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PIZOLITY Z JASKIŃ KUBAŃSKICH

(Tabl. X—XV i 4 fig.)

Pisoliths from Cuban Caves

(Pl. X—XV and 4 Figs)

STRESZCZENIE

Pizolity w jaskiniach kubańskich występują w różnych środowiskach, które ogólnie podzielić można na dwie grupy:

1. płaskie dna jaskiń,
2. małe baseny.

Na płaskich dnach wielu jaskiń obserwuje się stosunkowo grube warstwy nie scementowanych pizolitów. Tworzą one charakterystyczne pola pizolitów. Ich powierzchnia wynosi co najmniej kilka m². Największe obserwowane przez autorów pole tego rodzaju znajduje się w Cueva Humboldt, mierzy około 25×25 m, a miąższość warstwy luźnych pizolitów wynosi w nim co najmniej 30 cm.

Małe baseny są to niewielkie, stosunkowo płytkie zagłębienia. Skapująca ze stropu woda powoduje ruch znajdujących się w nich pizolitów.

Pizolity występujące w polach pizolitów

Główną masę pizolitów w polach stanowią formy sferoidalne, często kuliste, o średnicy 2—6 mm. Okazy większe są z reguły spłaszczone i występują na powierzchni warstwy (tabl. XI, fig. 3). Wszystkie pizolity są porowate, ich ciężar objętościowy waha się w granicach od 2,093 do 2,226 g/cm³.

Laminy w małych pizolitach są dwudzielne. Partia stropowa laminy zbudowana jest z bardzo drobnoziarnistego kalcytu (średnica kryształów rzędu 8—13 mikr.). Partia dolna laminy składa się z chaotycznie ułożonych igiełkowych kryształów długości od kilkudziesięciu do 200—300 mikronów. Wolne przestrzenie między nimi wypełnia bardzo drobnokrystaliczny kalcyt, taki sam, jaki występuje w stropowej części laminy, co powoduje, że granice między obiema częściami laminy i laminami sąsiednimi są nieostre (tabl. XIII fig. 1).

Pizolity występujące w basenach

Pizolity występujące w basenach odznaczają się dużą różnorodnością form (tabl. X fig. 1, 2). Wyróżnić wśród nich można formy sferoidalne (kuliste, owoidalne, owalne i dyskoidalne), (tabl. XII fig. 4, 5, 7), formy trapezoidalne (tabl. XII fig. 1), wieloboczne (tabl. XII fig. 3) i gruzłowate (tabl. XII fig. 9).

Pizolity te, jak wykazały badania rentgenograficzne, są zbudowane z kalcytu. Mają one większy ciężar objętościowy (od 2,42 do 2,635 g/cm³) niż pizolity z pól.

Pizolity (lub ich partie), które nie zostały zmienione przez późniejsze procesy rekrystalizacyjne, mają laminy zbudowane na przemian z jasnego i szarego kalcytu afanitowego (fig. 3, A, tabl. XIII, fig. 2).

W czasie procesów rekrystalizacyjnych kalcyt afanitowy jest zastępowany przez mozaikę drobnokrystaliczną (wielkość kryształów rzędu 4 do 10 mikr.). Ta mozaika z kolei ulega przemianie w grubokrystaliczną o promienistym układzie kryształów, których wielkość osiąga od 100 do kilkuset mikr. (fig. 3, B, C, D). Niekiedy powstają struktury o specyficznej budowie, takie jak struktury pierzaste (fig. 3, G, tabl. XIV, fig. 1, 2) lub kalafiorowe (fig. 3, H, I, tabl. XI fig. 1). Za wtórnym pochodzeniem mozaiki i struktur radialnych przemawia:

1) zastępowanie przez mozaikę drobnoziarnistą kalcytu afanitowego,
2) ząbkowane granice kryształów grubokrystalicznej mozaiki radialnej,
3) zachowane niekiedy ślady laminacji w obrębie struktur radialnych,
4) zanik laminacji przy przechodzeniu przez strefy silnie zrekrystalizowane,
5) wypychanie zanieczyszczeń w przestrzenie między kryształami w czasie wtórnego wzrostu kryształów.

W przypadku daleko posuniętej rekrystalizacji odtworzenie jej kolejnych etapów nie jest możliwe. Jednak i w takim przypadku widoczne są ślady pierwotnej budowy koncentrycznej w postaci smug zanieczyszczeń przecinających kryształy (tabl. XIV fig. 4).

Charakterystyczny kształt i budowa wewnętrzna pizolitów trapezoidalnych związana jest z obecnością dużego jądra o nieregularnych kształtach oraz ze wzrostem (w okresach wysychania basenów) maczugowatych wyrostków na górnej powierzchni pizolitów (fig. 4, B, tabl. XIV fig. 3, 5).

W przeciwieństwie do wspomnianych wyrostków wzrost struktur kalafiorowych uwarunkowany jest procesami rekrystalizacyjnymi.

W przypadku pizolitów wielojądrowych i struktur kalafiorowych obserwuje się duże podobieństwo budowy wewnętrznej pizolitów do form opisywanych jako onkolity, których powstanie związane jest z organizmami. W opisywanych przez autorów środowiskach jaskiniowych (stanowisko B w Cueva del Amistad) należy jednak wykluczyć możliwość współdziałania roślin. Nasuwa się stąd wniosek, że rozpoznanie organicznego pochodzenia onkolitów jedynie na podstawie ich wewnętrznej budowy nie jest możliwe.

Wnioski

Z obserwacji i z badań autorów wynika, że pizolity jaskiniowe występują w dwóch różnych środowiskach, które odznaczają się różnymi warunkami odgrywającymi rolę w powstawaniu tych utworów. Obrazuje to zamieszczone poniżej zestawienie:

pola	małe baseny
pizolity tworzą rozległe, grube pokrywy na płaskim dnie,	pizolity występują w małych, płytkich zagłębieniach,
przeważnie suche, rzadko zalewane przez wodę,	przeważnie zalane wodą,
wybitny wpływ klimatu powierzchniowego,	mikroklimat jaskiniowy,
stosunkowo szybkie wysychanie,	wysychanie stosunkowo wolne,
ruch pizolitów nie odgrywa poważniejszej roli,	silny ruch pizolitów wskutek skapywania wody,

Różne warunki panujące w tych środowiskach powodują w rezultacie wyraźne różnice w kształcie i w budowie wewnętrznej pizolitów:

pola	małe baseny
przewaga form sferoidalnych,	duża różnorodność form,
brak zlepieńców pizolitowych,	występowanie pizolitów przyrośniętych do dna,
brak śladów abrazji pizolitów,	powszechne ślady abrazji pizolitów,
mniejszy ciężar objętościowy (2,093—2,226 g/cm³),	większy ciężar objętościowy (2,42—2,63 g/cm³),
laminy dwudzielne, brak kalcytu afanitowego, słaba rekrystalizacja.	pierwotne laminy afanitowe, pospolite procesy rekrystalizacyjne.

Autorowie uważają, że pizolity występujące w polach tworzą się w krótkotrwałych okresach, podczas których dno jaskiń zostaje zalane wodą. Zachodzi to po gwałtownych, wielkich opadach. W procesie wzrostu pizolitów ruch ich nie odgrywa poważniejszej roli. Narastanie w takich okresach nowych warstewek na powierzchni pizolitów nie prowadzi jednak do scementowania poszczególnych okazów w obrębie pola. Przyczyna tego nie została wyjaśniona. Można jedynie przypuszczać, że pewną rolę odgrywać może obecność w wodzie zanieczyszczeń albo też szybkie wytrącanie się kalcytu.

Różnorodne kształty pizolitów występujących w basenach są wynikiem zróżnicowanych warunków procesu narastania kolejnych warstewek oraz również zróżnicowanych warunków procesu abrazji, zachodzącego okresowo i z rozmaitym nasileniem. Warunki te znajdują swoje odbicie w budowie wewnętrznej pizolitów.

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A b s t r a c t. Pisoliths in Cuban caves are found in two separate environments, distinguished on the basis of differences in the conditions of formation of the pisoliths: 1) flat bottom of caves (pisolithic fields), and 2) small-scale depressions. These differences are recorded in the internal structure and shape of the pisoliths. The pisoliths in pisolithic fields are formed during seasonal flooding of the cave floor. The fields comprise thick, uncemented layers of pisoliths covering considerable areas of the flat cave floor. The pisoliths are characterized by absence of evidence of abrasion, predominance of spheroidal forms, smaller bulk specific gravity, absence of aphanitic calcite, and inconspicuous recrystallization. The pisoliths in small-scale depressions may be formed either completely or only partially immersed in water. They are characterized by diversity in shape, ubiquitous evidence of abrasion, larger bulk specific gravity, aphanitic primary laminae, and common evidence of recrystallization.

INTRODUCTION

The materials and observations for this paper were collected in the Cueva del Amistad and in caves of the Caguanes Peninsula, during a speleological expedition to Cuba in the year 1961. For the description and location of the caves the reader is referred to earlier publications (R. Gradziński & A. Radomski, 1963, 1967).

It is generally assumed that cave pisoliths owe their origin to concretionary growth in agitated waters, and only a few authors (E. C. Emmons, 1928; S. C. Davidson & H. E. McKinstry, 1931; R. Gradziński & A. Radomski, 1957) consider these structures as being also formed under relatively quiet conditions in a non-agitated environment (see Table 1).

In addition, most articles describing cave pisoliths usually refer to splash cups and shallow ponds as being the places of their origin [1]. However, I. Viehmann (1960, 1963) has shown that cave pisoliths may form a layer, covering an area of several square metres, and similar occurrences in Poland have been recently recorded by R. Gradziński and T. Wróblewski (1967). Such pisolithic fields occur also in numerous caves of the Caguanes Peninsula, Cuba.

OCCURRENCE OF PISOLITHS IN CUBAN CAVES

Pisoliths are common in Cuban caves. They occur in various environments, which may be classified into two main groups:

1) flat bottom of caves,
2) small-scale depressions.

Flat bottom of caves

On the flat bottoms of many caves occur rather thick layers of uncemented pisoliths, here called pisolithic fields. The thickness of these deposits is by far greater than the diameter of any individual pisolith.

The most typical pisolithic fields were observed in the caves of Caguanes Peninsula. The horizontal dimensions of the biggest one known from the Cueva Humboldt are 25×25 m. The thickness of the layer of pisolith gravel in this cave reaches, in some places, at least 30 cm. All pisolithic fields have flat, horizontal surfaces.

The caves of Caguanes Peninsula form spacious horizontal mazes, developed at shallow depths below the surface. The thickness of the roof is generally less than 10 m. They communicate with the earth surface by large vertical entrances, formed by roof collapse. Speleothems (cave formations) are abundant and various, among them stalactites are predominant. During the dry season, there is no water in the caves. Even the rimstone pools become dried up. Calcite is precipitated only after occasional heavy rainfalls, when for a short period, shallow lakes are formed in caves, but the water disappears quickly because of infiltration and intensive evaporation.

