Life and Death at the Peştera cu Oase

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A Setting for Modern Human Emergence in Europe

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Part Two

The Cave and Its Contents

Editors' Note. Throughout the volume, the radiometric dates provided are indicated as being "Before Present" (BP), with a distinction made for the radiocarbon dates between radiocarbon years (^{14}C BP) and calendar years (cal BP). However, labeling dates in "years BP" is normally used solely for radiocarbon determinations, in which the "present" is A.D. 1950. For other dates, including the Uranium-series and electron spin resonance (ESR) ones provided in this volume, "before present" or "years ago" is in terms of the year in which the measurement was made. Given the magnitude of statistical uncertainties in almost all of the radiometric dates here (all except the recent goat metapodial), this technical distinction should make little difference in the evaluation of these ages.

5

The Ponor-Plopa Cave System: Description, Sediments, and Genesis

Silviu Constantin, Cristian-Mihai Munteanu, Ştefan Milota, Laurenţiu Sarcina, Mircea Gherase, Ricardo Rodrigo, and João Zilhão

Introduction

The Ponor-Plopa cave system is located in the central part of the Aninei Mountains, southwest of Steierdorf, a small neighborhood of Anina, at elevations ranging between 575 m (the Ponor) and 545 m (the Plopa resurgence) for the main river cave and ~600 m for the dry caves on the Plopa Plateau. The system includes a total of six caves of which two, Ponor and Plopa, were connected by cave diving. The remaining four caves are relatively small, inactive cavities that were connected to the system at various stages during its evolution.

The karst area is entirely formed within the massive reef Plopa limestones (Barremian), and its surface does not exceed 0.5 km^2 (Figure 5.1). To the north, it is bordered by a secondary ridge of the Culmea Frumoasă; to the west the limit is very well marked by the rocky cliff formed along the contact between the Barremian limestones and the Hauterivian mudstones, while to the south and east it is limited by the Miniş River. The overall topography of the karst plateau shows decreasing elevations toward the southwest, and the distribution and topography of the sinkholes suggest sinkhole alignments going from NNE to SSW, with a bend toward the east, right above the current Plopa resurgence. Such sinkhole alignments are usually considered to indicate either the broad directions of subterranean drainages or a succession of former ponors.

Exploration History

The impressive porch of the Plopa Cave must have been known from time immemorial, but the first intensive research was done by the geographer Vasile Sencu. His work spanned more than a decade and included the first explorations and surveys of the major caves in the Aninei Mountains, including the Buhui and Plopa. He drew and published detailed maps of the karst plateaus in the central Aninei Mountains. He also carried out most of the water-tracing experiments that established the underground drainages in these areas, including those of Ponor-Plopa and Uteriş-Irma (Senco, 1973; Sencu, 1964, 1977). He published the first maps and descriptions of the Plopa and Ponor Uscată caves (Sencu, 1964, 1978). Although some of his assumptions concerning underground stream connections were slightly contradicted by the additional exploration, these maps are still basic reference work (Figure 5.2). Due to the easy access, the caves were occasionally visited by tourists and local people; as a result, speleothems were almost totally vandalized in the easily accessible Ponor Uscată Cave. In the late 1980s, the Plopa Cave also suffered from human action; a diesel spillage in the upper reaches of the Ponor Stream massively polluted the cave, and the resultant black staining of the walls is still ubiquitous.

In 2001, the Pro Acva Grup of cavers and divers in Timişoara started the tremenduous work of declogging the Ponor sinking point and managed to pass the first sump up to the Sala Mare (the Great Chamber). Exploration and survey continued in 2002 resulting in the drawing of the complete map of the Ponor-Plopa cave system (Figure 5.3). A precise remapping of the surface features (Figure 5.1) was performed by a team led by Bogdan Bădescu from the "Exploratorii" Speleological Association in Reşiţa in 2006.

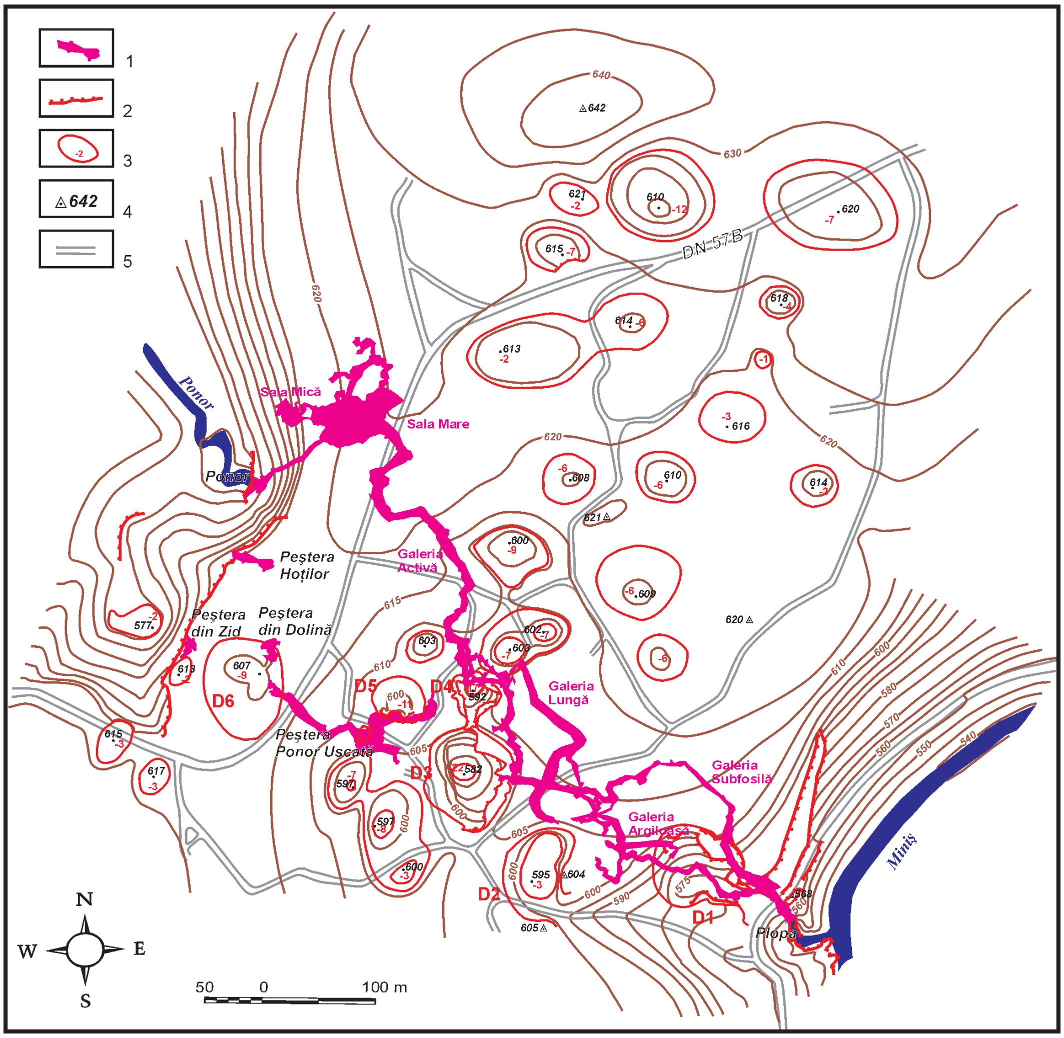

Figure 5.1 Map of the Ponor-Plopa karst area and simplified projection of surveyed caves. Topographic survey by Bogdan Bădescu and Asociaţia Speologică "Exploratorii" Reşiţa (contours at 5 m). Key: 1. cave projection; 2. limestone cliff; 3. doline and depth; 4. topographic points and absolute elevation; 5. roads. D1 through D6 are arbitrary indicators of several dolines significant for the genesis of the system as discussed in the text. Note that the superimposition of the underground and overground maps is based on the only two points shared by both the ponor and the spring. As the underground map was drawn using compass and clinometer measurements made across several difficult passages, namely, sumps, it must be borne in mind that the locational relationships between features of the endo- and the exokarst apparent in the combined map may be affected by the minor errors inherent in the procedure.

