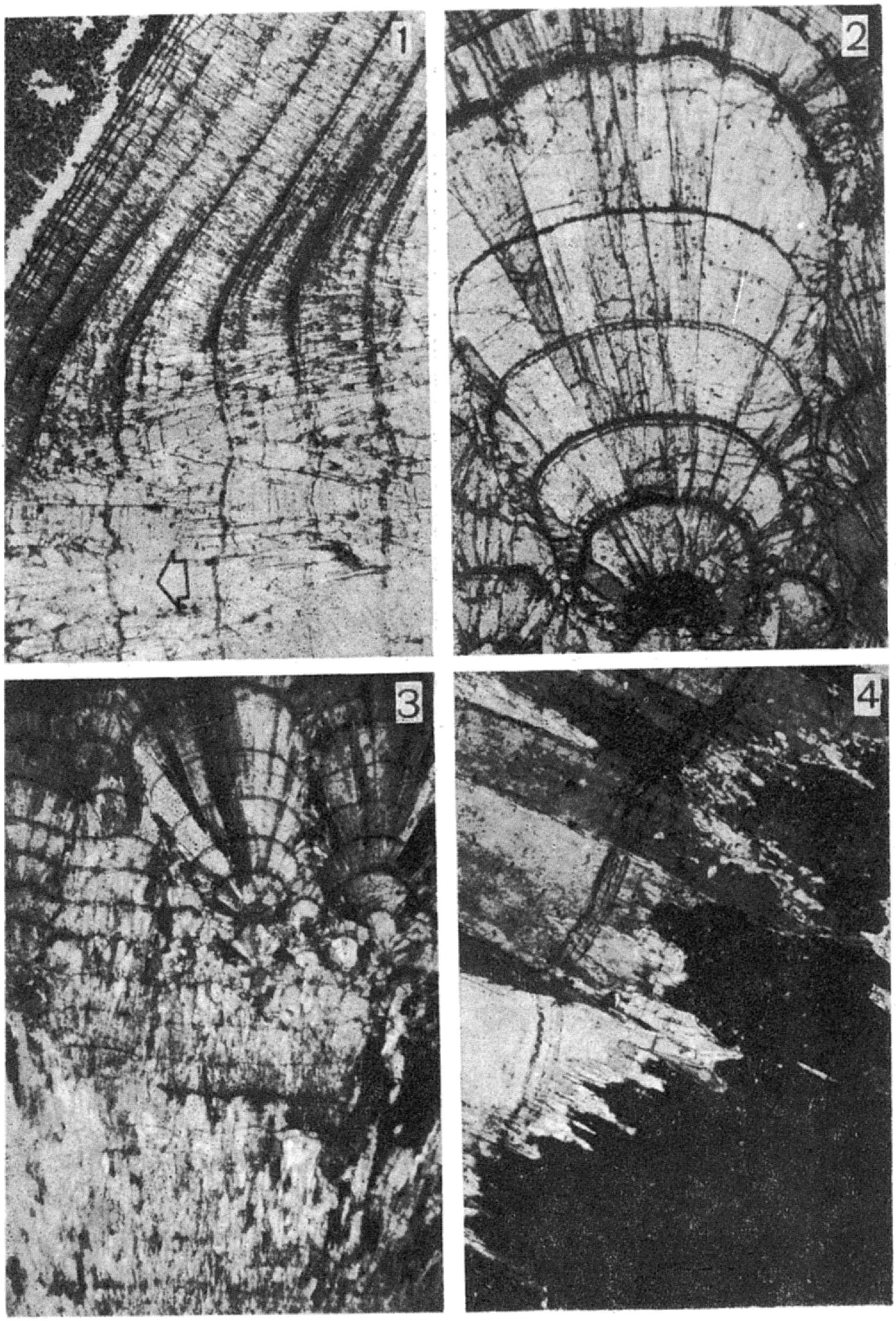


1 — Smooth, spherical ooids; × 4.