The dominant pisoliths forming the pisolithic fields are small (diameter 2—6 mm.) and spherical in shape. The bigger ones appear to be flattened and discoidal. Their maximum diameters measured reach: 41×34×20 mm, 29×27×19 mm, 30×26×13 mm. These big pisoliths are relatively rare and occur only on the surfaces of layers composed of small specimens. All specimens from the caves of Caguanes Peninsula are light-brown and do not exhibit effects of abrasion and polishing.

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[1] For references see: M. Kirchmayer (1963, 1965); G. Perna (1958); G. T. Warwick (1962).

Near the entrances to the caves, the pisoliths are accompanied by incrustations of calcite upon gastropod shells (mummies). Their maximum diameters reach 60 mm and the incrustation cover is up to 10 mm thick.

Small-scale depressions

These are described in the literature as splash cups, ponds, nests etc. They are usually filled with water, which disappears during dry seasons only. The pisoliths in the depressions are agitated by drops falling from the roof.

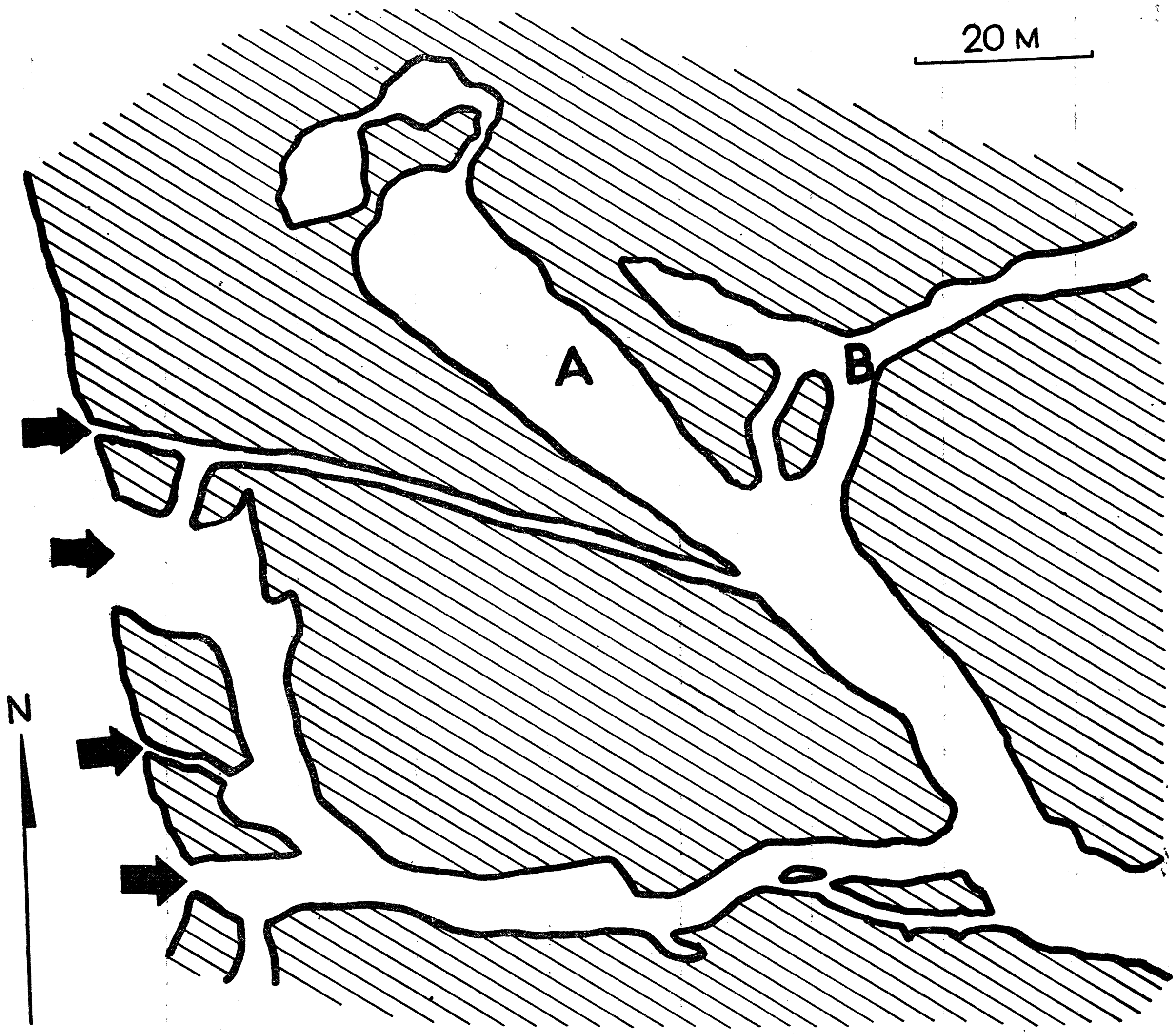

Fig. 1. Plan północno-zachodniej części jaskini Cueva del Amistad. A — stanowisko A, B — stanowisko B; strzałki oznaczają otwory wejściowe

Fig. 1. Sketch map of north-western part of Cueva del Amistad. A — Station A; B — Station B; arrows indicate cave entrances

Examples of such occurrences are provided by Station A and Station B in Cueva del Amistad (in Sierra de los Organos).

Station A is situated in the north-western part of the upper level of the cave (fig. 1). The bottom of a large chamber is covered here with large fallen blocks. The pisoliths occur in shallow irregular depressions formed on the upper surface of a large limestone block (Pl. X, fig. 1). The depressions, ranging from 1—3 cm in depth and from a few to 20 cm in diameter, are encrusted by a thin layer of calcite. The rate of dropping is here high, particulary during rainy seasons. However, in winter and

Tabela — Table 1

Occurrence and formation of cave pisoliths

Author	Cave, mine	Occurrence of pisoliths	Maximum diameter of pisoliths	Surface texture of pisoliths	Conditions of formation of pisoliths	Age of pisoliths
Emmons, 1928	Hidden Fortune Mine				without agitation	
Hess, 1930	Carlsbad Caverns	shallow, small, round ponds and nests	50 mm	polished, rough	agitation	
Davidson, McKinstry, 1931	Mexican mines	shallow nests or pools	30 mm	polished, rough	rolling unnecessary	25 years
Keller, 1937	Holton Cave	small cups	15 mm	smooth, rough	rolling	
Pond, 1945	Cave of Mounds	nests	4,4 mm	smooth		
Mackin, Coombs, 1945	Mine in Idaho	shallow, cuplike depressions	13 mm	polished, bisque	agitation	35—42 years
Baker, Frostick, 1947	Australian caves and mines	shallow ponds	70 mm	polished, bisque, pustulosed, furrowed	agitation	

Baker, Frostick, 1951	Caves at Port Campbell	shallow ponds	20 mm	polished, bisque, rough	agitation	
Barczyk, 1956	Cave at Wojcieszów	shallow pond	14,8 mm	bisque	agitation	
Liégeois, 1956	Grotte de Han	experiment	several mm	bisque	without agitation	
Gradziński, Radomski, 1957	Szczelina Chochołowska Cave	shallow pool	9 mm	smooth	without agitation	
Perna, 1959	Italian Caves	shallow pools	65 mm	various	agitation	
Viehmann, 1960 1963	Scarişoara Cave	fields of pisoliths	20 mm	smooth	agitation unimportant	
Kirchmayer, 1964	mines	nests		polished, bisque	agitation	30—100 years
Donahue, 1965	experiment	nests (splash cups)		smooth	agitation	0,34 mm/year

autumn, the depressions are devoid of water. The number of pisoliths in particular depressions varies from a dozen to several thousand specimens. Their size appears to be related to the dimensions of basins, i.e. the larger and deeper are the depressions, the greater is the diameter of pisoliths.

Station B is situated in a gallery near Station A. Here the pisoliths are to be found in a shallow and broad depression on the bottom of the gallery 3 m wide and 2 m high, and partly closed on both sides by blocks broken off, cemented and covered with flowstone.

On the flat bottom of the gallery, there are irregular depressions from 50 cm to 2 m in diameter. They are paved with cemented pisoliths and partly covered with clayey-limy red-brown sediment (Pl. X, fig. 2).

In October and December 1961, the gallery was dry and no dropping of water was observed, but there was evidence of the existence during rainy periods of a shallow seasonal lake. Its depth might have reached up to a dozen cm.

Most pisoliths in Stations A and B exhibit abraded and polished surfaces. Evidence of polishing is also visible in cross-sections. Pisoliths of both Stations differ in colour and shape. Those from the Station A appear to be white on polished surfaces and light-grey on the bisque-like ones. Pisoliths from Station B are red-brown. The colour of accompanying speleothems (cave formations) correspond to that of pisoliths.

The following types of pisoliths were collected from the Station A:

a) S p h e r o i d a l f o r m s (including ovoidal, discoidal and spherical forms) exhibit smooth surfaces which may be polished or bisque-like (Pl. X, fig. 1., Pl. XII, fig. 4., 5.). Their average diameter falls between 15 and 30 mm, and the biggest found attain 53 mm. While the surfaces of small specimens develop everywhere a high polish (cave pearls), the bigger ones are polished at their base only.

b) T r a p e z o i d a l f o r m s. The vertical cross section of these forms (see Pl. XIV, fig. 5.) resembles a trapezoid with corners more or less rounded, while the outline of the horizontal cross section is irregular. The pisoliths are laying usually with their wider base down. The top and bottom surfaces (the latter usually polished) exhibit fine rod-like nodules. The steeply inclined side-walls present a picture of grooved and ridged surfaces (Pl. XII, fig. 1.). The mean diameter of such pisoliths is about 20 mm, and the dimensions of the biggest found are 35×28×18 mm.

c) P o l y h e d r a l p i s o l i t h s are small (a few mm) and bounded by flat (sometimes even concave), generally polished faces (Pl. XII, fig. 8.).

d) R o u g h - s u r f a c e d p i s o l i t h s, built of clusters of radial crystal aggregates, usually range in dimensions from 2 to 5 mm (Pl. XII, fig. 9.).

e) C a u l i f l o w e r p i s o l i t h s are spheroidal flattened forms, covered on one side with large coalescent nodules. The opposite side is smooth. Their average size is 13—25 mm. Some of them are converted by abrasion into cave pearls.

f) M u m m i e s. At the Station A, besides typical pisoliths, gastropod mummies were found. Their maximum diameter reaches 25×20×16 mm.

Moreover at the same locality some limestone and speleothem fragments were observed. They show polished surfaces resembling those of cave pearls.

At Station A, the polyhedral and rough-surfaced forms dominate. The spheroidal and trapezoidal specimens are less frequent, while mummies and cauliflower forms occur sporadically.