Description of the Cave System

The Upper Levels of the Cave System

The Peştera cu Abri (Peştera din Zid) and the Peştera La Hoţu (Peştera Hoţilor) are two small dry caves (ca. 20 m and 35 m, respectively) that open in the limestone cliff blocking the Ponor Valley (see Figure 5.1 and Figures 3.10 and 5.4a). They are thought to be either former sinks of a paleo-Ponor stream or small side-valley caves draining part of the waters gathered from the Plopa Plateau. In 2004 to 2006, exploratory excavations were carried out in both the Peştera cu Abri and the Peştera La Hoţu by I. C. Băltean and colleagues, revealing Holocene and late Marine Isotope Stage (MIS) 2 archeological deposits (Băltean and Petrescu, 2007; Băltean et al., 2008).

The Peştera din Dolină and Peştera Ponor-Uscată are portions of the same cavity and are currently separated only by a breakdown accumulation sealed by flowstone. The Peştera din Dolină opens at the bottom of a 9 m deep sinkhole and consists only of a small, descending passage ~25 m in length. This cave functioned as a ponor, draining the water through the Peştera Ponor-Uscată and further on toward the Miniş River along a broad WNW–ESE

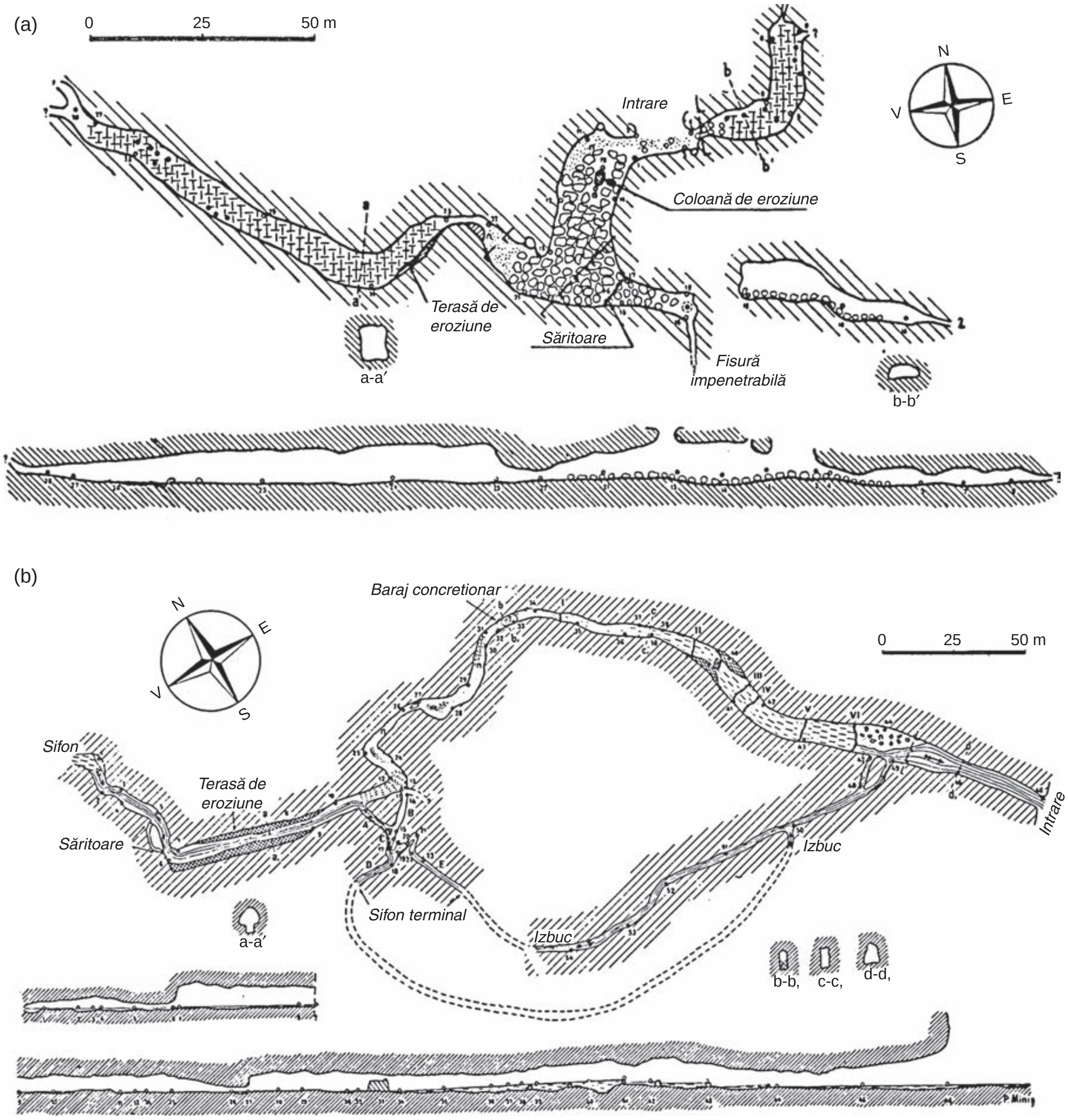

Figure 5.2 The first published maps of (a) the Ponor Uscată and (b) Plopa caves. (From Sencu, 1964.)

direction. The Peştera Ponor-Uscată can be accessed through a collapsed sinkhole (11 m deep) located in the central part of the Plopa Plateau (see Figure 5.1). The widening of the underground passage led to two collapses of the sinkhole's wall, which allow access to a vast chamber, ~20 m high (Figure 5.4b). From this chamber, a short side passage may be followed toward the east for about 40 m, after which it is totally clogged by flowstone. To the southwest (i.e., the former "upstream" direction), a large (~9–10 m) and high (10–15 m) passage may be followed until the rock collapse and flowstone clogging that separates it from the Peştera din Dolină. The floor of this passage is covered by an extensive clay deposit; toward the final part, it hosts several massive stalagmitic domes. Finally, a short passage in the entrance chamber area goes to the southeast after a 6 m deep step but soon becomes too narrow to allow human passage.

The total length of the galleries in Peştera Ponor-Uscată is 265 m. Its overall topography suggests an old drainage toward the Miniş River, with the eastern passage being either a former tributary collecting the waters from the upper reaches of the Plopa Plateau or a former drainage subsequently abandoned in favor of a shorter one that used the southeastern course.

