Environ Earth Sci (2010) 61:1561–1571
DOI 10.1007/s12665-010-0470-1

ORIGINAL ARTICLE

Speleogenesis and deposition of sediments in Cioclovina Uscată Cave, Sureanu Mountains, Romania

Anamaria Diana Häuselmann · Philipp Häuselmann · Bogdan Petroniu Onac

Received: 6 October 2009 / Accepted: 8 January 2010 / Published online: 5 February 2010

Abstract The sedimentary deposits from Cioclovina Uscată Cave yielded numerous paleontological, anthropological and mineralogical findings. However, until now, a study of the sediments and their depositional features and environment had not been conducted. Here, we present a complete study of the sediments within the *Main Gallery* with the purpose of documenting their origin, depositional mode and processes, and direction of the paleodrainages. Seventeen sedimentary profiles were mapped and analyzed. A complete map was drawn, based on the lithological description, laboratory analyses, and the exact position of the profiles in the sedimentary deposit and their location along the gallery. Although the deposition mode of the sediments is very complex, the distribution of three main complexes (silt, sand and pebbles) can be clearly distinguished, indicating a typical cave channel lithofacies. We recognize seven stages in the evolution of the cave; the third one indicates a sudden change in the climatic conditions at the surface.

Keywords Cave sediments · Speleogenesis · Cioclovina Cave · Romania

A. D. Häuselmann · B. P. Onac
Department of Geology, Babes-Bolyai University,
Kogalniceanu 1, 400084 Cluj, Romania

A. D. Häuselmann
Institute for Geology, Bern University,
Baltzerstrasse 1-3, Bern, Switzerland

Ph. Häuselmann
Swiss Institute for Speleology and Karst Studies,
c.p. 818, 2301 La Chaux-de-Fonds, Switzerland

B. P. Onac (✉)
Department of Geology, University of South Florida,
4202 E. Fowler Ave., SCA 528, Tampa, FL 33620, USA
e-mail: bonac@cas.usf.edu

B. P. Onac
"Emil Racovita" Institute of Speleology, Cluj, Romania

Introduction

Stream-transported sediments (surface equivalent of alluvium) make up the greatest part of cave sediment sequences (White, 2007). Water flowing underground is confined to a certain conduit size. Fluctuations in the water level and passage morphology will result in significant changes in depositional energy along the conduit (White and White 1968; Gillieson 1996; Knapp et al. 2004). By correctly interpreting the resulting depositional sequences, one can reconstruct the flow conditions (velocity, discharge and type of motion) and the entire cave evolution (Springer et al. 1997; Dogwiler and Wicks 2004; Sasowsky and Mylroie 2004; Springer 2005).

From a scientific point of view, Cioclovina Uscată Cave (i.e., Dry Cioclovina) is one of the most important caves in Eastern Europe. The cave is known to host the world's second largest phosphate deposit, mined at the beginning of the last century (Breban et al. 2003). Earlier as well as currently, the sediments of the cave were/are the source of numerous mineralogical, anthropological, archeological and paleontological findings (Roska 1912; Schadler 1932; Constantinescu et al. 1999; Marincea et al. 2002; Onac et al. 2002, 2007; Breban et al. 2003; Harvati et al. 2007; Soficaru et al. 2007). Despite their importance, only one preliminary and incomplete sedimentological profile was published by Murariu (1983). That study, however, does not consider the real thickness of sediment complexes observed in the gallery.

The objectives of this study were to establish the depositional environment, direction of paleoflow, and source area of the sediments by evaluating prior and recent sedimentological work (including mapping and description of sedimentary profiles), in an attempt to address the speleogenetic history of Cioclovina Cave.

Location and geologic settings

Cioclovina Uscată Cave is situated in the NW part of the Şureanu Mountains, on the territory of Boşorod village, Hunedoara County, Romania (Fig. 1). The cave lies in the Gradistea Muncelului-Cioclovina Natural Park (GMC) and was declared a scientific reservation in 1979. To enter the cave, permission from the Natural Monuments Commission of the Romanian Academy and the GMC Natural Park Administration is required.

From a geological point of view, the area is located in the NW part of the Sanpetru-Pui sedimentary basin. Crystalline schists of Precambrian age and Permian sedimentary deposits of hercynic molasse (conglomerates and sandstones) form the basement. Above, Mesozoic sedimentary deposits grouped into a lower terrigenous deposit (Liassic–Lower Dogger, with mica-rich sandstones, conglomerates, and sandstones with ferruginous levels), a middle carbonate deposit (Upper Dogger–Lower Cretaceous), and an upper terrigenous deposit (Upper Cretaceous, with conglomerates, micaceous sandstones with small coal intercalations, and clays) can be found. A small system of faults was active in the region, but only the Cioclovina Fault is important for the cave's formation (Stilla 1985). The cave is developed in Barremian–Aptian massive reef limestone and Oxfordian–Tithonian stratified limestone with chert nodules (Fig. 1).

Cave description and history

The entrance of the cave is located at 770 m above sea level. The cave length is 1,406 m, with 122 m in vertical development (Tomuş et al. 1999). The cave has a single