The following types of pisoliths are found at Station B:

a) Spheroidal pisoliths. The spherical forms are dominant here. The biggest specimen is an almost perfect sphere of diameter 82 mm. The flattened specimens show relatively low degree of flatness; in extreme cases rate of axes is 7 : 5.

b) Cauliflower pisoliths are usually bigger than those at Station A. Their diameters average 40 to 50 mm in length (Pl. XII, fig. 2.). The dimensions of the biggest one are 58×49×35 mm.

c) Baccate pisoliths are spheroidal in shape with pustulose and furrowed surfaces (Pl. XII, fig. 3.). The pustules are polished and furrows between them are bisque-like. They range in size between the limits of 15—25 mm.

d) Polyhedral forms (Pl. XII, fig. 6.). Most of polyhedral forms found here are derived from the abrasion of other types of pisoliths.

At the Station B, the spheroidal, cauliflower and polyhedral forms are numerous, while the other types appear to be less frequent (see Pl. X, fig. 2.).

CHEMICAL COMPOSITION AND BULK SPECIFIC GRAVITY OF PISOLITHS

The X-ray investigation show that pisoliths from Cueva del Amistad are composed of calcite [1].

The contamination by clay and iron compounds is insignificant. The maximum amount of impurities from Cueva del Amistad is about 1,5 per cent in comparison with 2,5 per cent in those from caves of Caguanes Peninsula (Table 2).

The measurements of the bulk specific gravity reveal that the porosity of specimens collected from pisolithic fields is higher than that of piso-

Table 2

Chemical composition of pisoliths

Component	Weigh per cent		
	Cueva del Amistad: Station A	Cueva del Amistad: Station B	Cueva Humboldt
SiO_2	0,65*	0,43*	1,68
Fe_2O_3	0,49	0,02	0,48
Al_2O_3	n.d.	n.d.	0,45
TiO_2	n.d.	n.d.	—
CaO	54,14	54,70	52,85
MgO	0,87	1,05	0,07
MnO	0,01	ev.	0,02

*) Insoluble components in hot HCl; n. d. — non determinated. Analyses carried out by W. Narębski and K. Prochazka.

[1] X-ray determinations carried out by J. Kubisz.

lithes collected in small-scale depressions. Differences in bulk specific gravity are shown in the table. 3.

Table 3

Bulk specific gravity of pisoliths

Cueva del Amistad, Station A:	
4 pisoliths, 36—52 mm in diameter	2,606 g/cm³
4 pisoliths, 25—35 mm in diameter	2,635 g/cm³
Cueva del Amistad, Station B:	
5 pisoliths, 37—52 mm in diameter	2,541 g/cm³
6 pisoliths, 18—31 mm in diameter	2,424 g/cm³
Cueva Humboldt (pisolithic field):	
6 pisoliths, 26—41 mm in diameter	2,093 g/cm³
5 pisoliths, 14—18 mm in diameter	2,173 g/cm³
several dozen pisoliths, 2—4 mm in diameter	2,226 g/cm³

INTERNAL STRUCTURE OF PISOLITHS

The most pisoliths investigated have allochtonous nuclei, in the form of detrical grains, such as fragments of rocks, speleothems (cave formation), shells etc.

However, many pisoliths are devoid of visible foreign nuclei (Pl. XV, fig. 1.). The first crystals or their aggregates precipitated from solution became centers of crystallization. They do not differ from crystals formed in later stages of pisolith growth. In such cases, either the central part of the specimen is devoid of lamination or the lamination is indistinct.

The character of nucleus will be discussed only in relation to its role in determining the shape of pisolith.

Two types of internal structures are distinguished:

1. concentric lamination,
2. radial structures.

Lamination is caused by: change in colour, size and/or orientation of crystals building the successive rings. Sometimes laminae are accentuated by the presence of impurities. The thickness of laminae varies from a few microns to a few mm.

The radial structures consist of elongated crystals oriented perpendicularly to the laminae. Their extinction is parallel to the long axis. Radial structures are sometimes superimposed on concentric lamination. In such cases, laminae are obliterated and the texture undergoes considerable changes (Pl. XI, fig. 2).

The concentric rings are primary structures formed by precipitation of calcite from solution, while the radial structures are generated during recrystallization (see p. 254).

Recrystallization changes the fabric of pisoliths to such degree that in many cases the primary form cannot be envisaged.

1. The pisoliths from pisolithic fields

The laminae of small-size pisoliths collected from pisolithic fields are bipartite. The top (outer) part of laminae is built up of a very fine crystalline calcite yellow or grey colored[1]. Crystal size is about 8—30 microns and usually grains of diameter less than 5 micr. are absent. Some crystals are rounded, while others are characterized by plane, intergranular faces. The top boundary of laminae is sometimes accentuated by the accumulation of brown, coloured impurities (Pl. XIII, fig. 1).

The lower part of each lamina consists of chaotically disposed needle--like crystals from several score to 200—300 microns long. The spaces between the needles are occupied by very fine crystalline calcite; therefore the boundaries of both parts of lamina and adjoining laminae are indistinct (fig. 2).

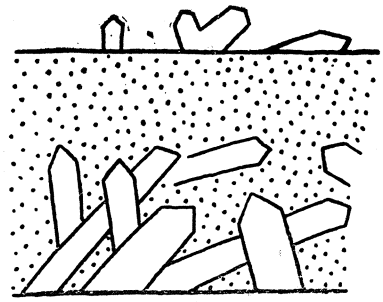

Fig. 2. Fragment zewnętrznej laminy pizolitu z pola pizolitów. Pola kropkowane oznaczają kalcyt drobnokrystaliczny

Fig. 2. Part of outer lamina of pisolith from pisolithic field. Dotted area indicates fine crystalline calcite

It is supposed that the needle-like crystals have formed during slow crystallization from solution. The very fine crystalline calcite, on the other hand, result from a fast precipitation during evaporation of lakes.

The recrystallization of laminae is indistinct. In the lower parts of laminae very fine crystals are replaces by fine mosaic composed of light and clear grains with toothed boundaries. Their diameters vary from 12 to 40 microns. The biggest individuals tend to grow normal to the surface of the lamina. During growth of crystals impurities are expelled and accumulate at the tops of needles.

The needle-like crystals develop along their longest axes at the expense of microcrystals. Impurities are here also pushed up outside. In the irregularities between the crenellated tops of needles, unabsorbed microcrystals are preserved. Many needles showing secondary growth pass through the boundaries of lamina.

The large pisoliths may show a different internal structure from that hitherto discussed. They exhibit a peculiar „palisade" texture of laminae (Pl. XV, fig. 3, 4). It originates from crystalline mosaic by recrystallization. Due to optical reorientation and integration of adjacent crystals, rod-like individuals with euhedral pyramid endings are formed. They are closely packed, normal to the concentric laminae. Extinction is parallel to their long axes.

The biggest crystals reach 0,7—1,3 mm in length and 0,05—0,3 mm in width. Many of them widen towards the outside of the pisolith or bifurcate due to the growth of new individuals on the top surface of the parent crystals.

Between the palisade crystals, impurities are abundant. The small crystals are developed within the lamina, the bigger ones may transect surfaces of laminae. Traces of lamination can be found inside the crystals or between them. Rarely, laminae build of aphanocrystalline calcite are preserved. During recrystallization curvature of laminae locally increases, by crystal growth from inside (Pl. XV, fig. 4).

[1] In this chapter, colours refer to the transmitted light.

2. Pisoliths from small-scale depressions
Pisoliths with regular concentric lamination

The most frequent type of pisoliths occurring in small-scale depressions are spheroidal forms with concentric rings surrounding the nucleus. Entire specimens or only portions of them unchanged by recrystallization are composed of aphanocrystalline calcite (diameter of grains less than 2 micr.). Lamination is caused by alternating light and grey calcite rings. Colour changes are probably brought about by the difference in grain size imperceptible under the magnification used (about 400×).

The aphanocrystalline calcite is susceptible to recrystallization. During this process, the primary lamination is completly or partly obliterated and pisolith texture undergoes far reaching changes.

In the first stage recrystallization develops within the light lamina. The aphanocrystalline calcite is gradually replaced by fine crystalline mosaic (grain diameter 4—10 micr., Fig. 3, B). The biggest crystals are rod-shape and oriented normal to the lamina. In farther development of this process, the laminae disappear by recrystallization and a large zone is built of coarse radial mosaic with crystals from 100 to 1000 micr. long (Fig. 3, C, D, E, F, Pl. XIII, fig. 3).

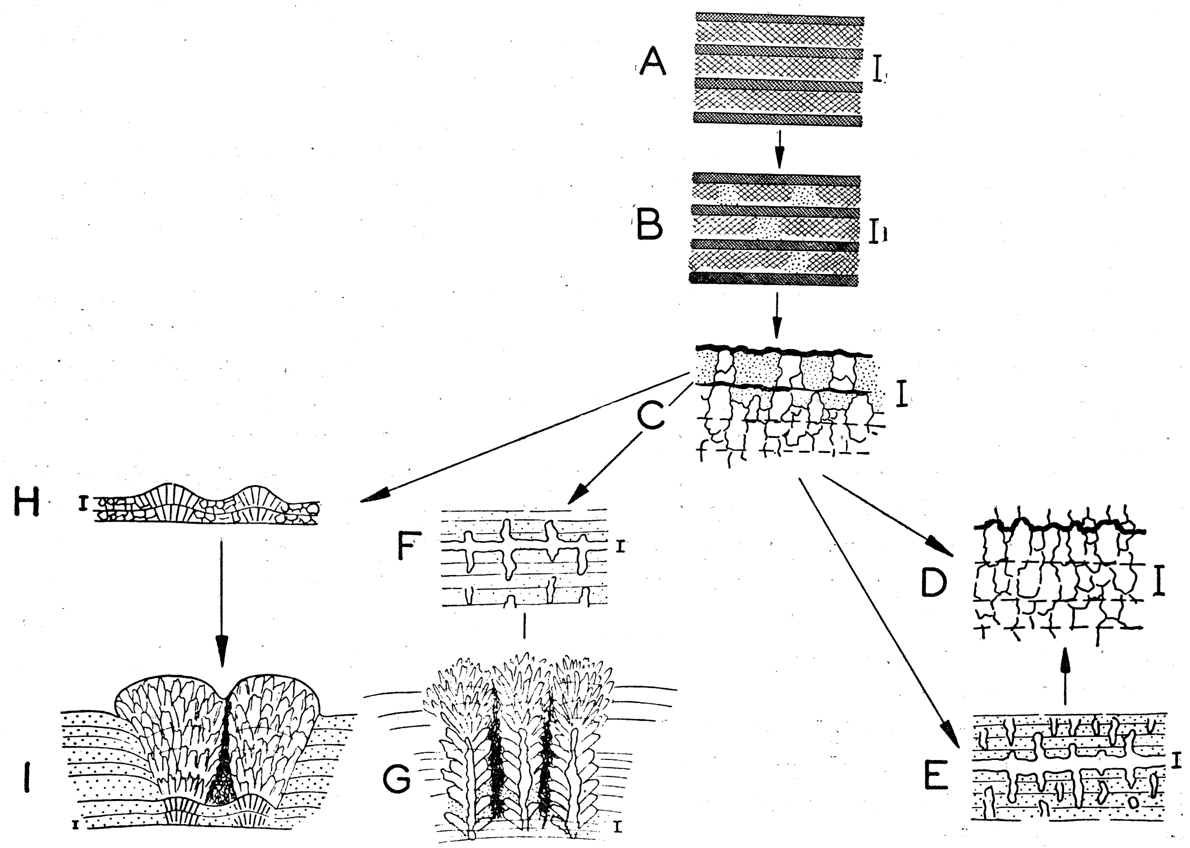

Fig. 3. Schemat rozwoju procesów rekrystalizacyjnych w pizolitach jaskiniowych. Bliższe objaśnienia w tekście (str. 254)

Fig. 3. Schematic diagram to show processes of recrystallization. Explanations in text (p. 254)

Radial mosaic zones are sometimes separated by sets of unchanged laminae, or by laminae in which recrystallization has stopped in the stage of fine mosaic (Pl. XIII, fig. 4).

