Fabrics and Origin of Speleothems in Hydrothermal Caves, Buda Hills, Hungary

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Speleothems (botryoids and floating rafts) in hydrothermal caves have an extraordinary delicate inner structure, which was examined by optical, cathode luminescent and electron microscope. Low-magnesian calcite cements show a great diversity of crystal morphology, some of them point to an aragonitic precursor. Intercrystalline porosity can be significant, solution enhanced pores may be partly filled with micritic internal sediments. Speleothems are generally not luminescent, though some fine dull-bright zonation indicates subtle geochemical changes during precipitation. δ18O stable isotope data prove the expected hydrothermal origin of the precipitates, palaeo-water temperature might have ranged between 35–70 °C. The host rock of the hydrothermal caves also shows a strong alteration trend, as a consequence of the hydrothermal action. δ13C stable isotope data let us distinguish two types of precipitates: one in the near-surface meteoric environment, and another in the deeper zone.

Introduction

Speleothem petrography has received relatively little attention. Previous work by Mauritz (1958), Ozoray (1965), Gado (1965), Koch (1985) and Bognár (1986), dealt more with the mineralogical composition of the speleothems. When crystal fabrics have been examined, the interpretations often oversimplified the process of precipitation. Therefore more than fifty samples of spelean carbonates were collected from different hydrothermal caves in the Buda Mountains (Fig. 1), where they form 1–10 cm thick coating on the walls of the cave passages. Polished thin sections were investigated by optical, cathodoluminescent and scanning electron microscope. In addition the evaluation of earlier 13C and 18O stable isotope measurements (Ford, Takács-Bolner 1991), more than forty new determinations were carried out to gain more information about hydrothermal speleogenesis.

The use of laboratory equipment, offered by Oxford University, is acknowledged (optical and scanning electron microscope at the School of Geography, cathodoluminescent microscope and mass spectrometer at the Department of Earth Sciences). Geochemical analyses were carried out at the Geological Institute of Hungary.

Petrographic description of the speleothems

The most common speleothems, found in almost all the hydrothermal caves are the botryoidal growths. These are 3–5 cm sized nodular bodies, composed of individual globules of 0.3–0.8 cm in diameter, built up of sub-mm size layers. The morphology of the botryoids is highly variable from cave to cave, and differences may exist within a single cave, too. They may display elongated columnar forms, but ooid structures also occur. Botryoids can cover the lower parts of cave passages to a depth of 6–8 cm. Crusts on the cave walls decrease upwards in thickness, becoming bare walls, which exhibit spherical solution forms (Fig. 2).

The micro-structure of the botryoidal growths shows much diversity. The boundary of the cave bedrock (which is generally an Upper Eocene limestone) and the speleothem is fairly sharp (Plate I, Photos 1, 2). The individual crystals of the botryoidal spelean carbonates are rhombohedrons, with their c-axis normal to the substrate, 40–50 µm in size. Within the crystals, inclusion-rich zones mark former rhombohedral terminations (Plate I, Photo 3). Slightly re-dissolved crystals sometimes terminate at the base of an overlying micritic layer of 80–100 µm average thickness. Elongated small calcite crystals, 70–80 µm in size, grow at the top of these micritic layers.

Ooid structure may also be a characteristic feature (Plate I, Photo 4). Ooids can be as big as 4–5 µm in diameter. The nuclei of ooids often consist of stacked triangular zoned calcite crystals, 80–100 µm in size, but they can also be composed of micritic sediment. The popcorn layers covering the nuclei are thin microcrystalline layers of 20–50 µm average thickness, having smooth, undulating surfaces, with poorly defined crystal terminations.
Although the present composition of the popcorn in the caves is low-magnesian calcite (according to XRD analyses), some features relate to former aragonite structures. These are feather-like, highly corroded crystal aggregations of 2 mm in length. Bunches of needles with an average size of 0.5 mm are also found in some botry-
oids. They are built up of straight needles, 3–5 µm thick and 300–400 m long, which are thought to be aragonites (Plate II, Photo 1). Remnants of former aragonite structures are most obvious, where bunches of crystals, 1.2–1.5 mm long, display sweeping extinction under crossed polars. Individual crystals within the bunches are slightly curved needles, 100–300 µm long and 10–40 µm wide (Plate II, Photo 2).