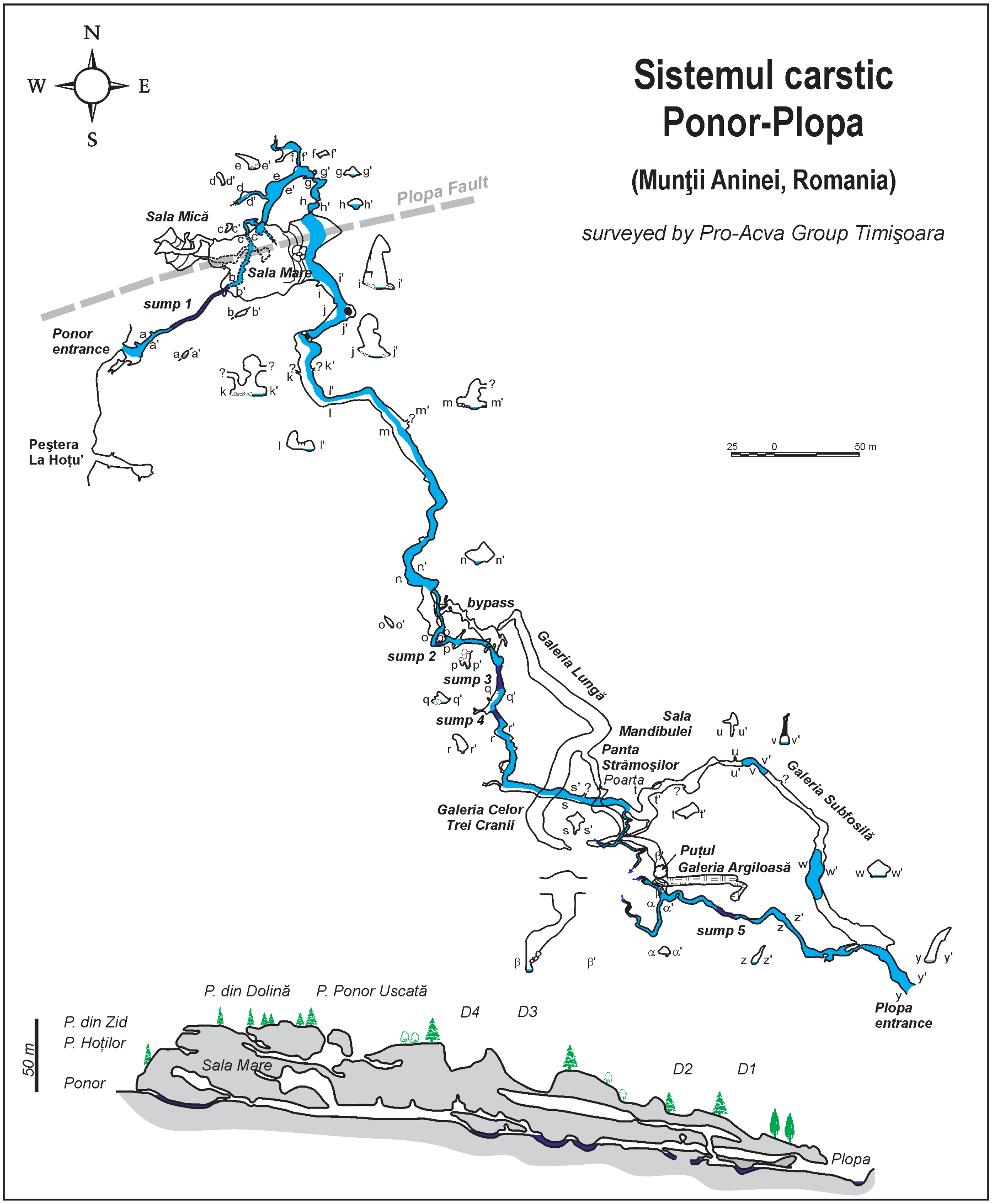

Figure 5.3 Simplified map of the Ponor-Plopa cave system.

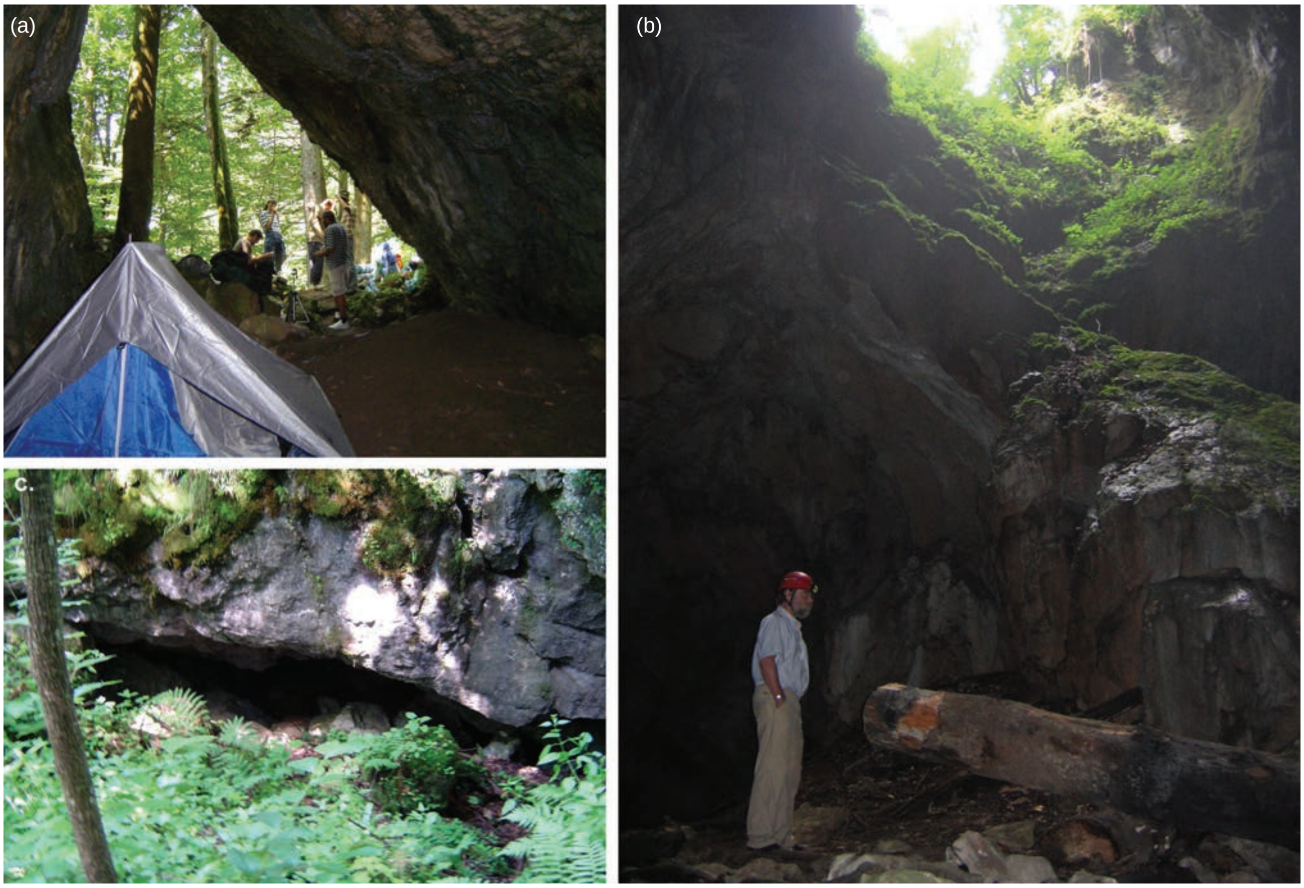

Figure 5.4 (a) The triangular entrance in Peştera Hoţilor. (b) Rainer Grün standing at the base of the main entrance in Peştera Ponor-Uscată. (c) The Ponor during the dry season.

The Ponor-Plopa Cave

The Ponor-Plopa Cave is a typical through-cave with a total length of surveyed passages that exceeds 2000 m in length. The ponor is usually blocked by debris (Figure 5.4c), although Sencu (1978) mentioned that the passage was accessible at low waters for some 50 meters. However, at least during the last decade this has not been the case, and the divers who first passed the initial sump had to remove a considerable amount of debris and timber accumulated at the sinking point. From there on, explorers encountered a first sump (Sump 1) consisting of a narrow, inundated passage ~100 m long, at the end of which a narrow passage on the left side leads to the ascending Sala Mică (the Little Chamber). The stream continues to flow northwest through narrow passages, carved along the contact between the "Lower" and the "Upper" Plopa limestones, then makes a U-turn to flow toward the south. It soon reaches the Sala Mare (the Great Chamber), a 100 × 50 m large room with a maximum height of ~25 m and its long axis oriented roughly along the Plopa Fault (see Figure 5.3). The chamber floor is covered by a scree cone, including large blocks. On the western side, the chamber ends with a smaller side passage, most probably a former ponor and natural entrance into the cave, now clogged by flowstone. Across the floor of the chamber, numerous fossil remains of cave bears are present, both scattered on the floor and in hibernation nests, but due to the difficult access, no further documentation of this deposit was carried out.

Downstream the Sala Mare, the river flows exclusively through the massive Plopa limestone beds and, consequently, the passage becomes larger and higher, exceeding 20 m in height in some places. The morphology of the passage suggests a rapid deepening of the stream, including remnants of phreatic tubes in the ceiling of the passage and an overall canyon shape. The river mainly flows along a NNW–SSE direction that matches one of the tension joints from the Plopa Syncline and uses WSW–ENE shear fractures to form a general rectangular meandering pattern. In places, massive speleothems, including stalagmites, domes, and calcite rimstone dams, are present, hinting at long periods of low or absent water input. The presence of pendants and of rocky terraces covered by gravel and sand also suggest a succession of hydraulic events alternating between sedimentation and subsequent sediment removal.

After some 500 meters, the passage becomes narrower, and the river forms three small sumps. The first of these sumps (Sump 2) may be avoided through a low bypass passage, but Sumps 3 and 4 can be negotiated only through diving. Beyond the fourth sump, the passage height increases to ~5 m, and its orientation changes to a W–E direction. After only ~150 meters, the stream flows to the south through some very narrow passages that soon become impassable. Some 1.5 meters above the sinking point, the Galeria Subfosilă continues along the same broad direction. Normally, all of the Ponor waters drain through the lower passages, but at high waters the Galeria Subfosilă acts as an overflow.

The Galeria Subfosilă is relatively large (5–15 m), often more than 10 m high, and becomes increasingly larger downstream. At least two erosional levels may be noticed as rock terraces covered by sand and, occasionally, by flowstone. In six places along the passage, massive rimstone dams up to 1.5 m high have been precipitated and extend across the entire floor. At high waters the passage is flooded, and the water fills up the pools, forming a series of cascading lakes with depths varying between 0.6 and 4 meters. In summer, the water may slowly drain from most pools; however, at least two lakes are permanent. After ~300 m, the passage gets even larger and intercepts the stream coming from the west. Downstream of this point, the height of the passage increases to more than 15 meters in height and, after only ~50 m, the river emerges through the triangular porch of the Plopa Cave (Figure 2.2), which is located at the base of a 30 m high limestone cliff and about 200 m from the Miniş River.