The succession of more or less recrystallized zones is in no way regular. In some pisoliths, the central part is more changed, in others, the outer one. It seems that the process of recrystallization is impeded by impurities.

Arguments for secondary origin of the coarse radial mosaic are:

1. replacement of aphanocrystalline calcite by fine mosaic,
2. saw-toothed boundaries of crystals,
3. traces of lamination inside the zone of coarse radial mosaic,
4. passing of individual crystals through several laminae,
5. expulsion of the impurities into intercrystal spaces.

Feather-like arrangement of crystals. In some instances the crystals formed during the recrystallization may show in vertical cross section feather-like orientations. They originate from fine crystalline mosaic (grain sizes ranges 4—27 micr., average 8—12,5 micr.) in which there appear elongated crystals oriented perpendicular to the lamination (Fig. 3, C). If these crystals are closely packed the progressing recrystallization leads to coarse radial mosaic. But when they are scattered (Fig. 3, F) in the fine mosaic, the feather-like structures are formed (Fig. 3, G).

In the latter case, radial crystals reach up to a few mm in length and become cores of the feather structures to be formed. The recrystallization of fine mosaic distributed between the cores results in the formation of crystals which are oriented at angle of 45—50° around them (Pl. XIV, Fig. 1, 2). In the top (outer) part of such structure, the core disappears and the side crystals, reaching here their maximum length, are disposed in fan-like manner.

The following arguments support a secondary origin of these arrangement:

1. the core and side crystals pass through concentric laminae; the laminae are well visible in the initial stage of structures discussed, in the full developed feather-like structures, only traces of laminae are preserved,
2. the feather-like arrangements are grouped inside the coarse radial mosaic or in the laminated part of pisolith; in the latter case, most laminae break off when reaching the recrystallized area. Those passing across the structure become concave outward,
3. in the spaces between the feather-like structures, impurities expelled during the crystal growth accumulate,
4. in places between the feather-like structures remnants of fine crystalline mosaic are preserved.

These structures are generally truncated by the overlying laminae. This prooves, that they had developed before the covering laminae were formed.

Cauliflower pisoliths

Nodules of cauliflower pisoliths exhibit in cross-section the fan-like orientation of crystals. In these structures, especially in their „ root" (lower) part, traces of primary lamination are visible (Pl. XI, fig. 1). In places, it may be observed that laminae in structures discussed are wider (8—142 per cent) than in the adjacent areas. Thickening of laminae causes an increase in curvature (Fig. 3, H). Inside the cauliflower structure, the laminae are built of fibrous calcite. Beyond them, laminae consist of crystalline mosaic (Fig. 3, I). Increase in thickness require supply of material from adjacent areas (A. V. Carozzi, 1962).

According to Carozzi (op. cit.), following succession of phenomena should be accepted:

1. deposition of concentric lamina,
2. recrystallization and formation of bundles of calcite fibres, causing the arching of the upper boundary of lamina,
3. deposition of successive lamina on the undulating surface of pisolith; its recrystallization begins at places predetermined by the occurrence of fibrous calcite in underlying laminae.

Each successive lamina has therefore a greater curvature and fan-like structures are gradually widening upwards (Pl. XI, fig. 1).

The cauliflower pisoliths are rather big and disc-shaped (see p. 251). Due to their pivoting movement in the water, the upper surfaces are not effected by abrasion, and here the intensive precipitation of calcite takes place. The original surface is usually preserved, but it may be abraded when pisolith is turned 180° around the horizontal axis. In this case, the internal structure of the pisolith is marked by concentric lines, visible on the polished surface. Formation of new calcite layers and cauliflower structures (under suitable conditions) takes place in turn on the actually upper side of the pisolith.

Spherulites

To this group belong the pisoliths with advanced recrystallization. The original texture of laminae is completly obliterated. The single calcite crystals reach considerable dimensions, sometimes even a few mm.

The final stage of this type of recrystallization is exhibited by the pisolith shown by fig. 2, Pl. XV. The whole pisolith is composed of radial, generally „dendritic" crystals. They length reaches 8 mm. The primary concentric lamination, in spite of complete recrystallization of calcite, is marked within crystals by bands of impurities. The majority of impurities however is accumulated in spaces between the crystals.

Trapezoidal pisoliths

The trapezoidal pisoliths have large nuclei irregular in shape (Pl. XIV, fig. 3, 5). The nucleus is surrounded by laminae which concordantly cover the irregularities of its surface. In such a way, dome-like or club-shaped bulges form on protuberances of the nucleus.

The joining plains of adjacent bulges are generally marked by fissures.

Toward the outside of pisolith, the relief of these irregularities becomes more and more gentle and finally smooth.

Laminae are built of aphanocrystalline calcite, which is replaced during the recrystallization by crystalline mosaic (grain diameter 17—30 micr.). At the first stage, recrystallization takes place in part of the laminae forming the slopes of bulges. Those with the greater curvature on the top of bulges remain unchanged (Pl. XIV, fig. 3, 4).

This phenomenon is not clear. It is supposed that water penetrating the fissures plays an important role in this process. It should be mentioned, however, that replacement of aphanocrystalline calcite by mosaic is observed also in regular laminae devoid of fissures.

On the surface of trapezoidal pisoliths there occur closely packed rod-like protuberances up to 2 mm high. They resemble the fungoidal structures described by R. Gradziński & R. Unrug (1960). Their top parts generally flattened are built of very thin laminae of aphanocrystalline calcite. On the slopes of the rod-like forms, laminae are curved down and in these places aphanocrystalline calcite is replaced by calcite mosaic (Pl. XIV, fig. 3).

Multinuclear pisoliths

The central part of such pisoliths is composed of several nuclei. In one specimen from Cueva del Amistad, the number of nuclei is about 15 (Pl. XV, fig. 1). In an early stage of growth each nucleus has its own pisolith cover. Later on, such nuclei accrete together and form a composite nucleus, surrounded in turn by common pisolith rings. Laminae of this cover follow the irregularities of the central zone. As a result of this, a newly created pisolith obtains a irregular „nodular" surface. The pisoliths mentioned above may be distinguished from the cerebroid oolithes (A. V. Carozzi, 1962) only in cross-section.

It shoulds be stressed that there exists a close resemblence between multinuclear pisoliths and oncolites. Genesis of the latter is considered to be connected with life activity of algae. In the case discussed, pisoliths were found at the Station B in Cueva del Amistad, where the cave configuration does not allow to admit the transportation of pisoliths from the earths surface. The algal activity in the cave must be exclused because of darkness. Observations presented here indicate that it is impossible to recognize the organic origin of oncolite-like forms on the basis of their internal structure exclusively.

Polyhedral pisoliths

Polyhedral pisoliths may be formed in two ways: 1) by abrasion (see p. 251), and 2) during the pisolith growth.

In this chapter, only pisoliths of the latter type will be discussed. Nuclei of these pisoliths are relatively big in comparision with their thin pisolith cover. They resemble to a certain extent the superficial pisoliths (or oolites), (L. V. Illing 1954, A. V. Carozzi 1962). In such pisolith the external cover reflects the shape of its nuclei, which often happen to be polyhedral.

It must be added that the polyhedral pisoliths are densly packed in small-scale depressions. Under these conditions, the abrasion caused by mutual friction of specimens works most intensively on their plane faces, and does not lead to rounding of edges. Pisoliths of this type are built of aphanocrystalline calcite which in planes recrystallize to give a very fine mosaic. Radial structures were not observed in polyhedral pisoliths.

ORIGIN OF THE PISOLITHS

From the observations described above, it follows that the pisoliths occurring in pisolithic fields and those occurring in small-scale depressions differ considerably. The differences between them in internal structure are especially marked, but the differences in the shapes, size, character of surface and bulk specific gravity of the pisoliths are also important. In the opinion of the authors, these differences are due to different conditions of formation of the pisoliths in the two above mentioned situations.

Pisoliths occurring in pisolithic fields

Observations by the authors, carried out in the caves of the Caguanes Peninsula, indicate that pisoliths occurring in fields are not subfossil, but, on the contrary, are formed recently. This is indicated by the location of pisolithic fields in relation to flowstone structures (formations) and other cave sediments, and the occurrence of pisoliths and gastropod mummies near cave entrances. It should be stressed that the deposition of speleothems (cave formations) is widespread and is very rapid in the caves of the Caguanes Peninsula, as evidenced by bottles dating probably from the 17th—18th century, covered with layer of calcite a few cm thick, found in Cueva Pirata. The gastropod mummies are very abundant and transitional stages from fresh shells to mummies covered by thick layer of calcite can be observed. Characteristically, in spite of the large numbers of shells supplied into the cave, the number of fresh shells is small, since they are rapidly covered with calcite.

The authors maintain that the pisoliths are formed in situ, within the fields in which they occur, and are not brought by running water from other places. No pisoliths were observed in the pools situated in the neighbourhood of the pisolithic fields, where only crystalline incrustations are present. Also no traces of seasonal streams were observed in the caves. Obviously, the caves situated at relatively shallow depths are flooded during heavy rains. Then the water forms lakes, which dry up rapidly, because of percolation and evaporation. The evaporation is assisted by the occurrence of numerous large openings in the roof.

If the possibility of transportation of pisoliths into the pisolithic fields is excluded, two possible explanations of the formation of thick layers of loose pisoliths must be considered:

1. the whole layer of pisoliths is agitated, so that cementation does not occur;
2. the accretion of pisoliths takes place without intense agitation, but in such a way as to prevent cementation.