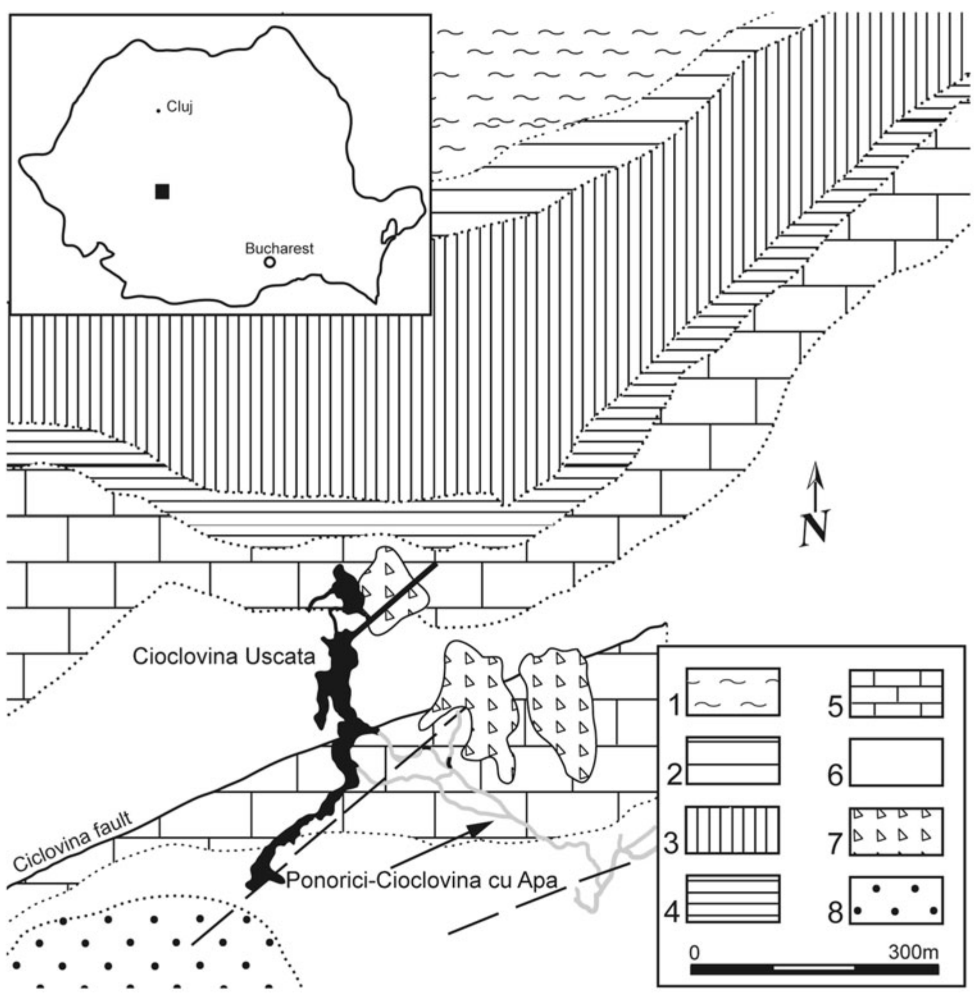


Fig. 1 The location of the cave in Romania (*inset*) and the surrounding geological formations (after Stilla 1985): *1* micaschists and gneiss (Precambrian), *2* conglomerates and red sandstones (Permian), *3* conglomerates and sandstones with schistose intercalations (Lias), *4* calcitic sandstones (Dogger), *5* limestone with chert intercalations (Oxfordian–Tithonian), *6* recifal limestones (Barremian–Aptian), *7* limestone breccia, *8* sandstones and clays (Cenomanian). Cioclovina Uscata is in *black* and the underlying Ponorici-Cioclovina cu Apa cave system is in *gray*

phreatic fossil level, oriented NE–SW, with short side passages. The passage height varies between 8 and 15 m, while the rooms may reach 27 m in height. In the *Bivouac Room* the fossil passage ends in sediment fill. On the floor of the *Bivouac Room*, a small hole leads to a series of downward climbs into the lower level. This lower level contains a 60 m long stream passage (running NE–SW) that is terminated at both ends in sumps. A 30 m high chimney out of the lower level connects with the continuation of the upper fossil level. These connecting passages represent an intermediate stage in the cave's evolution. As a consequence, the fossil passage is arbitrarily divided into the *Main Gallery* and the *Gallery after the Chimney* (Fig. 2). Today, the former link between these two fossil sections is filled with sediment.

Between 1912 and 1940, phosphate mining strongly affected all the sediments along the *Main Gallery*. Its sandy–silty sediments were mined due to their high phosphate content (up to 30% P_2O_5). More than 30,000 m^3 of sediments of the *Main Gallery* were removed (Gotzinger 1919). The level of the sediment prior to the mining operations can be observed in Fig. 3 (dotted line on the cave profile). The chimney was limiting the access into the *Gallery after the Chimney*; therefore, the rich siliciclastic (without phosphates) and chemical deposits remained intact.

Description of the studied area and methods

Our sedimentological study focused on the *Main Gallery* (587 m in length), which was remapped to generate a more accurate survey. All the investigated sedimentary profiles were precisely located on this new map, and the initial thickness of the sediment fill was measured on the walls. The height of the passages varies between 8 and 15 m with one exception, where a large section of the passage is filled by an old carbonate formation corroded at its lower part. At this site, the passage height is only 2.5–3 m. The passage morphology is typical phreatic with wall and ceiling cupolas, corrosion notches and ceiling pendants. In the *Entrance Room*, well-developed wall karrens are visible where the sediments were removed, suggesting a possible epiphreatic genesis of the passage.

In some sections of the *Main Gallery*, thick flowstone is precipitated on top of the sediment. Other speleothems (stalactites, stalagmites and rimstone gours) are preserved near the entrance and after the rimstone gours area. These speleothems are not corroded, but most of them show the effects of the mining activities (gray color, displaced or even broken). New calcite crusts are forming where active percolation is present. Murariu (1983) calculated a growth rate of 0.1 mm/year for such deposits. In the area of the paleoflowstone, an old deposit of calcite rafts was noticed.

The sediment in Cioclovina Cave is mostly sandy–silty in texture and attracted attention because of its richness in vertebrate bones and phosphates nodules/impregnations. Gotzinger (1919) estimated a P_2O_5 concentration of 1.32–29.74% depending on depth and location of the sediment. The geochemical environment under which the phosphate-rich deposit accumulated is not yet fully understood. The minerals identified throughout time (Onac 2003; Onac et al. 2007) point towards distinct stages of limestone and siliciclastic phosphatization processes that are visible throughout the cave (see Fig. 4).

There is a major difference between the sediments deposited in the *Main Gallery* and those accumulated in the *Gallery after the Chimney*. In the last one, the predominant sediment is composed of pebbles, with sandy intercalations, but without bones, phosphate impregnations or weathered limestone blocks. Imbrications and dissolution holes can be observed here. The gallery is very rich in speleothems, including a 113 cm high triangular monocrystalline stalagmite.

Although much of the sediment was removed from the *Main Gallery*, additional profiles and prospecting pits allowed us to follow systematically the lithology and deposition mode for the remaining body of sediments. By deepening some of the prospecting pits, the bedrock was exposed. Seventeen profiles were documented (drawn and

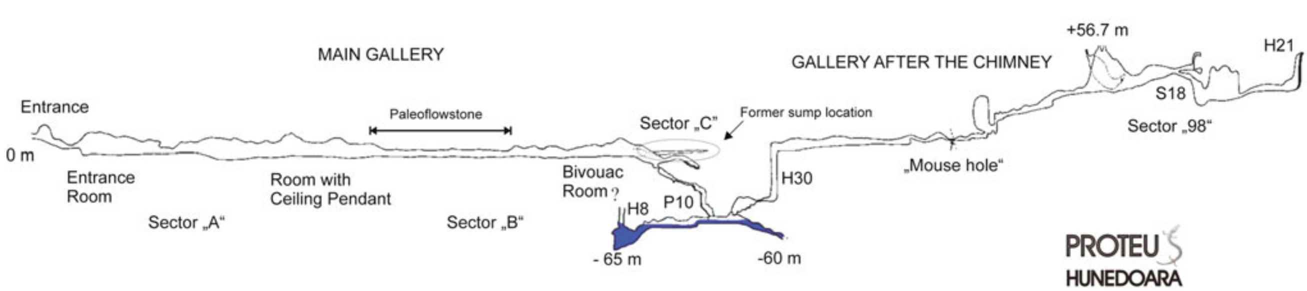


Fig. 2 Longitudinal cross-section through Cioclovina Uscată Cave (from Tomuş et al. 1999, modified). Sectors A and B represent side passages not shown on this profile