Botryoids from the Erdõhát út Cave have extraordinarily exotic patterns which cannot be compared with any of the other types. They consist of ooids 1 mm in diameter, which are composed of 30–40 µm dark brown micritic clumps (Plate II, Photo 3, 4). Some of these micritized grains contain small half globules (Plate III, Photo 1). This structure is very common in bacterially induced carbonate precipitations (CHAFETZ 1986). The micritic ooids are surrounded by slightly curved, saddle shaped calcite crystals, 150–200 µm in length and 20–30 µm wide, with squared crystal terminations (Plate III, Photo 2). The outer parts of the ooids are composed of a great variety of cements, these are 0.5 mm calcite blades with bunches of straight aragonite needles, 50–80 µm in length, 50–60 µm thick micritic layers, yellowish-brown ferroan-calcite layers, etc. (Plate III, Photo 3, 4). Some micritic ooids are surrounded only by a layer 60–80 µm in thickness, composed of isopachous calcite cement, in which the crystals are strongly corroded.

Intercrystalline porosity in the popcorn (about 5%) appears most commonly as elongated pores between calcite blades, parallel to the c-axis of the crystals, of comparable size to an individual crystal. Lens shaped pores 0.4 mm in height and 1–1.5 mm in length are also found between the botryoid layers. Crystal terminations which project into these pores are strongly re-dissolved. Micritic internal sediments may partly fill these solution enhanced pores (Plate IV, Photo 1). Different generations of late calcite cements may also fill the intercrystalline pores of the botryoids (Plate IV, Photo 2).

Another characteristic kind of speleothem in the Buda caves are the floating rafts. They are composed of cemented calcite plates (floes) 1–5 mm in thickness, and are found at various levels in the caves (Fig. 2). “Christmas trees” are local cone-shaped accumulations of the floating rafts of 0.3–1.0 m in height (Fig. 2).

The micro-structure of floating rafts from different caves is much more uniform than that of botryoids. They are built up of calcite blades, 0.8–1 mm in size, with their long axis normal to the underlying substrate (Plate IV, Photo 3).

Non-occluded porosity, which can be as much as 10%, includes intracrystalline pores, 300–400 µm in size, moulds of re-dissolved crystal terminations, elongated pores 0.5–1 mm in length, which formed between the crystals, parallel with their c-axis during growth. 4–5 mm sized, elongated pores (about 5%), partly filled with micritic internal sediments occur at the top of the calcite blades (Plate IV, Photo 4). Crystal terminations, which project into these pores are re-dissolved.

In contrast with the brightly luminescent host limestone of the caves, none of the botryoids were luminescent, though some micritic layers in the samples showed dull blue-lilac or brown luminescence (Plate I, Photo 2). The micritic nuclei of the ooids had dull orange-brown luminescence with micron size bright orange spots and so did micritic internal sediments. Bright orange luminescence with few dull zones was observed in the first generation of the late calcite cement, filling intercrystalline pores.

The botryoids from the Erdõhát út Cave have both unique micro-structure and luminescence properties. Generally, the micritic nuclei of ooids showed dull-bright blue or lilac luminescence (Plate II, Photo 4). There was significant difference in the luminescence of the different types of “coatings”, they were all nonluminescent or dull blue, lilac luminescent, independent of their structure.

Floating rafts were generally not luminescent, though a few samples had dull brown luminescence with some bright orange layers.