Many facts are against the first explanation. The agitation of the whole thick layer of pisoliths would be possible only by large seasonal streams, but there is no evidence of their existence. Drops falling from the roof of the cave can agitate only the superficial layer of pisoliths, and this would not prevent the cementation of the lower layers. Moreover, the pisoliths occur also in places in which the energy of falling waters is entirely negligible. There are no traces of abrasion of the surface of pisoliths which would be expected in case of a strong agitation. The surfaces of pisoliths are always rough and unpolished, and no traces of abrasion are visible in cross-sections.

All these reasons indicate that the second explanation should be accepted.

The deposition of the consecutive layers forming the pisoliths takes place probably during the seasonal flooding of the cave floor and the drying-up afterwards of the lakes formed in the cave. This process is recorded in the structure of the individual laminae (see p. 253).

The lack of cementation of the pisoliths has not yet been satisfactorily explained. It is supposed that the presence of impurities in water may be of some importance, and possibly also the rapid precipitation of calcite. It should be stressed that nearly all mummies are not cemented to the substratum in spite of their large size and weight.

Pisoliths from small-scale depressions

In the case of the small-scale depressions, the agitation of water caused by drops falling from the roof and the resulting abrasion of pisoliths are obviously the principal formative agents, characteristic for this environment.

The authors carried out a series of experiments in order to determine the optimal conditions of agitation of the pisoliths. Laboratory trays, china cups and watch glasses were used as basins in which were placed cave pisoliths of various size and shape, and plaster of paris spheres with diameters from 15 to 90 mm. The water was agitated by drops falling from an altitude of between 1 and 2 m, and various frequencies of falling of drops were tested.

In a dry basin, only the small pisoliths directly hit by the falling drops were agitated. With the rise of the water level, neighbouring pisoliths begin to move. The strongest agitation of the pisoliths takes place in a layer of water whose depth ranges from a half to one diameter of the pisoliths. With increasing depth of water, the agitation of the pisoliths stops rapidly, depending on the diameter. Pisoliths with diameters ranging from 40 to 90 mm were not moved when the depth of water reached 1 to 2 diameters, while the smaller pisoliths were not moved under a depth of water equalling 2—5 diameters. An increase in the frequency of falling drops, an increase in the altitude of fall and a tendency towards a hemispherical shape of the bottom of the basin all increase the intensity of movement of the pisoliths.

The above observations explain why the cave pearls in caves and mines are found as rule in small and shallow depressions (see Table 1). The polishing of their surface is possible only under a small depth of water. Cross-sections of cave pearls often reveal the presence of several abrasion surfaces. Polishing of the surface occurred repeatedly, slowing down or even entirely interrupting the accretion of new layers of calcium carbonate. However, the duration of the abrasion periods must be small in comparison with the total time of formation of a pisolith, and the size-reducing effect of abrasion is generally small in comparison with the size-increasing accretion of the consecutive layers. The pisoliths are abraded when increases occur in the percolation of water into the cave and in the intensity of the „rain" falling from the cave roof. The accretion of new layers predominates when the water percolation ceases, and the pisoliths are submerged in water saturated with calcium carbonate (G. Baker, A. C. Frostick, 1947).

The speed of the abrasion process can be estimated on the basis of an experiment carried out by the authors: a pisolith, collected at Station B, Cueva del Amistad, with spherical shape (slightly flattened), 21 mm in diameter, was placed in a china crucible and agitated by drops of water, falling from an altitude of 1,6 m, with frequency 80—90 drops per minute. After 10 days, the smooth but dull surface of the pisolith was polished. The weight reduction during that period amounted to 0,8 per cent.

The pisoliths freely turned by falling drops obtain a more or less spherical shape. A restriction of the pisolith's movement results in a flat or polyhedral shape.

A freshly deposited layer in a pisolith has always a dull surface. The smooth, shining surfaces are the result of abrasion. Therefore the character of the surface of a cave pisolith depends on that whether it is in a phase of accretion or abrasion, as well as on its shape and relation to neighbouring pisoliths. The spherical pisoliths have whole surface either bisque-like or polished. The flattened and trapezoidal pisoliths have only polished undersides. The polyhedral pisoliths which are closely packed in a depression usually have polished surfaces.

Independently of the shape of the nucleus and the seasonal abrasion of the surface, the shape of a pisolith depends largely upon the conditions of deposition of the individual layers. If the whole pisolith is submerged (Fig. 4, A), the newly deposited layer has a more or less uniform thickness.

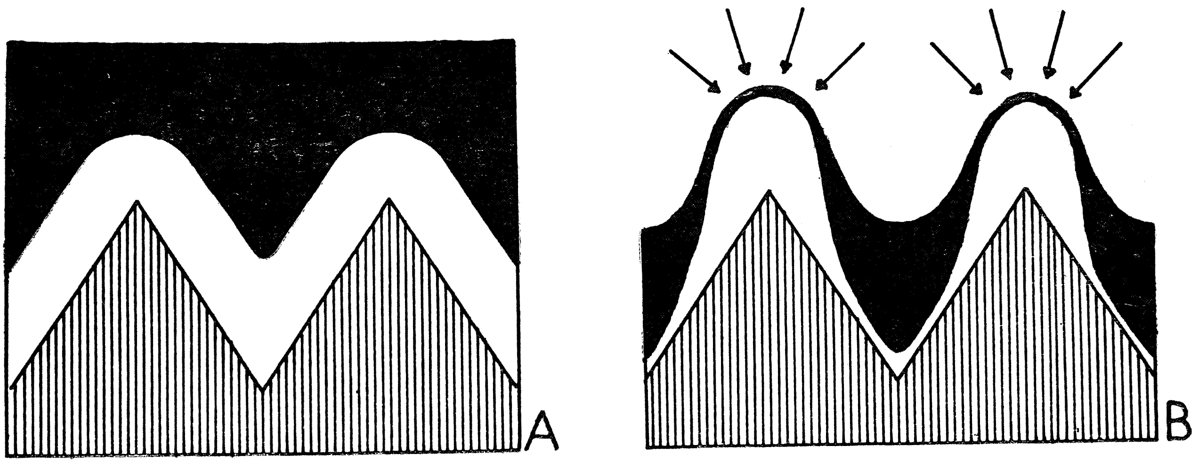

Fig. 4. Schemat odkładania się warstewki kalcytu na nierównej powierzchni podłoża: A — całkowicie zanurzonej w wodzie; B — częściowo wynurzonej. Podłoże zakreskowane, kalcyt biały, woda czarna, strzałki oznaczają strefę maksymalnej depozycji. Bliższe objaśnienia w tekście (str. 260)

Fig. 4. Schematic diagram showing deposition of calcite lamina on surface irregularities: A — completely submerged in water; B — particularly submerged. Substratum lined, calcite lamina white, water black, arrows show the areas of maximum calcite deposition. Explanations in text (p. 260)

The growth of the individual laminae lead, in this case, to the smoothing of the irregularities of the pisolith surface. If instead, only a part of the surface of the pisolith is submerged (this takes place during the drying-up of the depressions) the part above the surface of the water is covered only by a thin film of water maintained by molecular forces. The precipitation of calcium carbonate occurs then in the places where the water film is the thinnest, i.e. on the peaks of irregularities of surface (Fig. 4, B). The water is supplied continuously to such points from the neighbouring depressions of pisolith's surface. In this way, irregularities of the surface are accentuated, and finally fungoidal protuberances extend from the upper surface of the pisolith.

In some cases, trapezoidal pisoliths are formed in this way. In shallow depressions, which frequently dry up, the fungoidal protuberances grow on the upper sides of pisoliths, while continuous layers are deposited on the lower sides, which latter are moreover abraded from time to time. The accretion of the fungoidal protuberances is most intense on the perimeter of the pisoliths and in this way the pisoliths attain a shape approximating to inverted truncated cone. As the center of gravity rises, the pisolith may fall on its side and the process will be repeated on another side.

The cauliflower structures are also probably formed during the periodic drying-up of water in the basin, but they are closely related in genesis to the recrystallization of the layers of their substratum (see p. 256).

The baccate pisoliths are formed in a variety of ways. They have the form of spherical pisoliths, being covered on their entire surface by cauliflower or fungoidal structures.

The various shapes of pisoliths occurring in small-scale depressions result chiefly from different conditions in the deposition of individual layers, which are from time to time subjected to abrasion of various intensities. These differences are also marked in the internal structure of the pisoliths.

CONCLUSIONS

Pisoliths occur in caves in two different environments, characterized by different conditions of formation of these deposits. These differences are:

pisolithic fields:	small-scale depressions:
pisoliths form large, thick covering layers on a flat bottom,	pisoliths occur in small, shallow depressions,
usually dry, rarely flooded important influence of external climate	usually flooded, cave microclimate,
rather rapid drying-up,	relatively slow drying-up,
agitation of pisoliths unsignificant,	strong agitation of pisoliths,

The resulting differences in shape and structure of the pisoliths are.

pisolithic fields:	small-scale depressions:
predominance of spheroidal pisoliths,	diversity of shapes,
pisolithic conglomerates absent,	pisoliths attached to the substratum,
abrasion of pisoliths absent,	abrasion of pisoliths ubiquitous,
bulk specific gravity smaller,	bulk specific gravity larger,
laminae bipartite, aphanitic calcite absent, weak recrystallization,	primary laminae aphanitic, recrystallization common.

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REFERENCES

Baker G., Frostick A.C. (1947), Pisoliths and ooliths from some Australian caves and mines. *J. sediment. Petrol.*, 17, pp. 39—67.

Baker G., Frostick A.C. (1951), Pisoliths, ooliths and calcareous growths in limestone caves at Port Campbell, Victoria. *J. sediment. Petrol.*, 21, pp. 85—104.

Barczyk W. (1956), Pizolity jaskiniowe w jednej z grot w Wojcieszowie (On cave pisoliths from Wojcieszów, Polish Sudeten), *Acta geol. pol.*, 6, pp. 327—336.

Carozzi A.V. (1962), Cerebroid ooliths. *Trans., Illinois Acad. Sc.*, 40.

Davidson S.C., McKinstry H.E. (1931), „Cave pearls", oolites and isolated inclusions in veins. *Econ. Geol.*, 26, pp. 284—291.

Donahue J. (1965), Laboratory growth of pisolite grains. *J. sediment. Petrol.*, 35, pp. 251—256.

Emmons R.C. (1928), The state and density of solutions depositing metalliferous veins. *Trans., Amer. Inst. Mining Eng.*, 46, pp. 303—320.

Gradziński R., Radomski A. (1957), Utwory naciekowe z „mleka wapiennego" w jaskini Szczelinie Chochołowskiej (Caverns deposits of „rock milk" in the Szczelina Chochołowska Cave). *Rocz. Pol. Tow. Geol.* (*Ann. Soc. Géol. Pol.*), 26, pp. 63—90.

Gradziński R., Radomski A. (1963), Types of Cuban caves and their dependence on factors controlling karst development. *Bull. Acad. Pol. Sc., Sér. sc. géol. géogr.*, 9, pp. 151—160.