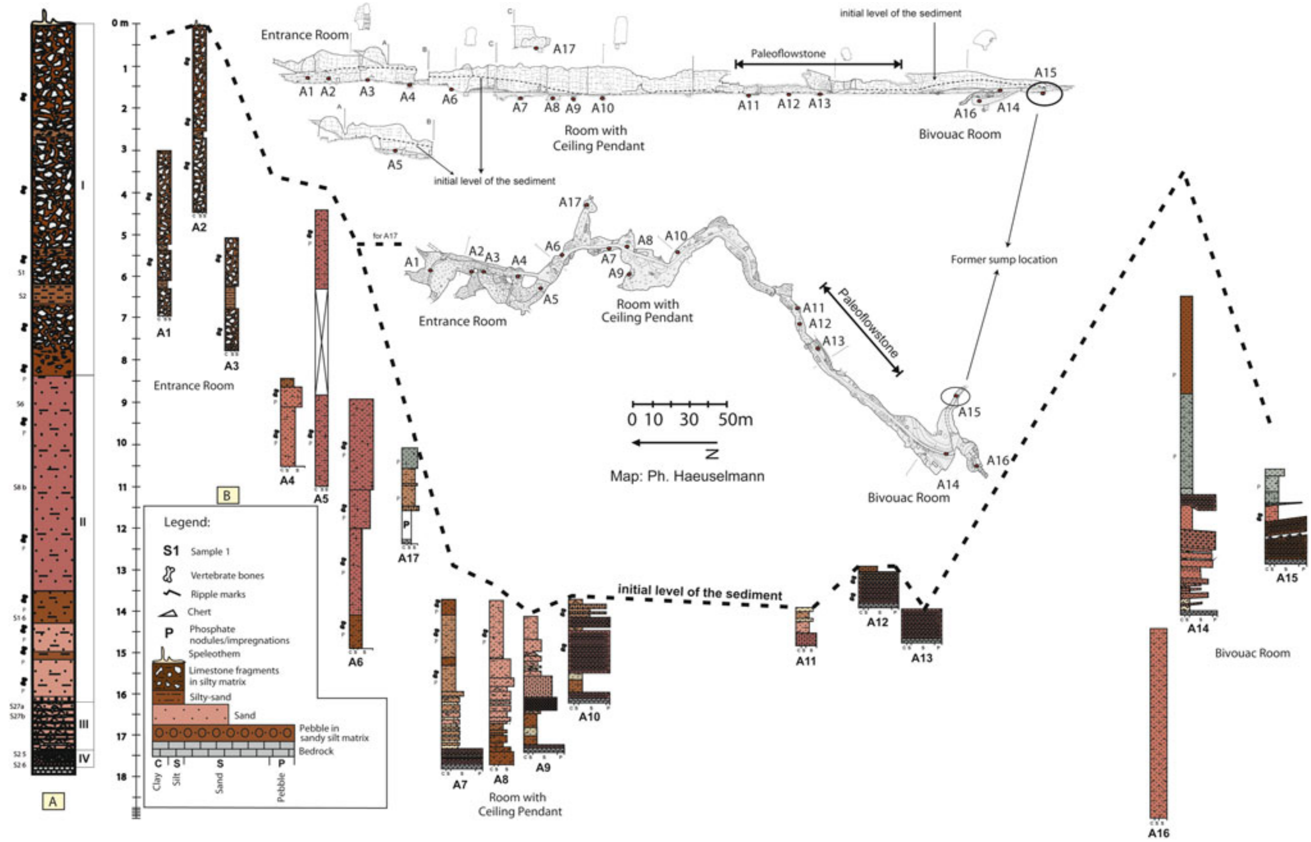


Fig. 3 **a** Synthetic profile based on the sedimentary complexes within the *Main Gallery*. The location of samples shown in Fig. 5 is indicated here. **b** Detailed map of the *Main Gallery* showing the lithology of all profiles and their location. The *dashed line* represents the upper sedimentary fill prior to phosphate extraction

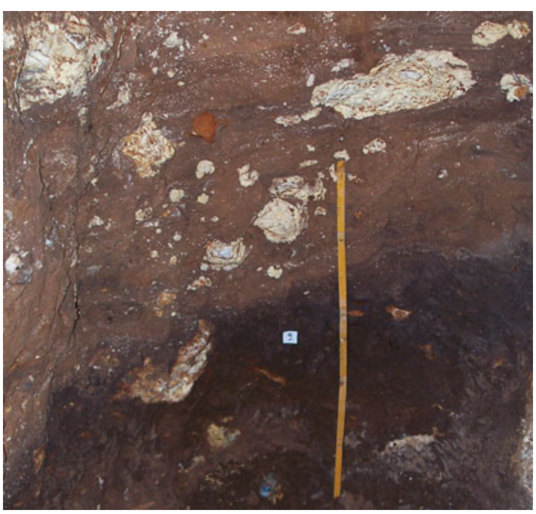


Fig. 4 Phosphate nodules and weathered blocks in the Upper Sandy Complex

described) and their exact position within the deposit was mapped. From each layer, a sediment sample was collected. A total of 93 samples were analyzed by sieving (fraction > 0.063 mm) and their grain size parameters plotted (Boian 2007). The results of the grain-size analyses will only be summarized here, as they are not the topic of this paper. To precisely determine the pebbles' petrology, thin sections were made.

Results

Traces of sediment preserved in small wall fissures and notches allowed us to reconstruct the highest level of the sediment throughout the *Main Gallery* (Fig. 3b). Unfortunately, in other sections of the cave, such indicators are missing due to the mining activities; hence the original height of the deposit remains uncertain. The initial level is dropping rather abruptly (~14 m) between the *Entrance Room* and the *Room with Ceiling Pendant*. The uppermost limit of the sediment deposit in this part of the cave is indicated by a calcite flowstone, still visible near the entrance zone.

Field and laboratory analyses enabled us to differentiate four main lithological complexes (from top to bottom; Fig. 3a):

I. The Sandy–Silty Complex, at the top of the sedimentary sequence, hosting large amounts of limestone breakdown fragments and vertebrate bones;
II. The Upper Sandy Complex, hosting the phosphate-rich sediments (nodules, impregnations and phosphatized material);
III. The Lower Sandy Complex, showing sedimentary structures and intercalations of finer sediment layers;
IV. The Pebbly Complex, directly overlying the bedrock.