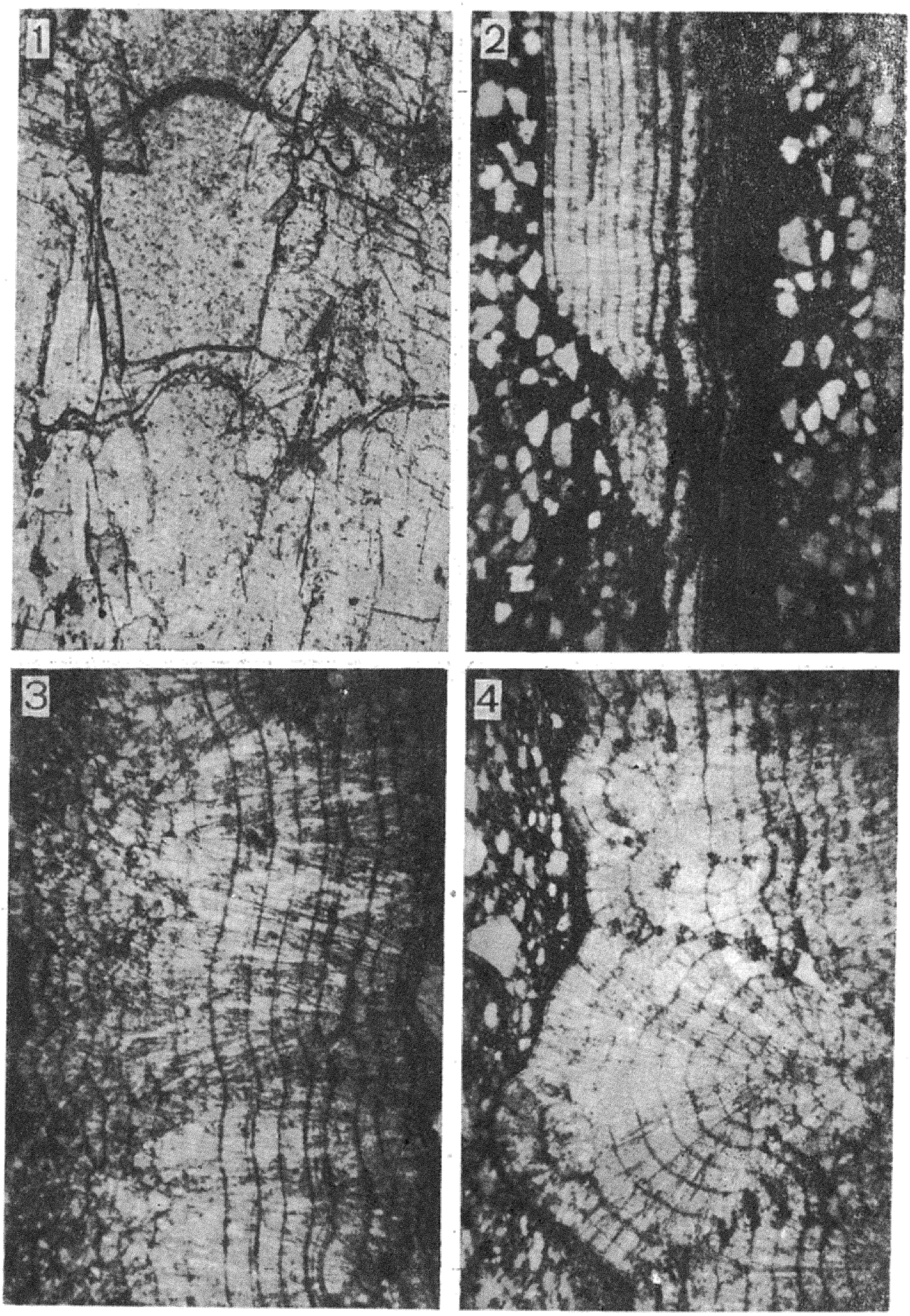
2 — Ooid with a cauliflower structure; × 4.

3 — Central section of an ooid: dark nucleus and microspar part of the cortex visible, higher up concentric laminae with fibrous structure; × 65.

4 — Secondary radial structure of an ooid: elongate crystals cross several concentric laminae; × 27.



1 — Partial obliteration of laminae in a coarse radial mosaic; growth direction arrowed; × 65.
2 — Flabelliform structure formed on uneven substrate; nicols crossed, × 65.
3 — Flabelliform structure (top), and relics of fibrous laminae in a coarse radial mosaic; × 27.
4 — Denticulate contact between crystals in a coarse radial mosaic; nicols crossed, × 144.



1 — Large triangular crystal and ghost line of resorbed acicular crystals (centre); × 144.
2 — Thin laminated deposit: partly eroded flowstone between sandy layers; × 27.
3 — Wavy laminae in a flowstone layer formed on uneven sandy layer (residues preserved); × 27.
4 — Uneven top surface of a flowstone layer, due to irregular course of the laminae; nicols crossed; × 27.