The sector located upstream of the junction between the underground river and the Galeria Subfosilă includes a narrower passage with its jagged limestone floor entirely occupied by the underground river. Upstream of the junction, a "duck-under" (short part of the passage where the low ceiling forces explorers to free-dive for about 0.5 m) occurs. After only ~60 m of river passage, Sump 5 is encountered. This sump is 20 m long and 5 m deep; it is generally referred to here as the Sifonul ("the Sump"), since it was the only sump the team had to pass to reach the Oase sector. Beyond the sump the passage regains relatively large dimensions but only for ~ 30 m until the Vestiarul. The river then receives a small tributary, most probably originating from an upstream diffluence of the underground stream, but both passages become quickly impassable due to their small size. However, the cave continues through a typical collapse shaft that opens in the ceiling of the river passage. For consistency, we will describe it as part of the Ponor-Plopa Cave, although genetically the passages above the shaft (see Figures 3.1–3.8) belong to what we previously described as the upper levels of the system.

From the riverbed, a debris cone formed by limestone blocks covered with clay may be climbed for about 7 m; it leads to the bottom of a 17 m high shaft, the Puţul ("the Shaft"), shaped as an asymmetric funnel. The southern and eastern sides of this shaft are vertical, but its western and northern sides are inclined in the upper part (see cross section β–β‘ in Figure 5.3). The access through the shaft involves climbing its northwestern side, along a drainage channel apparently carved by a former waterfall between massive flowstone formations. In the upper part of the shaft, on its southern and western sides, massive clay deposits are present. By climbing up the southern side to the top of the clay deposit, the upper levels of the system can be reached—the portions designated the Peştera cu Oase.

The first portion is the Galeria Argiloasă ("the Clayey Passage"); this is a relatively large passage (up to 10 m wide and ~6 m high) with the floor entirely covered by brown clay with desiccation cracks. The passage hosts numerous speleothems, including stalactites, curtains, massive domes, and numerous candlestick stalagmites. It ends after ~60 meters by clay clogging, and its end corresponds at the surface to a small blind valley located several hundred meters away from the current Plopa entrance.

On the northern side of the shaft, the main passage continues toward the northwest through a large passage with its floor distinctively occupied by rimstone dams (Galeria Gururilor). After ~50 m a short side passage appears on the left, close to the recovery point known by the cave workers as "the Cafeteria." Further on, the main passage becomes steeper, and, after a ~2 m ascending step, it comes to what initially looked as a dead end. Here, by enlarging a small blowing hole, the explorers were able to pass a narrow squeeze, currently closed with a gate, and enter the Galeria Culcuşurilor passage. The Galeria Culcuşurilor is an ascending passage ~1–4 m high and 2–5 m wide. Its floor is covered by clays deposited over the stabilized surface of a thick fill consisting of intermixed gravel, sand, speleothem fragments, and bones. The end of this ~30 m long passage consists of a steep slope (the Panta Strămoşilor), which leads to the Sala Mandibulei, a typical confluence chamber located at the intersection of two large passages: the Galeria Lungă and the Galeria celor Trei Cranii. The Sala Mandibulei has a height exceeding 15 m and displays numerous collapsed boulders and massive broken speleothems on its floor. Fossil bones are present all around, either encrusted in calcite or lying loose (on the floor or underneath the collapsed blocks).

The Galeria Lungă follows broadly a SSE–NNW direction for ~150 m, with heights that exceed 20 meters.

The overall shape of the passage suggests an underground canyon with terraces carved in rock on both sides at elevations of 3–4 m. Its floor is encrusted with calcite for most of its length, except for the final part where a debris cone of fine sand and gravels clogs the passage.

The Galeria celor Trei Cranii starts from the Sala Mandibulei in the opposite direction and has an average width similar to that of the Galeria Lungă. However, its heights are smaller and decrease from more than 15 m to less than 1 m toward the end. While the ceiling of the passage remains broadly flat, its floor consists generally of a sediment dump cone and therefore ascends from the Sala Mandibulei toward the end. The deposits are mostly covered by flowstone and brown clay in the first half of the passage. Toward its end, the sediment becomes apparent and consists of a mixture of fine gravel, sand, and clay. An erosional terrace was carved into one of the walls at ~1 m above the floor but, overall, fluviatile erosion features are not as prominent as in the Galeria Lungă. Apart from the omnipresent cave bear remains, including hibernation nests (see Chapter 10), the sediments in the Galeria celor Trei Cranii also contain small bone fragments including those of recent mammals (see Chapter 10 for discussion). Both the Galeria Lungă and the Galeria celor Trei Cranii display a large number of speleothems of which some have been uranium-series dated and provide a minimum postglacial age for the clogging of the passages (Chapter 6).

Cave Sediments and Morphology

Cave morphological features and sediment analysis may yield important information on the history and genesis of a cave system. In the case of a complex system such as Ponor-Plopa, the broad picture is thought to be understood. The system was formed by the underground drainage of the Ponor Stream (and possibly some of its former tributaries) through the highly karstifiable Plopa limestones to reach the base level of the Miniş River. This was done through a typical succession of karst hydrologic catchments as shown in Chapter 4. However, when trying to "fine-tune" the timing of the series of events that led to the present situation, things are not straightforward. This was the major challenge for all researchers involved in the Peştera cu Oase study: to understand the evolution of the system as much as this was relevant to the accumulation of the bone deposit.

To obtain a better understanding of the formation processes involved, cave sediment studies were carried out in two sections: (1) the sediments in the Puţul; and (2) the sediments in the excavation area at the Panta Strămoşilor. In the Puţul, samples were collected along a 13.36 m high trench from its southern wall. In the Panta Strămoşilor, a few samples were collected for rockmagnetic analysis along a ~1 m deep excavation section, as reported in Chapter 9. A detailed description of the excavated deposits is given in Chapter 10.

The Sediments from the Puţul

A sampling trench was excavated in the southern wall of the Puţul; the principal purpose was to retrieve unoriented samples for the analysis of magnetic properties (see Chapter 9). However, in the preliminary stages of the research grain-size measurements were performed, and the structural and textural parameters of the deposits were also analyzed. A total of 149 sediment samples were collected at intervals ranging between 0.01 and 2.27 m depending on sampling conditions (Figure 5.5).

Grain-size measurements on fine samples were performed by treating ~5 g of the bulk sample for 14 days in a plastic box with ~0.4 ml of a 1% solution of $Na(PO_3)_n$, where n ≈ 25 (i.e., Graham's salt). A quantity of ~2.5 g sample was later extracted from the box and treated again with ~0.2 ml of 2% solution of Graham's salt. The grain-size fractions were highlighted by analyzing each sample on a HORIBA Partica LA-950V2 laser scattering particle size distribution analyzer. The coarser samples were analyzed by vibrating dry sieving of ~100 g of the bulk sample and weighing the sediment quantity retained on each sieve, on an OHAUS Scout digital balance, down to the 500 μm fraction, which was subjected to the same procedure as the fine samples. Calculations and plots were done using the GRADISTAT version 8 software (Blott and Pye, 2010); we applied the method of Folk and Ward (1957) and logarithmic statistics. The paleo-fall velocities were estimated with the Fall Vel software (Parker, 2004), which is developed on Dietrich's (1982) formulation.

Three major depositional phases could be recognized within the log, each of them composed of two to three sediment units. Starting from the bottom of the shaft, these are as follows.