There is no clear stratigraphic relationship between the first two complexes. However, between the *Entrance Room* and the *Room with Ceiling Pendant* we were able to correlate complexes II, III and IV, especially because in profiles A7 and A9 there is a complete succession of the lower three complexes (II, III and IV). The depth to the bedrock and the sediment thickness increases from the *Bivouac Room* towards the *Room with Ceiling Pendant*.

Given the complicated lithology and stratigraphy of all sedimentary profiles, the most important characteristics of each of the four complexes are summarized next. To support our observations and conclusions, selected grain size curves are shown in Fig. 5. For a complete description of all profiles and the detailed grain size analyses, one should consult the work of Boian (2007).

The Pebbly Complex

Directly overlying the bedrock, medium-size pebbles in a sandy matrix were deposited. The thickness of the complex is 0.5–2 m. In addition to the allochthonous pebbles, fragments of autochthonous limestone and chert, and, rarely, centimeter-size pieces of speleothems and vertebrate bones were found. The petrology of the pebbles consists of (from very common to less frequent): quartz varieties (translucid, bluish, and milk-like), mica-rich ferrilite, microlithic sandstone with charcoal impregnations, greywacke, quartzite, and quartzitic breccia with iron cement. Only one metamorphic pebble (gneiss) was found in all investigated samples. The maximum length of the pebbles are 7 cm and they are commonly well-rounded and well-polished. The only exception is a variety of ferrilite, which shows a plate-like morphology.

The sandy matrix is brownish-reddish in color, with some parts more grayish white (Fig. 6a). Locally, a yellowish sandy layer is intercalated. In the *Main Gallery*, no sedimentary structures are present. However, imbrications indicating a flow towards the *Entrance Room* were observed in the *Gallery after the Chimney*.

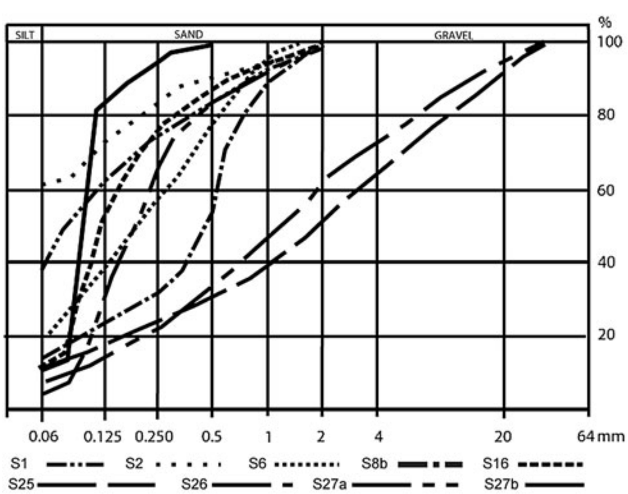


Fig. 5 Representative cumulative frequency distribution curves from the main sedimentary complexes (see Fig. 3a for their location)

The Lower Sandy Complex

This one is the most complicated sedimentary complex of all in the cave. Since it was equally deposited and eroded by a meandering stream almost all profiles exhibit variation in the sediment sequence or sedimentary structure. The complex consists of alternations of medium-size sand and silty–sand particles (Fig. 6b), with infrequent pebble layers. The color of this mica-rich sand is mostly brownish, but gray or uniform yellow layers are also observed (Fig. 6c). Between some layers, thin charcoal laminae are present. In the brownish sandy layers of A7 through A11, ripple marks, some with 1 m extension, are visible (Fig. 6d). The flow direction points towards the cave entrance. Along with ripple marks, other deformational structures are present: a 2 m track left by a plunged boulder in the sediment (in A7), and a dyke-like "intrusion" of the lower sandy layer into an upper pebble layer (visible in A10). The sandy particles have the same petrographic origin as the pebbles. A small difference is observed in the gray and yellowish colored sands, which are enriched in quartz and mica.

The Upper Sandy Complex

Due to its phosphate content and silty–sandy grain size of the material, this complex was the most important for economic purposes. Unlike the Lower Sandy Complex, this complex displays a monotonous (unvaried) succession. The only way to differentiate its horizons was their change in color (Fig. 4). The lower part of the complex is very compact; whereas in those sectors with breakdown, the sediment contains more sand and hence is less consolidated. The only sedimentary structure within this complex is represented by a variety of channel shapes (White 2007) (Fig. 6e). Small rounded quartz pebbles can be found in this complex, along with vertebrate bones in different stages of weathering.

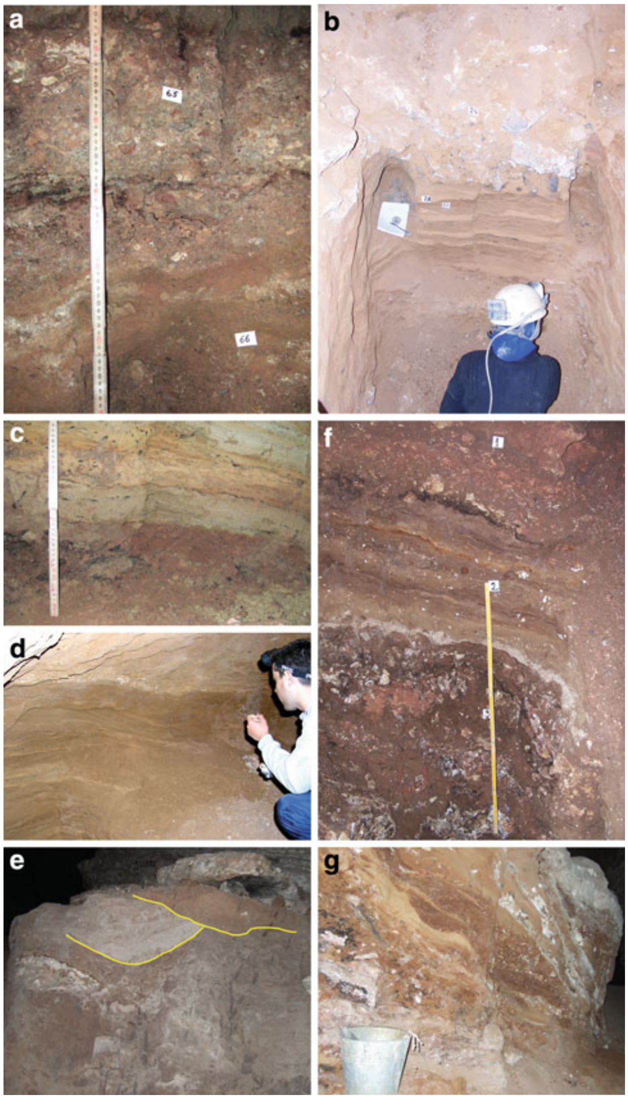


Fig. 6 **a** Pebbly complex in A12, **b** Alternation of ripple marks and fine sands at the base of A7. The *rectangular blocks* on *top* of the *profile* were deposited during phosphate extraction, **c** Gray and yellowish sand with charcoal intercalation at the base of A10, **d** Ripple marks in A8, indicating a flow direction towards the present-day entrance, **e** Channel shapes on top of the A15 profile, documenting an ancient powerful discharge, capable of remobilizing older sediments, **f** Homogeneous levels (label 2) of silt in the Silty–Sandy Complex, *Entrance Room*, between layers with angular limestone fragments (labeled 1 and 3). The *yellow ruler* is 1 m in length; **g** Sedimentary sequence in the *Bivouac Room*. The sediment was pushed from behind (upstream) towards the front