Fig. 2. Cross section of a hydrothermal cave passage with the most characteristic speleothems

A = crystal needles, B, E = botryoidal speleothems, C = floating rafts, D = “christmas tree”, S = spherical solution niche

2. ábra. Egy hidrotermás barlangjárat idealizált szelvénye a legjellegzetesebb szpeleotémák feltüntetésével

A = kristálypamacsok, B, E = borsókövek, C = kalcitlemezek, D = „karácsonyfa”, S = gömbfülke

Cathodoluminescence
Chemical composition

According to XRD analyses, the spelean carbonates were all calcites with 1–5% quartz content, excepting the botryoids from Erdőhát út Cave, which was mainly composed of ankerite (25–52%) and dolomite (30–56%) with 11–13% calcite and 5–8% quartz content.

Chemical composition of spelean carbonate samples was determined by ICP mass spectrometer at the Hungarian Geological Survey. All the calcites are low-magnesian calcites (Mg content ranged between 0.34 and 2.4%) with little (0.0007–0.02%) Mn content. Sr content was generally high (120–600 ppm).

13C–18O stable isotope data

Altogether 19 measurements were made from the host rock (Upper Eocene limestone) of the caves, with 13C values ranging between –1.44 and 1.95% PDB, while 18O values ranged between –5.12 and –9.73% respectively (Fig. 3).

28 measurements were carried out on botryoidal speleothems. Two separate groups are recognisable on the cross plot (Fig. 3). Botryoids from Ferenchegy, Pálvölgy and Erdőhát út caves have 18O values between –8.82 and –16.667% PDB and 13C values between 1.54 and 4.73% PDB. Samples from Bátori and Rácska caves display much more negative 13C values (between –2.145 and –8.776% PDB), and 18O values range within a more narrow interval between –9.3 and –12.118% PDB. Botryoidal speleothems from Szemlőhegy Cave seem to connect the two distinct groups with 13C values between 2.191 and –2.191, and 18O values ranging between –8.48 and –12.58% PDB.

Values of floating rafts display similar distribution among the caves, like botryoidal growths (Fig. 3). Samples from Pálvölgy Cave have 13C values between 0.69 and –1.22% PDB, with 18O values between –12.86 and –14.58% PDB. Floating rafts from Bátori and Rácska caves stand out again with their more negative 13C values of –2.012 to –7.59% PDB, while their 18O values range between –9.473 and –10.606 % PDB respectively. Samples from Szemlőhegy Cave display again medium values with –2.226 for 13C and –10.109 for 18O.

Fig. 3. 13C–18O stable isotope data from the host rock of the caves and the different speleothems and their interpretation

1. Host rock, 2. Botryoids, 3. Floating rafts
Even more interesting results came out from the lami-
na-by-lamina stable isotope analyses (Fig. 4). Both $^{13}$C and $^{18}$O values were plotted against “time”, which is of course relative, and is represented by moving from the centre to the outer parts of the sample (Fig. 5, 6).

$^{13}$C values become more negative outwards in the botry-
oid layers from Szemlõ-hegyi (Fig. 4 VII, Fig. 5 VII) and Bátori caves (Fig. 4 I, Fig. 5 b). A reverse trend in the $^{13}$C values was observed within the distinct layers of floating rafts in Rácska Cave (Fig. 4 VI, Fig. 5 c) and also in floating rafts covered by botryoids from Szemlõhegy Cave (Fig. 4 IX, Fig. 5 IX), while other samples showed different variations of increment and decrement with no regular pattern.

$^{18}$O values became more negative outwards from layer to layer in the botryoid covered floating raft from Szemlõ-
hegyi (Fig. 4 IX, Fig. 6 IX) and Bátori caves (Fig. 4 II, Fig. 6 II), and similar depletion in the heavy isotope was observed in the layers of floating rafts in Rácska Cave (Fig. 4 VI, Fig. 6 VI). Distinct layers of botryoidal growth from Szemlõhegy Cave had a similar pattern, however the value of the outermost layer was more positive (Fig. 4 VII, Fig. 6 VII).

$^{18}$O values of botryoid layers were shifted progressively towards more and more positive values in the samples from Ferenc-hegyi (Fig. 4 III, Fig. 6 III) and Bátori caves (Fig. 4 I, Fig. 6 f). An irregular oscillation trend was observed between the layers from Rácskai Cave (Fig. 4 V, Fig. 6 V).