Gradziński R., Radomski A. (1967), Spostrzeżenia nad rozwojem jaskiń i krasu kopiastego w Sierra de los Organos (Kuba) (Observations on development of caves and kegel karst in Sierra de los Organos, Cuba). *Acta geol. pol.*, 17.

Gradziński R., Unrug R. (1960), Uwagi o powstawaniu nacieku grzybkowego w jaskiniach (Remarks on the formation of fungoidal concretions in limestone caves). *Rocz. Pol. Tow. Geol.* (*Ann. Soc. Géol. Pol.*), 30, pp. 273—287.

Gradziński R., Wróblewski T. (1967), Szata naciekowa jaskini Raj (Cave formations in the Cave Raj). *Ochrona Przyrody*, 33.

Hess F.L. (1930), Oolites or cave pearls in the Carlsbad Caverns. *U.S. Nat. Mus. Proc.*, 77, f. 2813, art. 16, 5 p.

Illing L.V. (1954), Bahamian calcareous sand. *Bull. Amer. Ass. Petrol. Geol.*, 38, pp. 1—93.

Keller W.D. (1937), „Cave pearl" in a cave near Columbia, Missouri. *J. sediment. Petrol.*, 7, pp. 263—265.

Kirchmayer M. (1963), Höhlenperlen (cave pearls, perles des cavernes), Vorkommen. Definition sowie strukturelle Beziehung zu ähnlichen sedimentsphäriten. *Anz. Österr. Akad. Wiss., Math.-Naturwiss. Kl.*, Jhrg. 1963, pp. 223—229.

Kirchmayer M. (1964), Höhlenperlen (cave pearls) aus Bergwerken. *Sitzungsber. Österr. Akad. Wiss., Math.-Naturwiss. Kl.*, 173, pp. 309—349.

Liégeois P.G. (1956), A propos des perles de cavernes et concrétions analogues non encore décrites. *Ann. Soc. Géol. Belg.*, 80, pp. B 165 — B 169.

Mackin J.K., Coombs H.A. (1945), An occurence of „cave pearls" in mine in Idaho. *J. Geol.*, 53, pp. 58—65.

Perna G. (1958), Concrezioni libera di grotta. *Atti VIII Congr. Nat. Speleologia, pp. 108—120.* Como.

Pond A.W. (1945), Calcite oolites or „cave pearls" formed in a „Cave of the Mounds". *J. sediment. Petrol.*, 15, pp. 55—58.

Viehmann I. (1960), Přispěvky k vývoji jeskynnych perel (Un nouveau processus de genèse des perles de caverne). *Československy Kras*, 12, pp. 177—185.

Viehmann I. (1963), Un nou proces de geneză a perlelor de cavernă (Un nouveau

processus de genèse des perles de caverne). Lucrările Inst. Speleol. „Emil Racoviță", I—II, pp. 295—303.
Warwick G. T. (1962), Cave formations and deposits. In British Caving, 2nd ed., pp. 83—119, London.

OBJAŚNIENIA TABLIC
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Fig. 2. Laminy afanitowe. Pizolit z stanowiska A, Cueva del Amistad. ×80

Fig. 2. Aphanitic laminae. Pisolith from Station A, Cueva del Amistad. ×80

Fig. 3. Grubokrystaliczna mozaika radialna. Pizolit z stanowiska B, Cueva del Amistad. ×74

Fig. 3. Coarse-crystalline radial mosaic structure. Pisolith from Station B, Cueva del Amistad. ×74

Fig. 4. Rekrystalizacja strefowa. Widoczny front rekrystalizacji. Pizolit z stanowiska B, Cueva del Amistad. ×74

Fig. 4. Zonal recrystallization. Visible front of recrystallization. Pisolith from Station B, Cueva del Amistad. ×74

Tablica — Plate XIV

Fig. 1. Struktury pierzaste. Górna część struktur. Widoczne ślady laminacji koncentrycznej. Nikole równoległe. Pizolit z stanowiska B, Cueva del Amistad. ×35

Fig. 1. Feather-like structure. Upper part of the structure. One nicol. Visible traces of concentric lamination. Pisolith from Station B, Cueva del Amistad. ×35

Fig. 2. Struktury pierzaste. Dolna część struktur. Nikole skrzyżowane. Pizolit z stanowiska B, Cueva del Amistad. ×35

Fig. 2. Feather-like structure. Lower part of the structure. Crossed nicols. Pisolith from Station B, Cueva del Amistad. ×35

Fig. 3. Budowa wewnętrzna pizolitu trapezoidalnego. Laminy układają się początkowo równolegle do powierzchni jądra. Widoczne zastępowanie kalcytu afanitowego przez kalcyt mozaikowy. Na powierzchni pizolitu struktury grzybkowe. Pizolit z stanowiska A, Cueva del Amistad. ×10

Fig. 3. Internal structure of a trapezoidal pisolith. The initial laminae are parallel to the surface of the nucleus. Note the replacement of aphanitic calcite by mosaic calcite. Pisolith from Station A, Cueva del Amistad. ×10

Fig. 4. Fragment pizolitu trapezoidalnego. Widoczne zastępowanie kalcytu afanitowego przez kalcyt mozaikowy w pobliżu szczeliny. Pizolit z stanowiska A, Cueva del Amistad. ×53

Fig. 4. Detail of a trapezoidal pisolith. Note the replacement of aphanitic calcite by mosaic calcite near the fissure. Pisolith from Station A, Cueva del Amistad. ×53

Fig. 5. Przekrój pizolitu trapezoidalnego. Widoczne na górnej powierzchni wyrostki grzybkowe. Pizolit z stanowiska A, Cueva del Amistad. ×4

Fig. 5. Cross-section of the trapezoidal pisolith. Fungoidal concretions visible on the upper surface. Pisolith from Station A, Cueva del Amistad. ×4

Tablica — Plate XV

Fig. 1. Budowa wewnętrzna pizolitu wielojądrowego, Cueva del Amistad, stanowisko B. ×2,5

Fig. 1. Internal structure of a multi-nucleus pisolith, Cueva del Amistad, Station B. ×2,5

Fig. 2. Pizolit grubokrystaliczny o strukturze radialnej (sferulit). Cueva del Amistad, stanowisko A. ×20

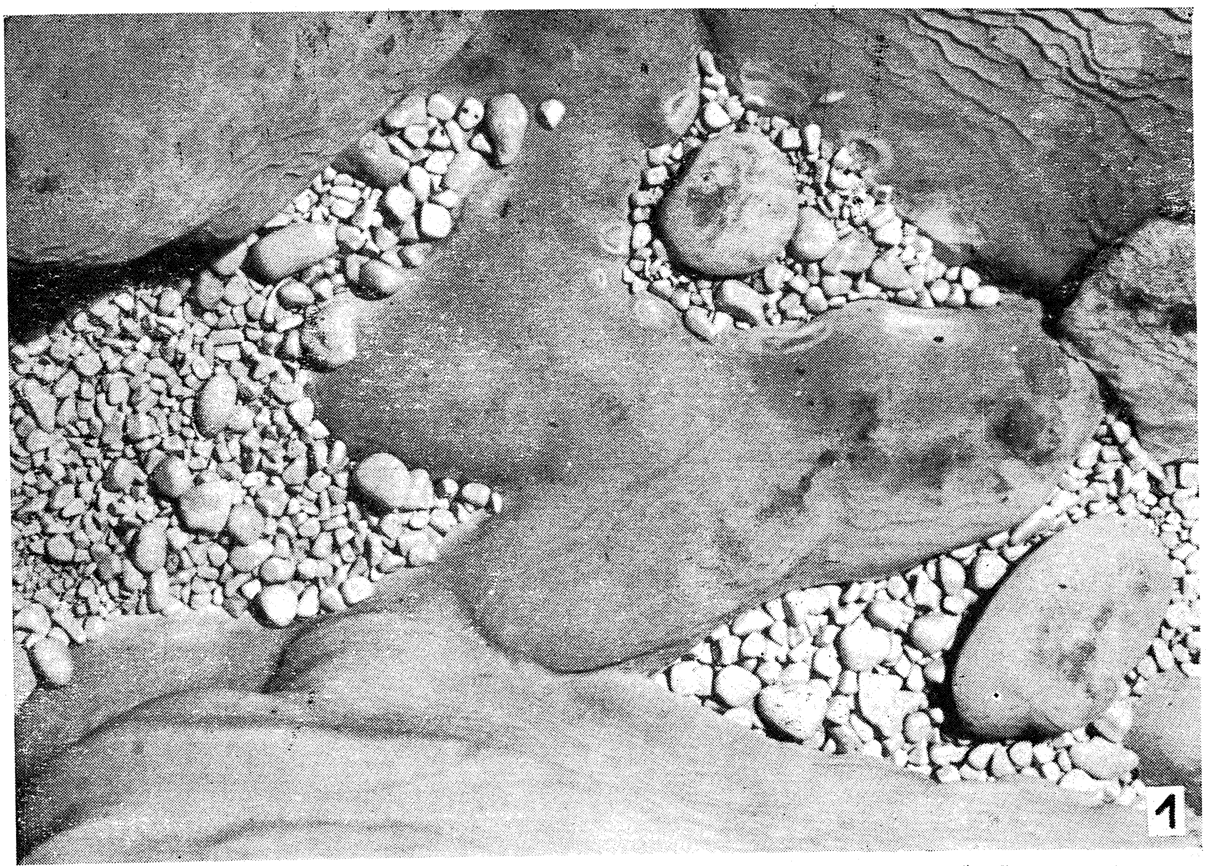
Fig. 2. Coarse-crystalline pisolith with radial structure (spherulite). Ghost-lines visible in the superficial part. Cueva del Amistad, Station A. ×20

Fig. 3. Laminy o strukturze palisadowej. Zanieczyszczenia tworzą ciemne plamy. Pizolit z pola, Cueva Humboldt. ×60

Fig. 3. Laminae of palisade structure. Dark stains caused by impurities. Pisolith from pisolithic field, Cueva Humboldt. ×60

Fig. 4. Struktura palisadowa. Ponad dużym kryształem widocznym w centrum fotografii widoczne resztki lamin pelitycznych. Pizolit z pola, Cueva Humboldt. ×60

Fig. 4. Palisade structure. Remains of pelitic laminae visible above the large crystal in the centre. Pisolith from pisolithic field, Cueva Humboldt. ×60