Phase I

For the lowermost 4.4 m of the profile, the sediments consist of a mixture of gravels, sands, and muds, forming beds with a massive structure and sharp boundaries (Unit A). The main grain-size classes vary between 0.5–77.3% (rudite), 16.3–98% (arenite), 1.4–47.4% (silt) and 0–0.1% (lutite) (Figure 5.6). The rudite fraction consists of two types of coarse clasts: (1) subrounded gravels, with various lithologies, coated by black manganese oxides that may have been fluvially transported and reworked from upper levels; and (2) carbonate clasts, with angular to subangular shapes, possibly related to limestone (cryoclastic?) weathering at the surface or along the cave walls

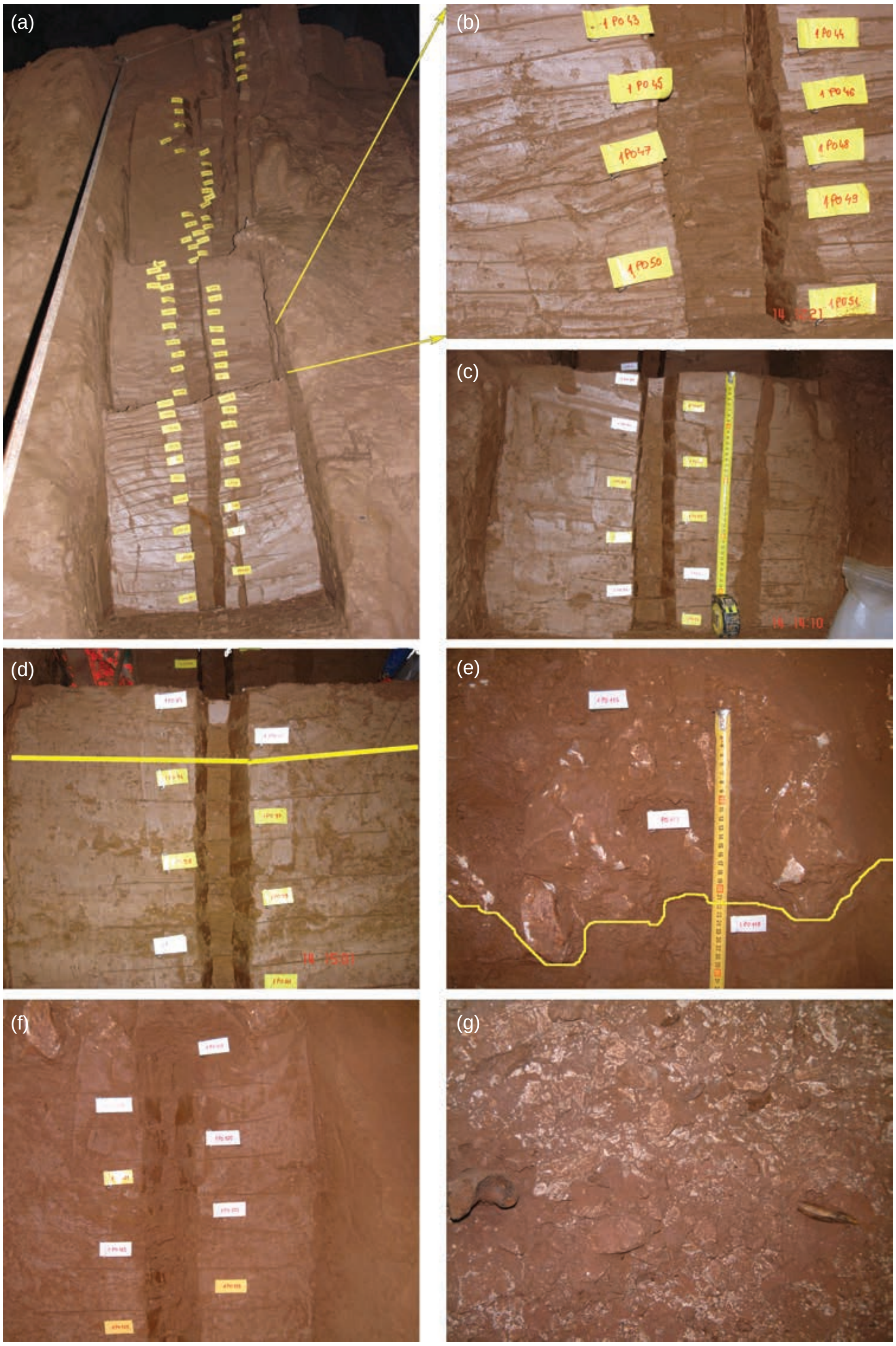

Figure 5.5 Typical lithofacies of the sedimentary sequence in the Puţul: (a) The upper part of Unit G (backswamp/slackwater facies). (b) Detail of image (a) showing deposits developed mainly in backswamp facies. (c) The lower part of Unit G (backswamp/slackwater facies). (d) The lowermost part of Unit G and the upper part of Unit F (both developed in a slackwater facies); the yellow line marks the transition between the units. (e) The lower part of Unit E (diamicton facies) and the uppermost part of Unit D (backswamp facies), delineated by the sinuous yellow line. (f) The upper part of Unit D (backswamp facies); on top of the image, the contact with the coarser deposits of Unit E can be also noted. (f) The lower part of Unit C (diamicton facies).

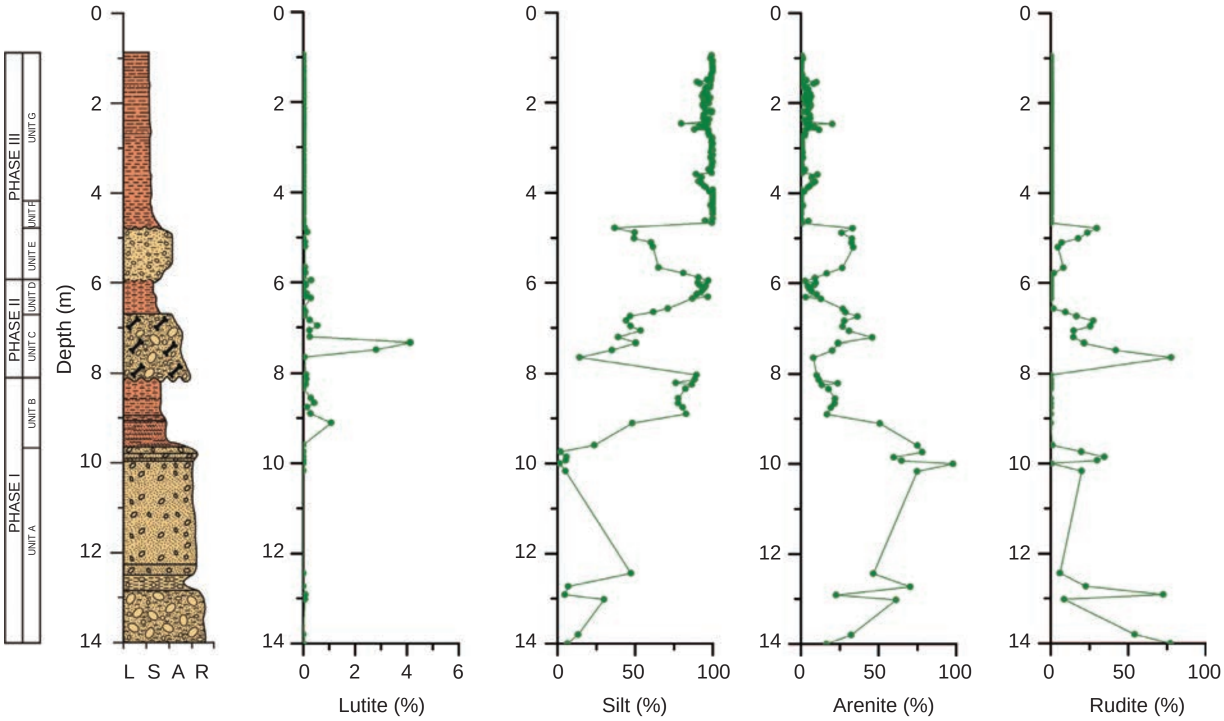

Figure 5.6 Lithologic log of the sampled section and grain-size data.