The Silty–Sandy Complex

This 8 m thick complex is only visible in the *Entrance Room*. Due to abundant dripping points and a higher relative humidity (>95%) as compared to the rest of the cave (70–95%), the sediments are damper and therefore tend to slide down the slopes. The sediments within the complex contain a large amount of limestone fragments and well-preserved vertebrate bones. The limestone fragments are 5–30 cm in diameter. They are angular or slightly rounded at the edges due to corrosion and represent a typical weathered surface. The only exceptions to this observation are 3-cm-size layers in which both the limestone fragments and bones are missing (Fig. 6f). Charcoal-enriched sediment occurs at several levels within the complex, but no traces of fire that would hint towards human activity were documented. Where the upper part of this complex is preserved, subhorizontal flowstones cover it. In the active percolation zones, such flowstones are still actively forming.

Between the *Entrance Room* and the *Bivouac Room*, the sediment strata are horizontal or slightly inclined (Fig. 6g). In the *Bivouac Room*, the sediment complex is more complicated, sometimes showing two directions of dip within the same profile. With one exception (A15), the strata dip towards the *Gallery after the Chimney* (south). Considering the lithologic sequence, one can assume a "pushing" effect of sediments from the *Gallery after the Chimney* towards the *Bivouac Room*. This process occurred during powerful flood events, when the water removed the sediments that were deposited upstream in a sump. This resulted in a complex stratigraphy, in which the order of the four sediment complexes is not always identical.

Particle-size distribution and interpretation

The grain size indicates a turbulent flow at the base of the succession, with the silty particles remaining in suspension, followed by a more laminar flow and finally stagnant water that allowed deposition of the finest-sized particles (more or less sorted). The transport of particles was mostly by saltation. The majority of the samples show a bimodal character, but normally, one grain-size class dominates. This potentially indicates several sources of sediment, e.g., contamination of the river load with sediment transported by percolating waters, post-depositional transformations of the sedimentary deposit, or the existence of a paleo-tributary. Probably the last one is more realistic.

Using the Hjulstrom diagram, we estimated a velocity of ~110 cm/s was needed for transporting/depositing the pebbles. Velocities of 40–50 cm/s, and 3–10 cm/s were estimated for the transport/deposition of sands (with ripple marks) and silty material, respectively. These values are only estimative and certainly varied during the transport and deposition of the sediments.

Speleogenesis

Although we have a complete sedimentary column described from the *Main Gallery*, it is not representative of the entire depositional history of the cave, because older sediments have been eroded before the present succession was deposited. A combination of sediment analysis, observation on cave morphology and speleothems, allowed us to propose a model of the Cioclovina Cave evolution. This is shown in Fig. 7 as three distinct stages labeled A, B and C.

The *Main Gallery*, the *Gallery after the Chimney*, and their side passages show rounded morphologies and some small-scale solution forms (scallops, pendants, and notches). These are diagnostic features for passages originating under continuous or periodic flooding events during phreatic and vadose conditions (Palmer 2007). Neither canyon passages (open or filled with sediments) nor meanders that would normally indicate a vadose phase within this period were found. The passage morphology shows that during this time the underground stream emerged to the surface somewhere at the right side of the *Entrance Room*, a passage that is now filled with sediments. Enlarging the initial karst conduit to its present-day size would have required a large amount of water, well in excess compared to the one drained presently by the valleys of the region.

Alternatively, floodwater paragenesis (i.e., the combined effect of upward corrosion and erosion above a sediment fill; Palmer 2007) could partially account for local passage enlargements. However, from the analysis of the cave morphology and the present sediment succession, one cannot examine the possibility of older stages of cave evolution. Traces of sediments found in the *Room with Ceiling Pendant* hint towards older fills within the cave. Due to the small amount of sediment present, a detailed reconstruction of the sequence cannot be made. We may assume that there was an older paragenetic phase (antigravitative erosion, see Pasini 2009) that caused the enlargement of the room. The roof pendant could hint to a paragenetic process, but the absence of more rock pendants or other paragenetic-related features (ceiling half-tubes, anastomosis, inverted canyons, etc.; Lauritzen and Lauritsen 1995) convinced us that this is not the case.

A lowering of the water table along with decreasing discharge created optimal conditions for vadose evolution (gravitational water flow). Under this new hydrological setting, the first siliciclastic sediments were deposited, and precipitation of calcite speleothems began. We assume that the so-called paleoflowstone (located between the *Room with Ceiling Pendant* and the *Bivouac Room*), formed about this time (Fig. 8a, b). We have no relevant