In both samples from Szemlõhegy (Fig. 4 VIII, Fig. 6 VIII) and Ferenc-hegy Cave (Fig. 4 IV, Fig. 6 IV), where measurements were taken from the contact of the Eocene limestone and the speleal carbonate, a positive shift in the $^{18}$O values was observed in the different parts of the li-
imestone closer to the speleal coating.

Discussion

Evolution and mineralogy of the speleal carbonates

As believed by most authors, botryoidal speleothems are phreatic forms, but they also may grow in the warm moist air of the cave (for a general review see Hill 1973).

The question as to why the botryoidal speleothems display such a great variety in morphology, remains largely unanswered. Alterations can be explained by differences in water movement patterns, temperature and chemical composition, all of which could have influenced the micro-environment controlling crystal growth.

The contrasting structure of botryoids from Erdõhát út Cave suggest a fundamentally different origin. The mass of the small, uniformly coated ooids indicates a high energy depositional environment. This could have been a for-
mer spring zone, as was hypothesised by Kraus and Takács-Bolner (1989). The small half globules and micritized grains seem to be bacterially induced precipitations, which is not uncommon in former thermal springs. The dolomitic-ankeritic composition of the speleothems is explained by the cherty dolomite host rock (Mátyáshegy Formation) of the cave.

Aragonite poses another relevant question, as most speleal carbonates from hydrothermal caves are supposed to have been primarily precipitated as aragonite, and transformed into calcite only in a later phase (Hill 1973, Kraus 1991).

XRD analyses have not shown any aragonite in the samples from the Buda caves. However, bunches of needles and feather-like crystal aggregations with sweeping extinction under crossed polarisers refer to some aragonitic precursor. Another line of evidence supporting aragonite-to-calcite neomorphism is the Sr content of the crystals. As Sr is more readily incorporated in the orthorhombic structure, its high concentration may indicate aragonite composition (Kinsman 1969, Bathurst 1975). At the same time a decreasing trend of Sr/Ca ratio with increase in temperature is known in inorganically precipitated aragonites (Scoffin 1987). As the Sr content of the botryoids from the Buda caves is not extremely high, this cannot be considered as a strong evidence for the former presence of aragonite. However, the above mentioned relation between the temperature and the Sr content may be an explanation for the relatively small amount of Sr in the hydrothermal cave precipitations in the Buda hills, which might once have been aragonites.

Porosity patterns in the botryoids and re-dissolved crystal terminations show, that even the phase of net precipi-
tation was interrupted by short intervals when the water became aggressive. Micritic internal sediments in the solution enhanced intercrystalline pores also indicate periods when crystalline carbonate precipitation was interrupted and replaced by clastic sedimentation.

The lack of luminescence in the botryoids prove that they were formed in dominantly oxidising environment. Mn, which is the most important activator causing lumini-
escence in calcites (Miller 1988) is not found in any concentration in the samples. However even pure calcites without activating ions can exhibit blue luminescence, which can be a reason for the blue luminescence observed in some botryoid samples from Erdõhát út Cave, but dolomite and/or ankerite can also show blue luminescence (Miller 1988). The micritic parts of the botryoids with dull luminescence, and the brightly luminescent late cements, filling some of the intercrystalline pores indicate a more reducing environment and show geochemical changes during precipitation.

Thin calcite rafts precipitate on the water surface, especially where there are dust, or fine debris as nucle-
ation sites. When they grow too large to be supported by surface tension, they settle to the bottom of the cave pool (Hill 1973, Ford, Williams 1989).