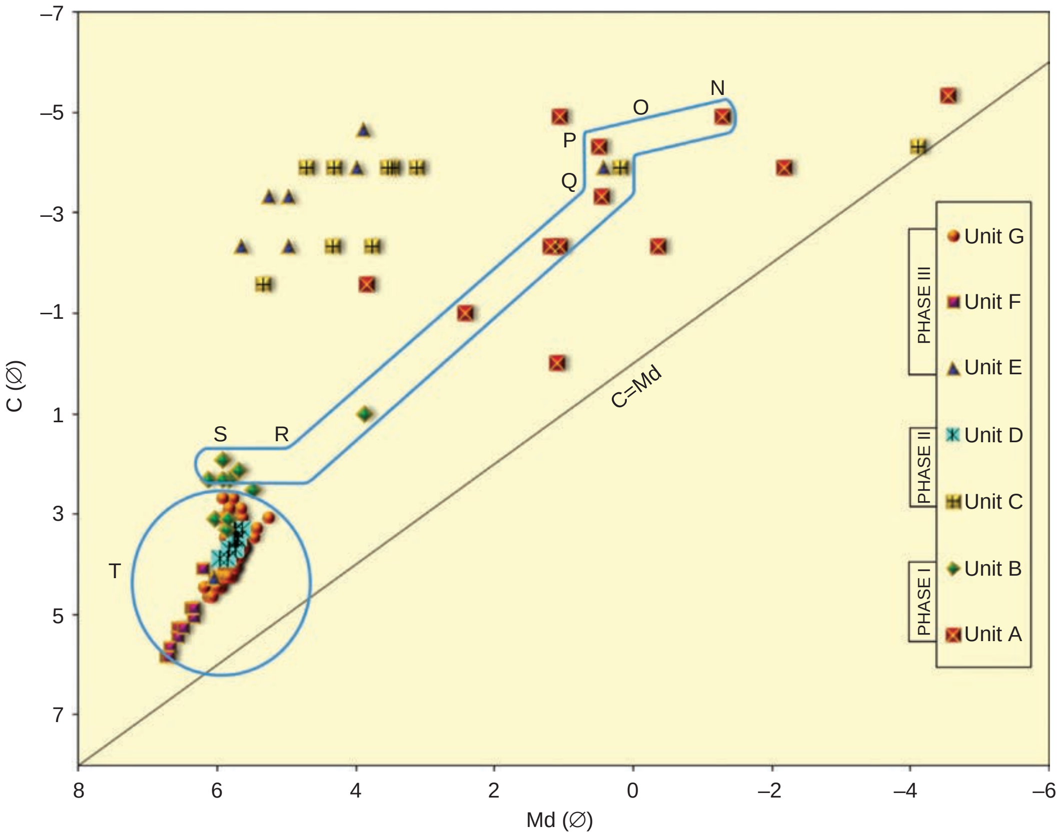

Figure 5.7 The Passega diagram of the sediments filling up the Shaft.

and ceiling. The cumulative grain-size distributions are polymodal, indicating a large variety of sediment sources and processes. On the C/Md plot (Passega diagram; Figure 5.7), the projections corresponding to Unit A are scattered, several points falling into four fields of the pattern (NO: rolling, OP: rolling and suspension, PQ: suspension and rolling, QR: graded suspension). The dispersion of some points outside the pattern indicates the total energy fluctuation (Royse, 1968). Overall, this unit is typical for a diamicton facies (Bosch and White, 2004), suggesting a high-energy environment, possibly a paleoflood event that triggered a clast-supported debris flow.

The next ~1.5 m of sediments (Unit B) consist of poorly sorted muddy sand. Several beds can be distinguished within this unit; the basal bed has a laminated structure, with wedged layers and sharp limits as opposed to the upper beds which exhibit a massive structure and transitional boundaries. On the Passega diagram, only one sample of Unit B can be related to a graded suspension, whereas the remaining points are mainly clustered within the RS (uniform suspension) and T (pelagic suspension) fields. The depositional model for this unit suggests a low-energy environment, typical for a backswamp facies (Bosch and White, 2004). This facies indicates that, for some reason, water accumulated in the shaft; the deposit was formed by weathering products—such as fine limestone breakdown clasts and white, brittle carbonate speleothem fragments found in the sediment—that settled along with a fine detritus.

Phase II

The second sedimentation phase also comprises the succession of a lower, coarse unit (C), followed by an upper, fine one (D). It thus indicates a similar transition from a dynamic environment to a low-energy one across the next 2.15 m of the section.

Unit C (1.5 m) consists of gravels, sands and muds, mixed up in several textural types giving a breccia-like aspect to the densely packed succession. This is slightly different from Unit A, due to the high abundance of angular to subangular limestone clasts, which increase the $CaCO_3$ content up to around 10% (Petrea et al., 2006). Apart from these angular pebbles, the coarse fraction also includes *Ursus spelaeus* bone fragments. Except for one sample that falls within the PQ (suspension and rolling) field in the Passega diagram (Figure 5.7), all the points fall outside the pattern, which is an indication of a highly fluctuating environment energy. Considering all variations of the sedimentological parameters, we argue that the diamicton facies of Unit C denotes yet another high-energy transient event, a clast-supported debris flow that also reworked cave bear bones in the sediment mass movement.

Unit C is capped by a sequence of ~0.7 m of poorly sorted sandy muds (Unit D, Figure 5.6). The unit of massive, red sandy muds, and muds is clearly delineated by sharp boundaries. The distribution curves shift from a bimodal pattern (mode 1: 6.14Ø), to a unimodal one (mode: 6.14Ø), marking the transition from a highly dynamic environment to a quiet settling. If the sandy muds exhibit the echoes of the high-energy deposition of Unit C, the muds prove the decrease in the energy of the environment, leading to the settling of finer sediment, mainly composed of silt-sized particles (90.4–97.1%). The single transport mechanism is equally revealed by the clustered pattern of the projections within the T (pelagic suspension) field on the Passega diagram as well as by the unimodal aspect of the distribution curves (mode: 5.94–6.14Ø). During the time period corresponding to the deposition of Unit D, a new decrease of the hydraulic energy again seems to indicate the formation of a "decanting pool," typical for a backswamp facies and similar to Unit B.

Phase III

The third sedimentation phase extends over about 5 meters and similarly begins with a mix of fine and coarse deposits (Unit E) that gradually change into finer lithotypes (units F and G). The prevalence of the matrix over clasts within Unit E and the slightly dynamic character of the fine Unit F are the main differences with the previous phases.

The breccia-like Unit E (1.2 m) consists of muds initially mixed up with various quantities of gravels and sands but purer at the top of the unit. The rudite clasts are mainly limestone and subordinately claystone pebbles; the carbonate input increased again to around 10%, whereas the percentage of organic matter exceeds 5% (Petrea et al., 2006). The various muds form a massive unit, with a sharp top boundary and a basal limit affected by differential compaction. As in the case of Unit C, only one projection falls into the PQ (suspension and rolling) field of the Passega diagram, and the scattering of the projections suggests fluctuations of the environment energy. The sedimentological parameters indicate a diamicton facies, and the deformed aspect of the basal limit shape for Unit E suggests a matrix-supported mud flow. Still, there is no argument for a subaerial exposure of the previously deposited sediments; neither flowstone nor any signs of a slackwater facies on top of Unit D were found, and therefore we speculate that this sediment mass movement may have taken place underwater.

Unit F (0.6 m) is the lowermost sector of a fine, 3.8 m thick succession of massive red muds, entirely consisting of silt fractions (Figure 5.6), with only slight oscillations of the grain-size statistical parameters. All of the samples show unimodal (mode: 6.34–6.73Ø), symmetrical

(Sk_I: −0.05 to +0.08), and mesokurtic (K_G: 1.01–1.09) distribution curves. The Passega diagram reveals a clustered pattern of the projections within the T (pelagic suspension) field, reflecting the decrease of the environment's energy and accounting for a single transport mechanism. The fine deposits of Unit F are better sorted compared with those typical for a backswamp environment and can be assigned to a slackwater facies developed in the shaft, during a time of slight vertical oscillations of the water level.

Unit G (3.2 meters) is the uppermost part of the sediment succession in the shaft and includes dark red muds, finely laminated across the last 2 m and rarely interbedded with poorly sorted sandy muds. The lamination suggests periodic qualitative and quantitative changes of the detritus filtered from the soil. There is a high amount of organic matter in these sediments, reaching up to 15% (Petrea et al., 2006). The projections of the samples pertaining to the Unit G on the Passega diagram are also clustered within the T (pelagic suspension) field. Sedimentological parameters support a backswamp facies (Bosch and White, 2004), standing for a quiet, rarely altered environment, supplied with fine weathering residue and soil material.

There are differences between the paleofall velocities (Figure 5.8) estimated for the coarse units, showing higher values and a clear decrease upward, and those assessed for the fine units, from which we inferred much lower values, oscillating in a very narrow range.

Discussion

Across the Puţul sequence, three distinct, fining-upward, detrital successions assigned to three different sedimentary phases can be noted. After a debris flow that may have blocked the downstream drainage and created the basal unit, the shaft functioned as a sedimentary trap, plausibly filled up with water. The backswamp pool recorded two other high-energy events, caused by paleofloods: a new debris flow; and a mud flow, forming diamicton units, separated and overlain by deposits related to periods of quiet settling, seldom affected by slight vertical oscillations of the water level. The grain-size statistical parameters (Table 5.1) reveal textural aspects (a partial removal of the fine fractions, a better sorting of the coarser sediment), highlighting the changes of the environment's energy. Moreover, the sedimentological parameters and the Passega diagram demonstrate the prevalence of uniform and pelagic suspension as transport mechanisms for the fine deposits.