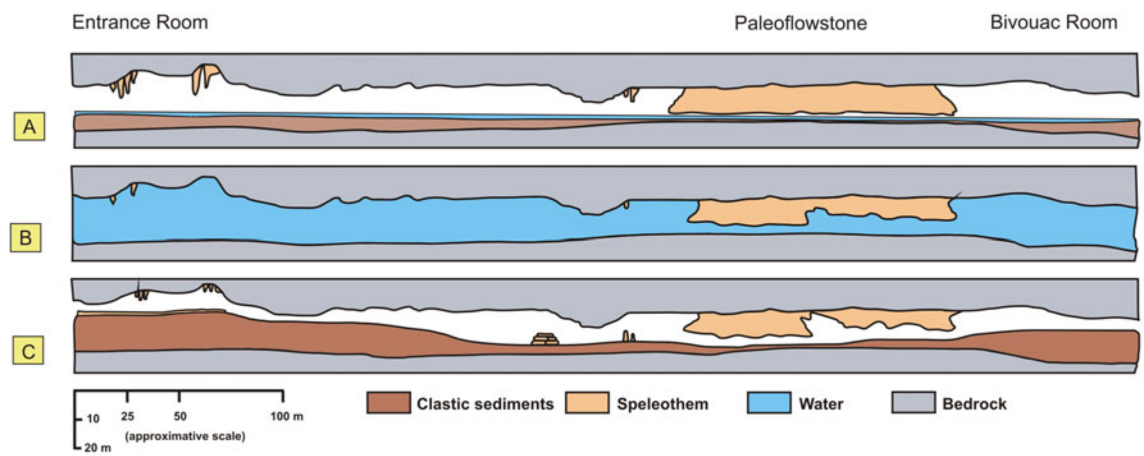
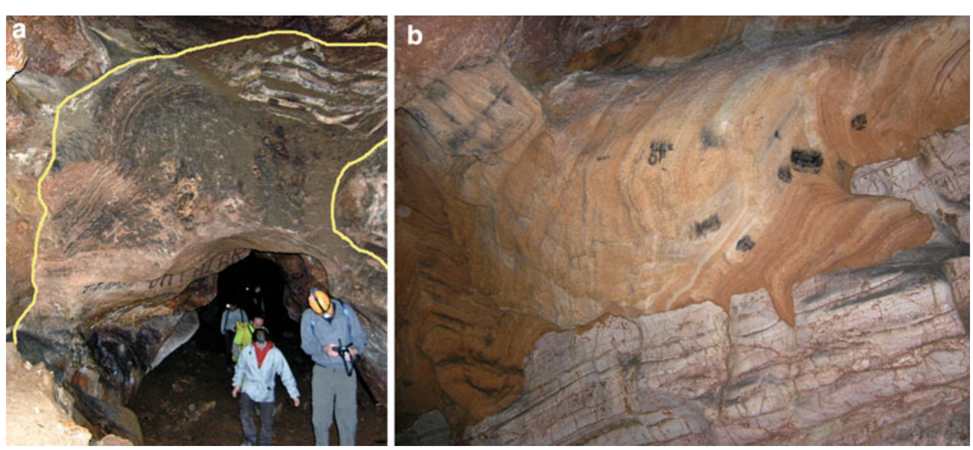


Fig. 7 Evolutionary stages in Cioclovina Uscată Cave history. For details see discussions in text

Fig. 8 **a** Paleoflowstone in the *Main Gallery*. The *yellow line* marks the approximate void size of the passage prior to flowstone deposition, **b** Corrosion forms in the paleoflowstone. It can be seen that the flowstone fills irregular wall structures of the original passage



information on the nature of these first siliciclastic sediments that were deposited, since only some clayey materials are still visible on the walls of the cave. This situation is shown on Fig. 7a.

Climatic changes at the surface (i.e., prolonged wet periods) may have periodically injected allogenic, aggressive floodwaters into Cioclovina Cave, causing water-level rise, and hence the return to (epi)phreatic conditions. During such events, most, if not all of the siliciclastic sediments were evacuated and the aggressive waters enlarged the cave passages and corroded the paleoflowstone. The water level above the streambed must have reached at least 6 m (cupolas within the corroded paleoflowstone) and possible phreatic conditions prevailed (Fig. 7b).

Following this stage, a second vadose period occurred. The sedimentary succession now present in the cave was deposited during this phase. Initially, directly overlying the limestone bedrock, the Pebbly Complex accumulated. The occurrence of fragments of broken speleothems within this complex indicates a previous vadose phase during which speleothems were actively growing. Scattered vertebrate bone fragments indicate that the cave was already inhabited or visited by animals.

Later during this phase, at least two areas accumulated water acting as sumps and/or lakes: the area between the *Main Gallery* and the *Gallery after the Chimney* (now filled with sediments, Sector C; profile A15) and the small area in the right side of the *Bivouac Room* (profile A16). The sedimentation in these two areas differs from the one along the main drainage axis of the underground river. Careful observations at site A15 may explain the grain-size differences between the sediments of the *Main Gallery* and those of the *Gallery after the Chimney* as follows: the water energy dropped and forced the underground stream to dump its main sediment load in the *Gallery after the Chimney*. Sands and small pebbles, however, were transported further away towards the *Main Gallery*. On the other hand, this may also explain the complex sequence of the sediments in the *Bivouac Room*, where powerful high-level floodwaters "pushed" the sediment already accumulated at the base of the sump. The second area (A16) was probably active only after high floods, when a small side lake developed near the main water flowing channel. This explains why only low energy silty sands were accumulated around site A16. All these sediments belong to the Lower Sandy Complex.

Later, small-scale fluctuations of flow velocity caused the deposition of alternating sand and silty–sand layers. First the yellowish mica-rich sand with coal impregnations was deposited. The presence of interbedded pebbly layers witnessed other major flood events. On top of this profile, ordinary flooding events deposited the layers of the Upper Sandy Complex. The lithostratigraphical differences observed in most profiles document variations of the cave stream that was meandering and often changed its energy. The only area where both Lower and Upper Sandy complexes are missing is under the paleoflowstone. Here, the small size (both width and height) of the gallery induced high water energy, causing the fine particles to be transported further away.

When the water energy dropped, the sediments of the Silty–Sandy Complex were deposited. The area under the paleoflowstone probably acted as a semi-sump, restricting the access of vertebrates further into the cave. Sorting occurred at the base of sediment columns in Sector A, an area with fallen blocks where medium-coarse sandy particles were deposited in front of obstacles. Towards the entrance, the sediments become finer.

Gradual filling of the entrance triggered the level of water to rise backward. The *Main Gallery* was first transformed into a long lake before it became completely flooded. A very low energy current transited the flooded passages (now inaccessible) above the *Main Gallery*, in Sector B. Under these conditions and along with lowering of the base level, a 30-m shaft and an associated meander that now connects the upper level of the cave to the lower level were formed. The *Main Gallery* became completely fossil (Fig. 7c).

The only evidence that would help in estimating the age of the present sediment is given by the vertebrate bones. The skull of *Homo sapiens fossilis* found (probably) at the base of the Silty–Sand Complex (Harvati et al. 2007) was radiocarbon dated to 29,000 calibrated years BP by Olariu et al. (2002). Remobilized bear bones collected within profiles near the cave entrance (from a depth of 60 and 80 cm below present day sediment surface) were also dated by means of ^{14}C to about 32,000 and 40,000–50,000 cal. BP, respectively (Soficaru et al. 2007; Pacher pers. comm.).

Conclusions

Despite the fact that a substantial volume of work has been carried out in Cioclovina Cave, it is difficult to conclude on its speleogenesis, because determination of the timing of each cave evolution phases is not yet available. The age of cave sediments could be precisely obtained by means of cosmogenic dating (Granger and Muzikar 2001). Such an approach would then allow for correlations between various sedimentation events and records of Pleistocene climate changes. Despite the absence of such information, however, the present work is the first of this kind aiming to present a tentative speleogenetic history of Cioclovina Cave.