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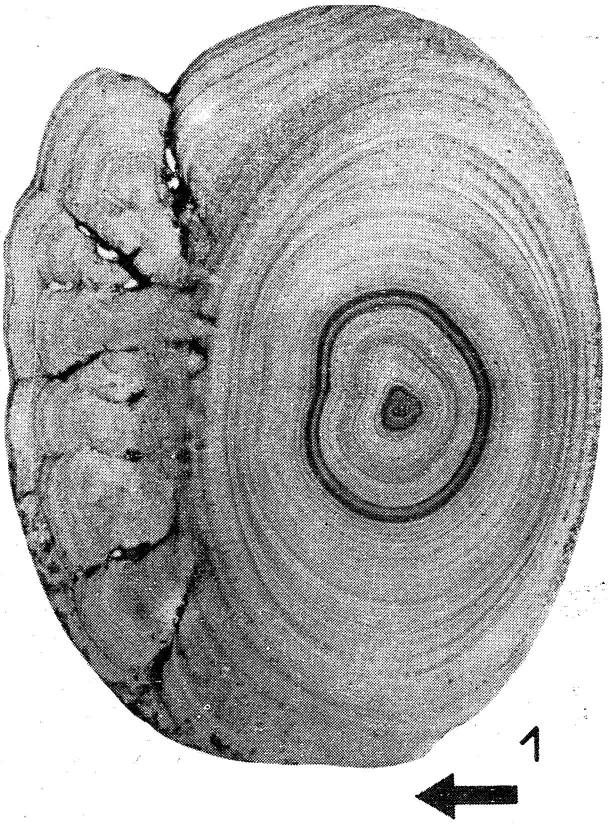

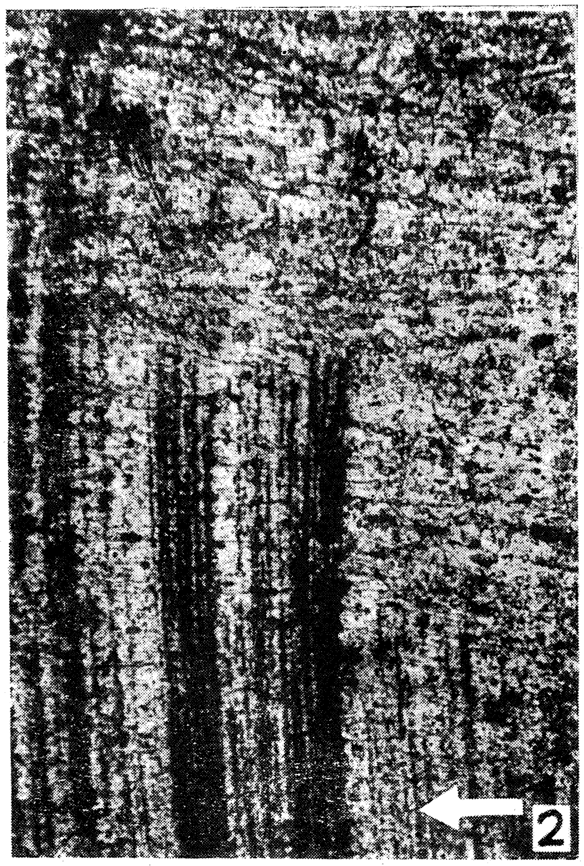

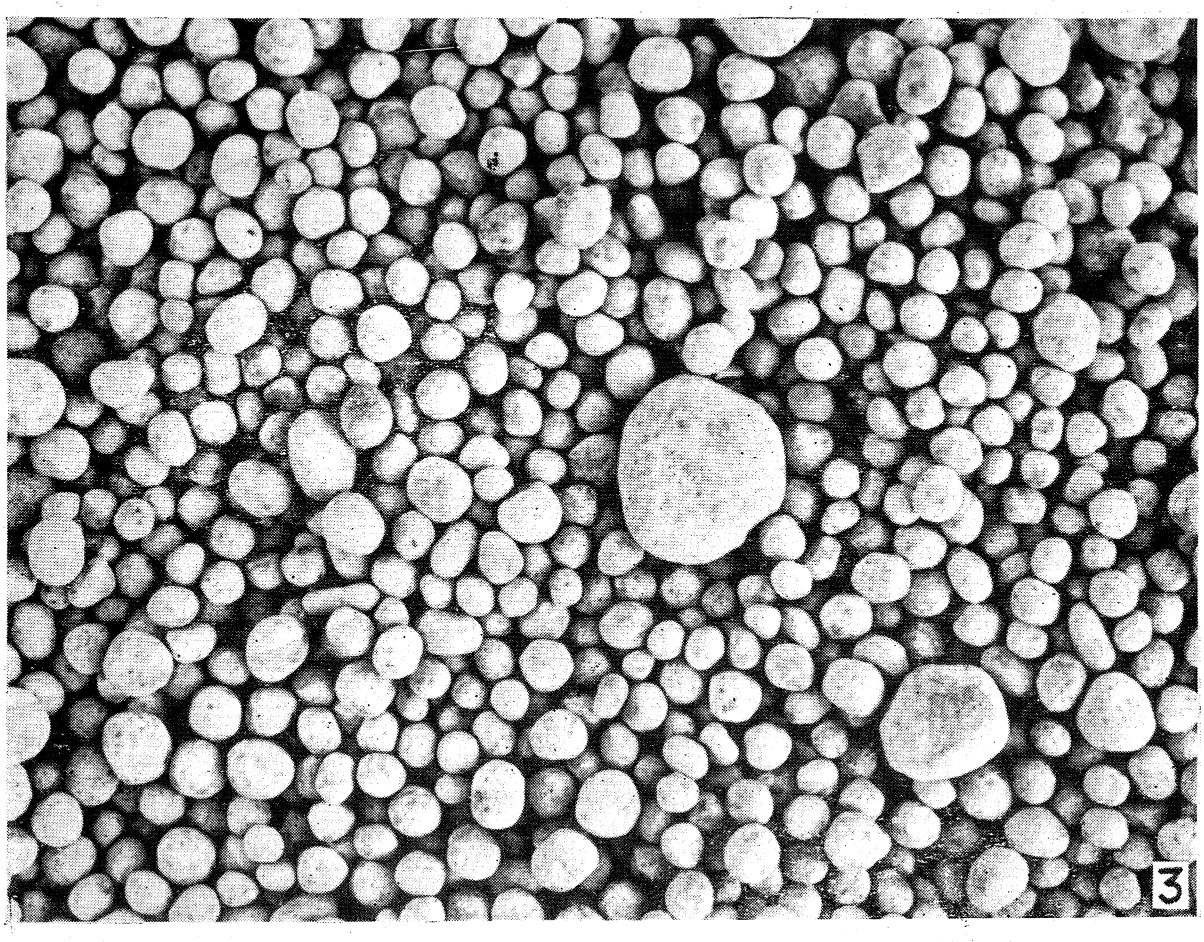

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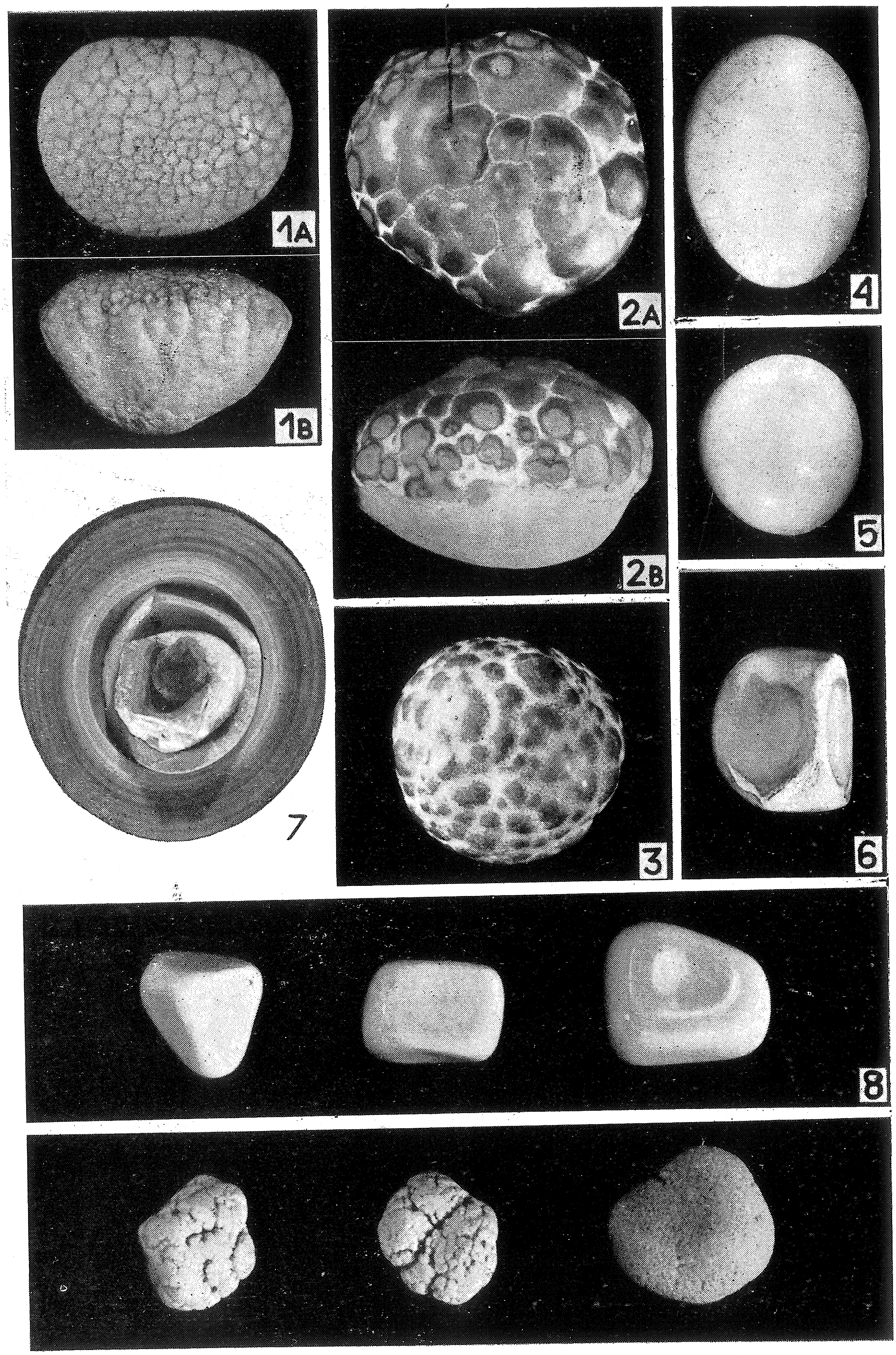