The relatively large amount of intercrystalline porosity between and within the floating raft layers bordered by re-
dissolved crystal terminations is evidence of changes in water chemistry. Micritic internal sediments might have washed into these pores at the bottom of the cave pool, where the rafts settled down. The general nonluminescent pattern, similar to that of the botryoids, also indicates oxidi-
sing environment.
Fig. 4. Location of the detailed $^{13}$C–$^{18}$O stable isotope measurements

4. ábra. A rétegenkénti $^{13}$C–$^{18}$O stabil izotóp mintavételi helyek

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Interpretation of the $^{13}$C–$^{18}$O data

The $^{13}$C and $^{18}$O values of marine limestones range roughly between –2 to 2% PDB (Anderson, Arthur 1983). The $^{13}$C values of the host rock of the hydrothermal caves in the Buda Mountain (shallow marine Upper Eocene limestone) are within this interval, but the $^{18}$O values are shifted towards more negative values. This indicates a strong alteration trend, possibly as a consequence of hydrothermal action.

Calcites of freshwater diagenesis have $^{18}$O values of about –3% PDB (Scoffin 1987). Increase in temperature decreases the $^{18}$O value (Ford, Williams 1989), the more negative $^{18}$O values of the speleothems of the Buda caves support their suspected hydrothermal origin. The $^{18}$O values let us deduce the palaeo-water temperature, in which precipitation occurred. Increase in temperature decreases the $^{18}$O values by about 1% for each 4.3 °C, so calcite precipitated in deep burial is generally depleted in $^{18}$O (Scoffin 1987). According to this calculation, speleothems from the Buda caves might have precipitated from thermal water, 35–70 °C in temperature.

However the differences between the positive $^{13}$C values of the samples from Ferenc-hegyi, Pál-völgyi and Erdőhát út caves, and the negative values of Bátori and Rácska caves suggest dissimilar environments. The invariant $^{18}$O coupled with variable $^{13}$C is termed the meteoric water line. This pattern is the result of the variation in amount of the dissolved soil-gas CO$_2$ and the extent of rock-water interaction (Lohmann 1988). Meteoric ground waters are charged with atmospheric and soil-derived CO$_2$, enriched with the light $^{13}$C isotope and depleted in the $^{13}$C isotope. The $^{13}$C values of samples from Rácskai and Bátori caves are very close to that of the atmosphere, where $^{13}$C = –7 (Anderson, Arthur 1983), so they reflect near surface precipitation in the freshwater zone, where the influence of organic fractionation is the greatest.

As ground water percolates down, out of contact with gaseous CO$_2$ in the soil, the lighter $^{13}$C isotope is progressively exhausted and $^{13}$C values increase (Scoffin 1987). Enrichment in heavy isotopes (mainly in $^{13}$C) is also resulting from progressively greater rock-water ratios (Anderson, Arthur 1983). The more positive $^{13}$C values occur in regions, where carbonate rock $^{13}$C values buffer the pore water $^{13}$C values, whereas more negative values occur where less carbonate rock-water interaction is possible (Anderson, Arthur 1983). Calcites precipitated from thermal waters are also enriched in $^{13}$C (Ford, Williams 1989). The positive $^{13}$C values from the Buda caves therefore may reflect precipitation in the deeper zone, and/or greater rock/water ratio, than ones from Bátori and Rácska caves.

The secondary trends in the $^{18}$O values gave us more detailed information about the palaeo-water temperature. The more negative $^{18}$O values in progressively outward layers in the floating rafts covered by botryoids from Szemlő-hegyi and Bátori caves, and in the floating raft layers from Rácska Cave indicates, that precipitation occurred from water with increasing temperature. The assumed shift in temperature is 10.6 °C in Szemlőhegy, 10.7 °C in Bátori and 2.3 °C in Rácska Cave. The maximum difference between the botryoid layers in Szemlőhegy Cave is 21 °C.