A complete sedimentary profile was drawn based on the lithological description, laboratory analyses, the exact position of profiles in the sedimentary deposit, and their location in the gallery (see Fig. 3b).

The presence of four major lithologic complexes was documented as follows (from top to bottom):

I. A Silty–Sandy Complex, containing large amounts of limestone fragments and the vast majority of vertebrate bones;
II. An Upper Sandy Complex, with phosphate impregnations and nodules;
III. A Lower Sandy Complex, with a complicated architecture and intercalations of finer sediments;
IV. A Pebbly Complex above the cave bedrock.

The reconstruction of the sedimentation history along the cave passages is based on changes in sediment grain size, sorting, and differences between each sedimentary sequence in the investigated profiles (Shackley 1972; Gillieson 1996; Springer 2005). All these are typical indicators for a cave channel flow-type lithofacies (Springer et al. 1997; Bosch and White 2004).

Combining data gathered from elaborated sedimentary sequence analysis and morphological observations, the following stages in the evolution of Cioclovina Cave are hypothesized below:

1. Formation of the cave under phreatic conditions;
2. A vadose phase during which the first sediments and the large flowstone before the *Bivouac Room* were deposited (Fig. 7a);
3. A return to phreatic conditions when sediments were washed out of the cave and corrosion affected the flowstones (Fig. 7b);
4. New vadose flow regime; this has initiated a new cycle of sediment deposition (presently seen in the cave; Fig. 7c);
5. Progressive backward rise of the water level along the cave passages as a result of sediment obstructing the cave entrance;
6. Closing the link between the *Main Gallery* and the *Gallery after the Chimney*.
7. Genesis of other passages (including meanders and shafts) at or below the level of the *Main Gallery* (now filled with sediment), and subsequent transport of previously deposited sediments along the main gallery;
8. Formation of the 30 m shaft (near the *Bivouac Room*), and complete fossilization of the main passage.

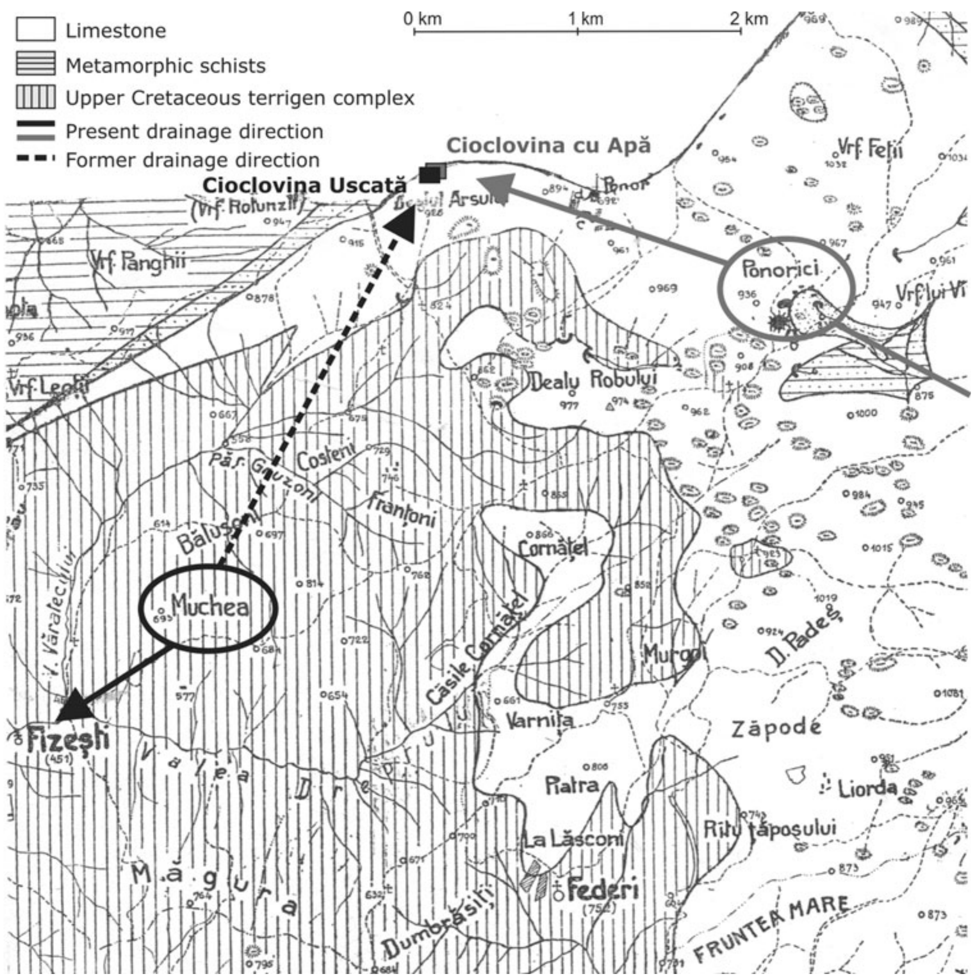


Fig. 9 Map showing the location of the Cioclovina Cave and Muchea Hill, from where pebbles were transported into the cave. *Arrows* indicate past and present drainage directions. The flow direction of the underlying (younger) Cioclovina cu Apa Cave is marked in *gray*, the one corresponding to Cioclovina Uscata Cave is in *black*

The change from vadose to (epi)phreatic conditions in stage 3 was probably induced by catastrophic surface river floods. During such events, triggered by local or regional extreme climatic conditions, caves receive large amounts of water and sediments that promote both solution and mechanical erosion (Doehring and Vierbuchen 1971; Palmer 2001; Van Gundy and White 2009).

The depositional setting, mineralogy, and grain size of the sediments at the bottom, indicate a warm and humid climate. In contrast, based on the granulometry of the sediments within the Silty–Sandy Complex and the abundance of vertebrate bones and limestone fragments (frost shattering), we speculate a colder climate during which the cave was often used as shelter by animals.

The water flow direction, revealed by imbrications and ripple marks, was from the *Gallery after the Chimney* towards the cave entrance. The lithology of the sedimentary deposit and the petrography of the pebbles indicate a source area in the region of Dealul Muchea. Presently, the surface waters of this region are drained in a direction opposite to Cioclovina Cave (Fig. 9). The lack of pebbles of metamorphic origin emphasizes a paleosource area outside the metamorphic zone.

This study provides the first documented step in understanding the cave speleogenesis and the paleogeographic evolution of the Cioclovina region. To advance understanding on these problems one has to examine closer the sediments and the morphology of other galleries within the Cioclovina cave system and neighboring caves. The description and drawings of all profiles along the main cave passage will help the present or future scientific studies conducted in Cioclovina Cave. Henceforth, the investigated levels or strata from which samples are collected can be precisely located and used for comparative purposes when studying sediments of other caves in the same area. A number of unanswered questions, mainly related to the exact time of the cave origin, can be addressed in the future through a variety of paleomagnetic, cosmogenic, paleontologic, and paleoclimatic interdisciplinary studies.