At least two possible stream ways may be considered as sources of sediments. The first and perhaps most obvious is a stream entering the ponors of either Galeria Lungă or Galeria celor Trei Cranii and flowing through the Panta Strămoşilor and down the shaft to reach the main Ponor stream. The second is the Ponor main stream itself. During flooding seasons (spring and late autumn) the water is presently known to rise at least 3–4 meters above its present base level, upstream of Sump 5, which is enough to inundate the base of the shaft. We can speculate

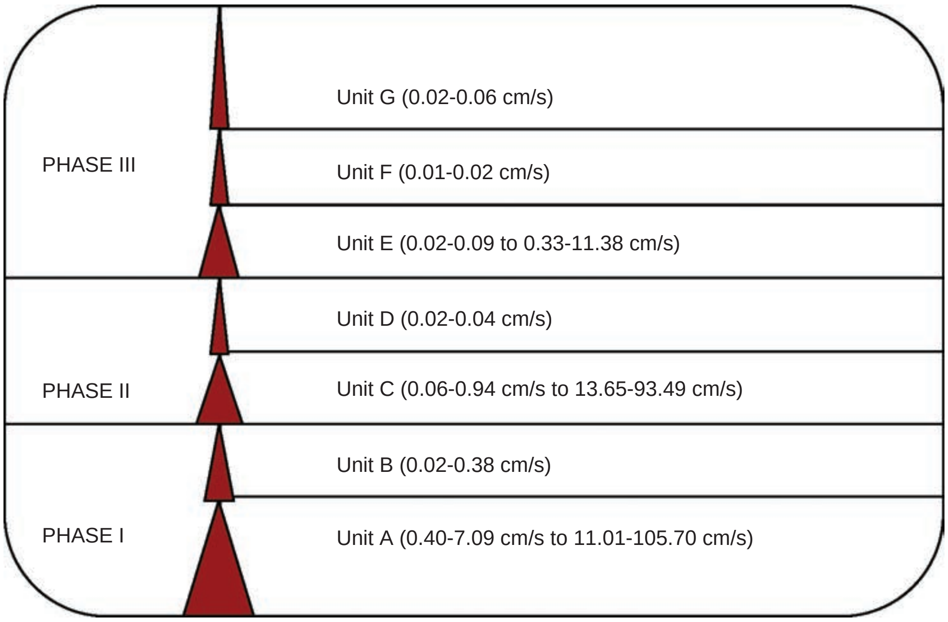

Figure 5.8 The evolution of the particles paleo-fall velocity and grain size across the Shaft (a larger base of a triangle from the column represents a coarser unit).

Table 5.1 The main grain-size statistical parameters of the analyzed sedimentary fill of the Shaft (Puţul)

UNIT	MODE 1 Mo 1 (Ø)		MEDIAN Md (Ø)		MEAN Mz (Ø)		SORTING σ_I (Ø)		SKEWNESS (Sk_I)		KURTOSIS (K_G)	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
A	–5.41	6.14	–4.55	3.84	–3.30	3.39	1.84	3.61	–0.54	0.75	0.54	2.09
B	2.03	6.34	3.89	6.13	4.24	5.86	1.30	2.27	–0.30	0.22	0.66	1.04
C	–4.48	6.14	–4.11	5.34	–1.83	5.02	2.12	4.41	–0.45	0.91	0.57	2.47
D	5.94	6.14	5.65	5.97	5.59	5.96	1.08	1.36	–0.09	0.02	0.83	0.99
E	–4.78	6.34	0.44	6.06	1.50	6.05	0.90	4.05	–0.58	0.29	0.59	1.69
F	6.34	6.73	6.20	6.75	6.17	6.75	0.49	0.93	–0.05	0.08	1.01	1.09
G	3.99	6.14	5.26	6.19	5.23	6.19	0.67	1.28	–0.19	0.04	0.78	1.14

Notes: Units A to G are from bottom to top of the sequence.

that much higher water levels may have been reached in the pre-Holocene, possibly favored by a different underground topography. The structure and sedimentological parameters of the three sedimentary phases are (1) the alternance of diamicton units capped by low hydraulic energy deposits, (2) the absence of any sign of subaerial evolution, and (3) diamicton units showing decreasing flow energy from units A through E, from debris flow to mud flow according to the grain-size statistical parameters (Table 5.1) and to the estimated paleo-fall velocities (Figure 5.8). These phases suggest that the coarser units were sourced from the upper levels of the Peştera cu Oase, but they were deposited in a shaft that was partially filled with water at that time. This could explain the absence of subaerial features and the morphology of the boundaries between coarser and finer units, the latter being deposited by decantation from a slackwater pool, once the inflow from the upper levels ceased.

A possible scenario for the deposition of the sediments in the Puţul could thus be:

1. During extreme torrential events (or time periods experiencing heavy rainfall seasons), Ponor stream waters could have accumulated upstream of Sump 5 and inundated the shaft from the bottom up.
2. At the same time (or possibly with some delay considering the smaller catchment area), the waters draining the Plopa Plateau into the ponors represented by the Galeria Lungă or the Galeria celor Trei Cranii introduced sediments into the Galeria Culcuşurilor and beyond, with finer material, including medium-sized gravels, sands, and small bone fragments being washed into the shaft and deposited underwater as diamicton units.
3. At the end of the pluvial events (or epochs), the water inflow from the upper passages ceased, and fine sediments were deposited through decantation on top of diamicton units before the water from the shaft slowly drained out.
4. This process may have been repeated at least three times, with less hydraulic energy being involved for the deposition of the units originating from the upper levels from unit A to C and E. This may be due to either a decrease in flow rates of the inflow or the clogging of the Panta Strămoşilor at the Poarta or a combination of both.

The Stratigraphy of the Galeria Culcuşurilor

The deposits filling the Galeria Culcuşurilor could be observed in the framework of the excavation of the Panta Strămoşilor (Chapter 10). From top to bottom, three stratigraphic units were recognized: Surface, Level 1, and Level 2. The Surface unit refers mainly to bones lying atop either the calcite crust or Level 1. Level 1 then consists of a 5–30 cm thick mixture of complete bones, bone fragments, speleothem fragments, and limestone blocks within a matrix of sandy silts, in places encrusted by carbonate from the percolating waters or capped by flowstone. Level 2 features a coarser sediment, mostly sands and sandy silts with a notable fraction of rounded pebbles and rolled speleothem fragments (but featuring differentiated subunits such as homogeneous lenses of clay or bars of coarse sands and gravel) and including many small-sized bear bone fragments throughout.

While the Surface and Level 1 units reflect the operation of local processes relating to the final stages of the history of the Plopa-Oase system, the diversity of the Level 2 deposit suggests an extended, modulated accumulation process. The geometry and other features of the buried cave wall (see Figures 10.3b and 10.4a), in turn, indicate that the base of the gallery lies much deeper and that the excavation concerned only the upper reaches

(~65 cm in the N37 grid unit) of a very thick fill accumulated over a substantial period of time ending ~50–45 ka BP.

Due to the poor chronological control of the Puţul sequence, it is at present impossible to correlate between the debris flow events recorded in its Units C and E and the formation of the Panta's Level 2 deposits. The latter, however, provide a good illustration of what the sediments accumulated immediately downstream of the Sala Manidbulei in the framework of the torrential events considered in step (2) of the aforementioned formation scenario would have looked like.

The Genesis of the Ponor-Plopa Cave System

Understanding the genesis of a complex cave system is, in most cases, not straightforward. The big picture of how a karst drainage evolved may be sometimes easier to understand (in this case, see the evolutionary scenario in Chapter 4), while establishing the details and timing of a particular succession of events requires a combination of observations on the morphology of the cave, the relationship between the underground and surface topography, the presence of various cave deposits, and their structures and ages. In the following chapters, different dating results are presented as they serve to establish a detailed time frame for the depositional events in Peştera cu Oase. This section discusses only the general evolution of the Ponor-Plopa cave system as revealed by the morphology, topography, and subterranean deposits from cave passages as known to date.