Conversely the positive shift in $^{18}$O values from progressively outer layers suggests precipitation from gradually cooling waters. The calculated shift in temperature in these cases are 22.1 °C in Ferenc-hegyi Cave and 7.5 °C in Bátori Cave.
Fig. 6. Distribution of the $^{18}$O stable isotope data and the calculated palaeo-temperatures

6. ábra. A $^{18}$O stabil izotóp értékek rétegenkénti eloszlása, és az értékek alapján számított paleo-hőmérsékletek
Conclusion

Spelean carbonate formation was not a continuous process of precipitation as minor re-dissolution events and other types of sedimentation interrupted it from time to time. The great morphological diversity (both macro- and microscopically) can be explained by differences in water movement pattern, temperature and geochemistry, which could all have influenced crystal growth. Some of the speleothems might have precipitated as aragonite and recrystallised to low-magnesian calcite only later. The virtual absence of luminescent properties of the speleothems indicates precipitation in an oxidising environment, though some fine dull-bright zonation refers to subtle geochemical changes during the precipitation.

$^{18}$O stable isotope data proved the suspected hydrothermal origin of the speleothems. Palaeo-water temperature, from which precipitation occurred, might be as high as 35–70 °C. Even the host rock of the caves (Upper Eocene limestone) was hydrothermally altered. $^{13}$C stable isotope data showed two phases of cave formation, the older in the near-surface environment, and the younger in the deeper zones, where the influence of the meteoric waters could not be identified.

References


lytükből felépülő pamacsok, és ezek seprős kioltása keresztezett nikolok alatt valószínűsíti, hogy a mészanyag eredetileg aragonitként vált ki, és csak a későbbiek során kristályosodott át a stabil módosulatot jelentő alacsony Mg-tartalmú kalcittá, amely a kiválások jelenlegi anyagát alkotja.

A borsókövekben és a kalcitlemekben megfigyelt oldással megnagyobbodott kristályközi pórusok arra utalnak, hogy a szpeleotémák képződése nem egy folyamatos kiválási periódus volt, hanem azt olyan rövidebb időszakok tagolták, amikor a víz oldóképessége átmenetileg megnövekedett.

Az erősen negatív $^{18}O$ stabil izotóp értékek a szpeleotémák hidrotermális eredetét igazolják, a becsült keletkezési hőmérséklet 35–70 °C között változott. A barlangi alapközet (felső-eocén Szépvölgyi Mészkő) minták is jelentős hidrotermás átalakulást mutatnak.

A $^{13}C$ izotóp értékek két jól elkülöníthető populációt alkotnak. A Bátori és Rácskai barlangok szpeleotémáinak negatív $^{13}C$ értékei arra utalnak, hogy ezek a kiválások a felszínközeli, meteorikus zónában alakultak ki. A többi rózsadombi nagybarlang pozitív $^{13}C$ értékei ugyanakkor mélyebb zónában való keletkezést jeleznek, ahol a felszíni talaj/atmoszféra eredetű könnyű $^{12}C$ izotóp már nem volt kimutatható. Ez egyben a barlangképződés két fázisát is kijelöli, egy idősebb felszín közelit, és egy fiatalabb, uralkodóan mélyeségi eredetű.
1. Border between the Upper Eocene limestone (host rock of the cave) (R) and the botryoidal speleothem (S). The speleal carbonate contains a micritic layer (M), which is assumed to be the insoluble residue of the limestone, Pálvölgy Cave.

A felső-eocén mészkő (a barlang alapkőzet) (R) és a borsókő (S) érintkezése. A szpeleotémát mikrites sáv (M) tagolja, amelynek anyaga valószínűleg a mészkő oldási maradéka, Pál-völgyi-barlang.

2. Cathodoluminescent photomicrograph of the border layer. The limestone is brightly luminescent (B), the botryoidal speleothem is nonluminescent (N), while the micritic layer has a dull luminescence (D). Pálvölgy Cave.

Az érintkezés katódolumineszcens képe. Az alapkőzet fényesen lumineszcens kép (B), a borsókő nonlumineszcens (N), míg a mikrites zóna átmeneti, tompa lumineszcenciát (D) mutat, Pál-völgyi-barlang.

3. Rhombohedral calcite crystal terminations in the botryoid are shown by fluid inclusion rich zones, Pálvölgy Cave.

A borsókőben a kristálynövekedést a kalcitcsúcsokat kirajzoló folyadékzárzvány dús zónák jelölik, Pál-völgyi-barlang.