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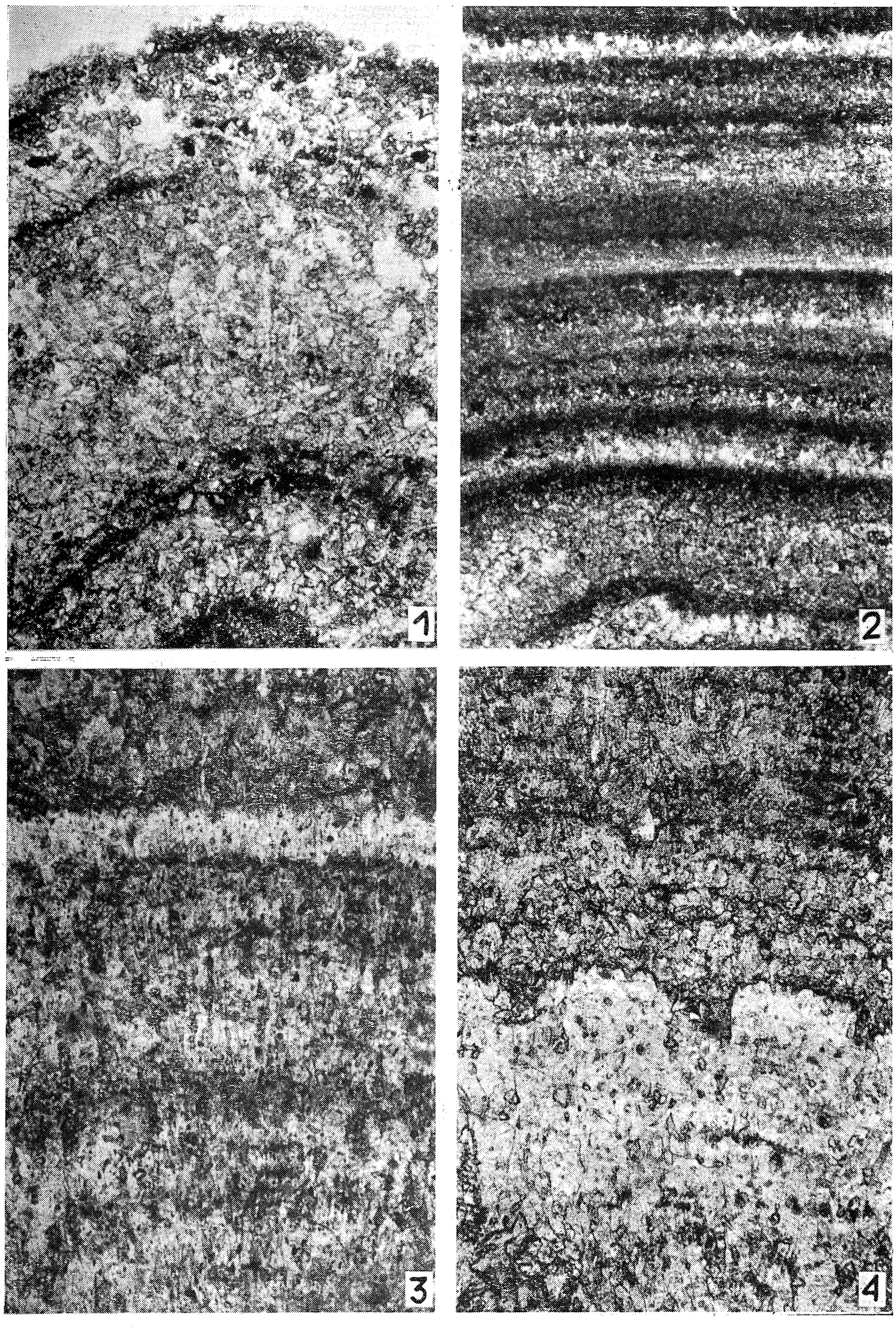

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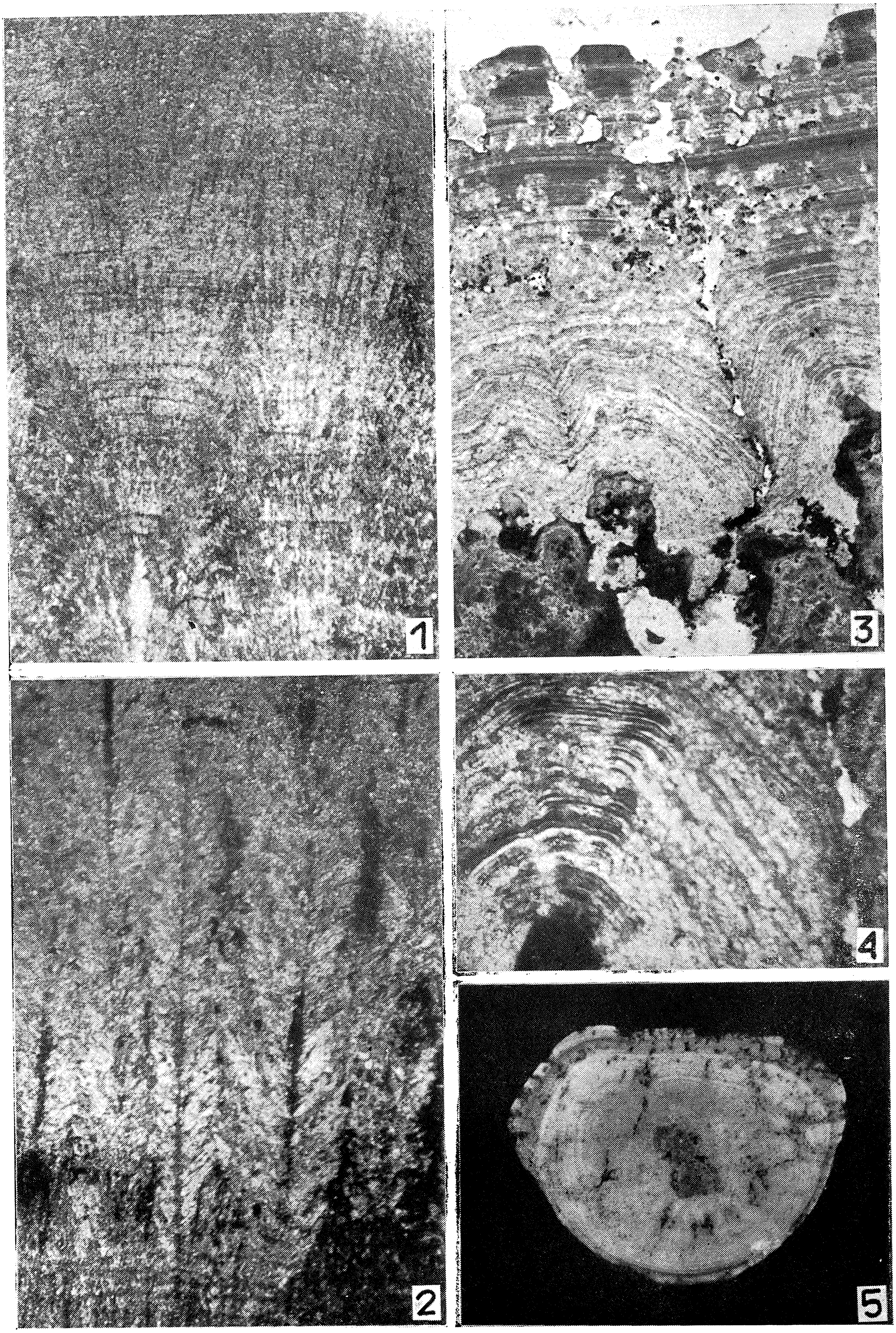

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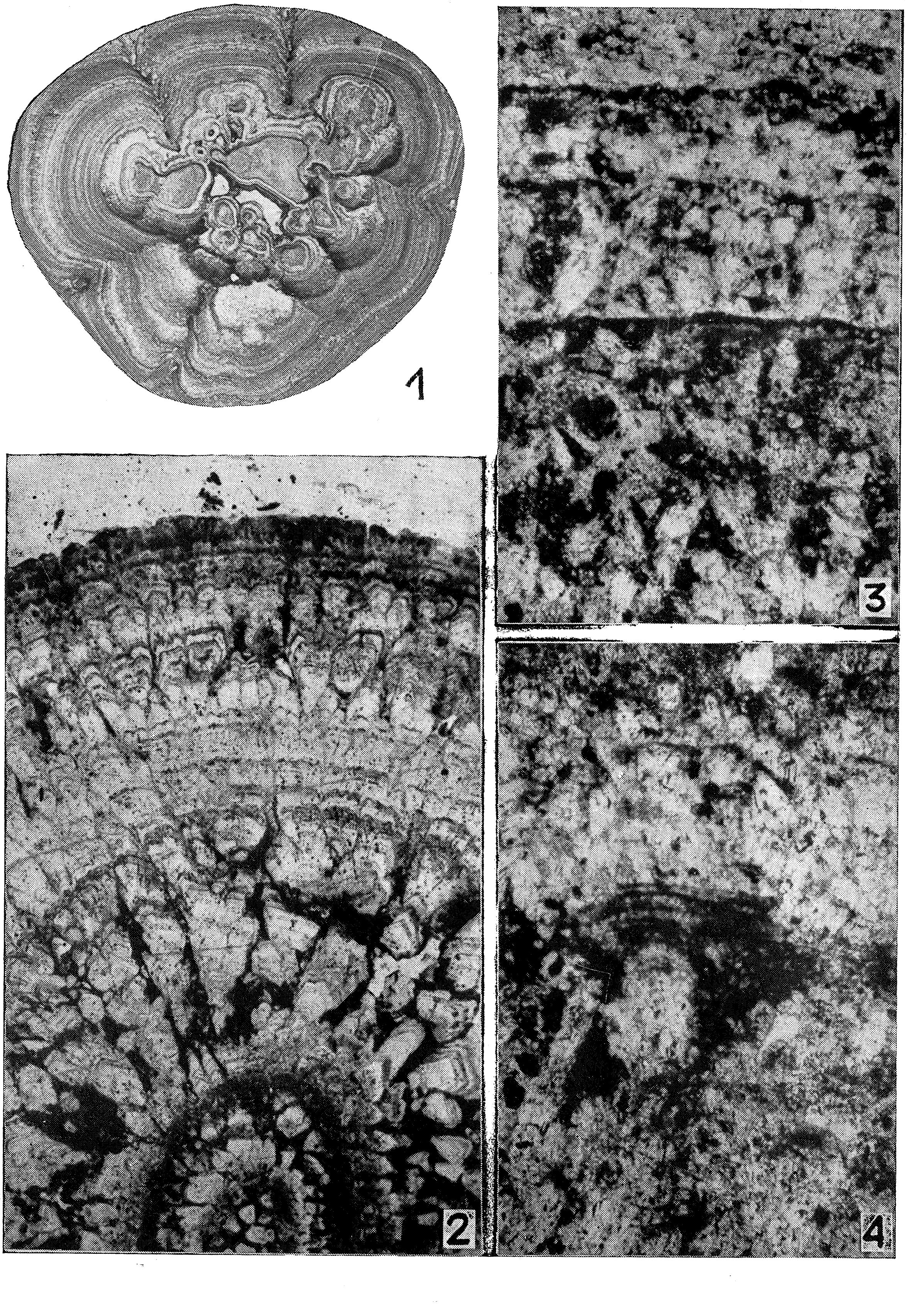

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