Acknowledgments The authors would especially like to thank the Administration of the Gradistea Muncelului-Cioclovina Natural Park for granting permission to collect samples for the present study. Special thanks are extended to Georgiana Soit, Corina Fuer, Mihai Iliescu, Cristina Cizmas, Gheorghe Boian, and Speleo Club Proteus Hunedoara for support during the fieldwork and to Dr. M. Pacher for sharing with us unpublished ^{14}C dates from Cioclovina Cave. Editor G. Doerhoefer and two anonymous reviewers are acknowledged for their comments that helped improve the manuscript. Partial funding for this research was provided by the Romanian CNCSIS grant #1696 to BPO.

References

Boian AD (2007) Speleogenesis and sediment accumulation in Cioclovina Uscată Cave (Munţii Şureanu). Unpubl. BSc thesis, Babeş-Bolyai University, Cluj-Napoca (in Romanian)

Bosch R, White WB (2004) Lithofacies and transport of clastic sediments in karstic aquifers. In: Sasowsky ID, Mylroie J (eds) Studies of cave sediments—physical and chemical records of paleoclimate. Kluwer Academic/Plenum Publishers, Dordrecht/New York, pp 1–21

Breban R, Şerban M, Viehmann I, Băicoană M (2003) The history of guano-phosphate exploration and discovery of human fossils in Ciclovina Uscată Cave. Clubul de Speologie "Proteus" Hunedoara 8, 151 p (in Romanian)

Constantinescu E, Marincea S, Craciun C (1999) Crandallite in the phosphate association from Cioclovina cave (Sureanu Mts., Romania). In: Anastasiu N, Ilinca G (eds) Mineralogy in the system of earth sciences. Imperial College Press, London, pp 1–5

Doehring DO, Vierbuchen RC (1971) Cave development during a catastrophic storm in the Great Valley of Virginia. Science 174:1327–1329

Dogwiler T, Wicks CM (2004) Sediment entrainment and transport in fluviokarst systems. J Hydrol 295:163–172

Gillieson D (1996) Caves. Processes, development, management. Blackwell, Oxford, pp 143–166

Gotzinger G (1919) Die Phosphathöhle von Csoklovina, Siebenbürgen. Mitteilungen der Geographischen Gesellschaft, Wien LXII(7):303–333

Granger DE, Muzikar PF (2001) Dating sediment burial with in situ-produced cosmogenic nuclides: theory, techniques and limitations. Earth Planet Sci Lett 188:269–281

Harvati K, Gunz P, Grigorescu D (2007) Cioclovina (Romania): affinities of an early modern European. J Hum Evol 53(6): 732–746

Knapp EP, Tery DO, Harbor DJ, Thren RC (2004) Reading Virginia's paleoclimate from the geochemistry and sedimentology of clastic cave sediments. In: Sasowsky ID, Mylroie J (eds) Studies of cave sediments—physical and chemical records of paleoclimate. Kluwer Academic/Plenum Publishers, Dordrecht/New York, pp 95–106

Lauritzen SE, Lauritsen Å (1995) Differential diagnosis of paragenetic and vadose canyons. Cave Karst Sci 21(2):55–59

Marincea S, Dumitraş D, Gibert R (2002) Tinsleyite in the "dry" Cioclovina Cave (Sureanu Mountains, Romania): the second occurrence. Eur J Mineral 14:157–164

Murariu A (1983) Considerations on the sedimentary deposit from Ciclovina Uscată Cave. Bul Speol FRTA-CCSS 7:55–68 (in Romanian)

Olariu A, Skog G, Hellborg R, Stenström K, Faarinen M, Persson P, Erlandsson R, Alexandrescu E (2002) Dating of some Romania fossil bones by combined nuclear methods. J Radioanal Nucl Chem 253(2):307–311

Onac BP (2003) Checklist of the Romanian cave minerals. Theor Appl Karstol 16:83–89

Onac BP, Breban R, Kearns J, Tămaş T (2002) Unusual minerals related to phosphate deposits of Cioclovina Cave, Sureanu Mts (Romania). Theor Appl Karstol 15:27–34

Onac BP, Effenberger H, Breban R (2007) High-temperature and „exotic" minerals from the Cioclovina Cave, Romania: a review. Studia Univ Babeş-Bolyai, Geologia 52:3–10

Palmer AN (2001) Dynamics of cave development by allogenic waters. Acta Carsologica 30(2):13–32

Palmer AN (2007) Cave geology. Cave Books, Dayton, 454 p

Pasini C (2009) A terminological matter: paragenesis, antigravitative erosion or antigravitational erosion? Int J Speleol 38(2):129–138

Roska M (1912) Traces de l'hommc diluvien dans la caverne Cholnoky à Cioclovina. Trav sect numismat et archéol du Mus Nat de Transylvania à Koloszwar

Sasowsky ID, Mylroie J (eds) (2004) Studies of cave sediments-physical and chemical records of paleoclimate. Kluwer Academic/Plenum Publishers, Dordrecht/New York 330 p

Schadler J (1932) Ardealit, ein neues Mineral $CaHPO_4 \cdot CaSO_4 + 4H_2O$. Zb Mineral A, pp 40–41
Shackley ML (1972) The use of textural properties in the analysis of cave sediments. Archaeometry 14(1):133–145
Soficaru A, Petrea C, Doboş A, Trinkaus E (2007) The human cranium from the Peştera Cioclovina Uscată, Romania. Curr Anthropol 48(4):611–619
Springer GS (2005) Clastic sediments in caves. In: Culver DC, White WB (eds) Encyclopedia of caves. Elsevier/Academic Press, Amsterdam/Boston, pp 102–108
Springer GS, Kite JS, Schmidt VA (1997) Cave sedimentation, genesis, and erosional history in the Cheat River Canyon, West Virginia. GSA Bull 109(5):524–532
Stilla A (1985) Géologie de la région de Haţeg–Ciclovina–Pui–Băiţa. Ann Inst Géol Géophys 66:92–179
Tomuş B, Breban R, Pleşa D (1999) Complexul carstic Ciclovina–Bazinul 2063. Clubul Speologilor „Proteus" Hunedoara, pp 21–22
Van Gundy JJ, White WB (2009) Sediment flushing in Mystic Cave, West Virginia, USA, in response to the 1985 Potomac Valley flood. Int J Speleol 38(2):103–109
White WB (2007) Cave sediments and paleoclimate. J Cave Karst Stud 69(1):76–93
White EL, White WB (1968) Dynamics of sediment transport in limestone cave. Natl Speleol Soc Bull 30:115–129