4. Nuclei of ooid-like botryoidal growth are composed of zoned, triangular shaped calcite crystals, Bátori Cave.

Az ooid szerkezetű borsókő magját háromszögletű, zónás kalcitkristályok alkotják, Bátori barlang.
1. Boryoid, composed of bunches of crystal needles, possibly after an aragonitic precursor, Ferenc-hegyi-barlang
A kristálypamacsokból felépülő borsókö anyaga eredetileg aragonit lehetett, Ferenc-hegyi-barlang

2. Slightly curved crystal needles (likely, originally aragonite) show sweeping extinction under crossed polars, Szemlő-hegyi-barlang
Az eredetileg valószínűleg aragonit anyagú hajladozó kristálytük csoportja keresztezett nikolok alatt seprős kioptást mutat, Szemlő-hegyi-barlang

3. Nuclei of botryoids are composed of dark micritic clumps surrounded by an isopachous calcite fringe, Erdőhát-úti-barlang
A borsókő magját sötét mikrites folt alkotja, melyet izopach kalcit cement vesz körbe, Erdőhát-úti-barlang

4. Central micritic clumps have a bright-dull blue or lilac luminescence (B-D), while surrounding calcite cement shows a dull blue luminescence (D), Erdőhát-úti-barlang
A borsókő magját alkotó mikrites rész fényes, esetenként tompa kék, lilac lumineszcenciát mutat (B-D), míg az azt körülölelő cementrétegek tompa kéken lumineszkálnak (D), Erdőhát-úti-barlang
1. Nucleus of the botryoid contains small half globules, which are likely to have been bacterially induced precipitation, SEM photomicrograph of an etched thin section, Erdőhát út Cave
   A borsókö központjában kis félgömb alakú kristálycsoportokat tartalmaz, amelyek valószínűleg bakteriális eredetű kiválások, étetett csiszolat elektronmikroszkópos képe, Erdőhát-úti-barlang
2. SEM photomicrograph of saddle shaped calcite crystals, surrounding the central part of the botryoid, Erdőhát út Cave
   A borsókö magját körülölelő cementkéreg nyereg alakú kalcitkristályokból épül fel, elektronmikroszkópos felvétel, Erdőhát-úti-barlang
3. Different cement layers in the botryoid, Erdőhát út Cave
   A borsókövet felépítő változatos összetételű és morfológiájú cementkérek, Erdőhát-úti-barlang
4. Etching emphasises the differences between the layers of the botryoid, SEM photomicrograph, Erdőhát út Cave
   Az eltérő cementkérek etetés során hangsúlyosan váltnak, elektronmikroszkópos felvétel, Erdőhát-úti-barlang
1. Solution enhanced inter-crystalline pore (P) in the botryoid is partly filled with micritic internal sediment (S), scale bar is 1 mm, Pálvölgy Cave

A borsókö oldással megnagyobbodott belső pórusát (P) részben mikrites belső üledék (S) tölti ki, a fehér csík 1 mm-es, Pál-völgyi-barlang

2. Inter-crystalline pore is filled with two generations of late calcite cements, scale bar is 1 mm, Ferenchegy Cave

A borsókö belső pórusát két generációs késői kalcit cement tölti ki (C₁, C₂), a fehér csík 1 mm-es, Ferenc-hegyi-barlang

3. Floating rafts are composed of big calcite blades, where inter-crystalline porosity (P) is also significant, Pálvölgy Cave

A kalcitlemezeket mm-es nagyságú kalcit romboéderek építik fel, itt is gyakoriak a kristálynövekedés által közbezárt belső porusok (P), Pál-völgyi-barlang

4. SEM photomicrograph of the micritic internal sediment in the inter-crystalline pore of the floating raft, Pálvölgy Cave

A kalcitlemez belső pórusát részlegesen kitöltő mikrites üledék elektronmikroszkópos képe, Pál-völgyi-barlang