The overall karst topography indicates that the first underground drainages were established along the lithologic contact between the Lower and Upper Plopa limestones, which is now marked by the limestone cliff at the west side of the Plopa Plateau. The first drainages from the Ponor toward the Miniş River were established in today's upper levels, via the Peştera din Zid, to the Peştera Ascunsă, to the Peştera Ponor Uscată, and then the Peştera cu Oase. Taking into account the apparent alignments of dolines and sinkholes as well as local tectonics, we can speculate on the possible presence of a concurrent underground drainage from the Uteriş stream toward the Miniş (see Figure 4.6), but as yet there is no additional evidence supporting this hypothesis.

The topography of the galleries suggests a drainage oriented WNW–ESE from the Ponor Cliff toward D1 and D2—the "open dolines" located at the ends of some small blind valleys ~40 m above the Plopa entrance (see Figures 5.1 and 5.9). Considering both the morphology of the passages and the combined surface–cave topography, a possible scenario is that the oldest drainage used a route that passed from the Peştera Ponor Uscată to the Galeria Lungă and reemerged at the surface through the Galeria celor Trei Cranii and the D2 sinkhole (Figure 5.10a). Subsequently, the underground stream may have been reoriented to a lower level from the Sala Mandibulei via the Panta Strămoşilor, Galeria Gururilor, and Galeria Argiloasă to resurge in the D1 sinkhole. Following the deepening of the Ponor Stream, the underground drainage was gradually reoriented at the level of Sala Mică, to the Sala Mare, to the upper meanders along the current streamway, to the Galeria Subfosilă, to finally resurge at the Plopa entrance (Figure 5.10b). The final stage in the development of the karst system was the establishment of the current drainage from the Ponor via the current streamway and sumps toward the Plopa resurgence (Figure 5.10c).

With the deepening of the Ponor Stream, the upper levels of the cave system, such as the Peştera cu Oase, remained largely devoid of a permanent stream flow with their catchment areas restricted to the northern and southern parts of the Plopa Plateau. The system was dissected by collapses that separated the Peştera Ascunsă from the Peştera Ponor-Uscată, created the shaft entrance in Ponor Uscată, and separated the latter from the Galeria Lungă through the typical collapse sinkhole D4. Ultimately, the Galeria Lunga and the Galeria celor Trei Cranii acted as ponors of the temporary streams formed within the endorheic basin of Plopa.

It seems reasonable to presume that the relatively fast deepening of the Ponor and Uteriş valleys was

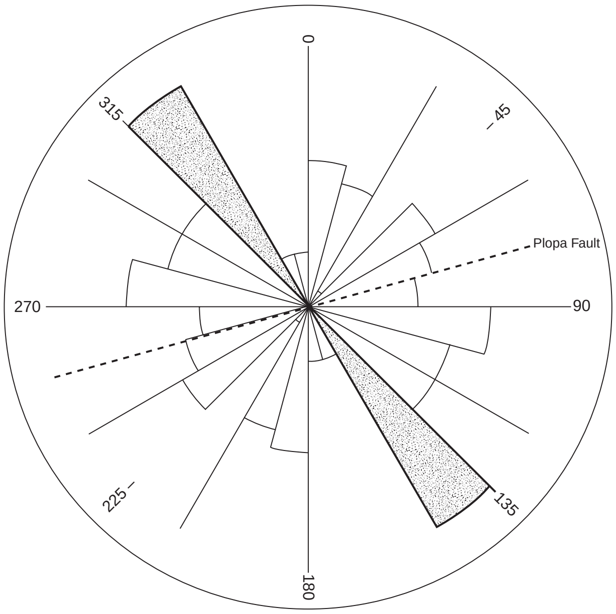

Figure 5.9 Rose diagram showing the preferential passage bearings in the Ponor-Plopa cave system. Note that the majority of the passages are close to a NNW–SSE bearing. The dashed black line shows the bearing of the Plopa strike-slip fault.

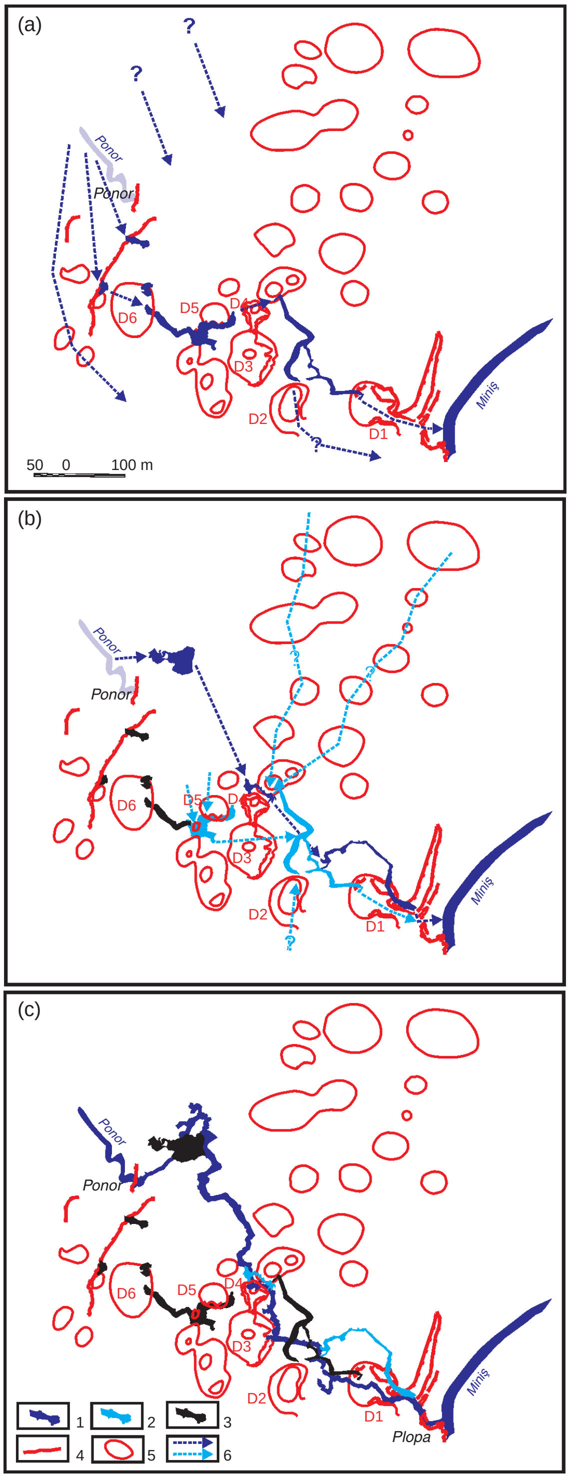

Figure 5.10 Tentative scenario of the evolution of the cave passages in the Ponor-Plopa area. (a) Inception stage: successive karst captures along the Ponor Cliff toward the Peştera Ponor-Uscată-Galeria Lungă-Galeria celor Trei Cranii-D2 (D1). (b) Deepening stage: the Ponor stream creates the Sala Mare sector and flows toward the Miniş via the Galeria Subfosila. Some of the upper levels acted as temporary drainages for the endorheic basin of Plopa. (c) Current stage: the only main drain of Ponor-Plopa, a few temporarily flooded passages and all upper levels being hydraulically inactive. Key: 1. Underground passage, permanent flow; 2. Temporary flow; 3. Dry passage; 4. Limestone cliff; 5. doline; 6. Possible drainages pathways: dark blue—permanent; light blue—temporary. Note that drainages indicated in (a) and (b) are not synchronous so the suggested inputs–outputs of the system indicate possible reorientations of the drainages during the same stage. See text for more details.

caused by an equally fast incision of the Miniş hydraulic base level. This gradient increase led to the formation of the current drainages. On the other hand, in the upper levels the (temporary) streams were most likely captured through the Puţul toward the newly established main streamway Ponor-Plopa (Galeria Activă). The sediments accumulated along the southern wall of the shaft seem to have mixed sources—that is, a coarser fraction washed out from the Peştera cu Oase during torrential episodes and sedimented within a silty matrix from a shaft partially filled with the water accumulated behind Sump 5. After the last glacial maximum, the water and sediment inflow through the Peştera cu Oase decreased and finally ceased; consequently, the rapid speleothem formation typical for the Holocene covered in many parts of the Peştera cu Oase the older sediments or collapsed blocks. In the Galeria Gururilor, the formation and preservation of rimstone dams attest for a very slow water flow with (almost) no sediment transport, since this would have destroyed these fragile speleothems. In the Galeria Argiloasă, as early as ~17 ka BP, stalagmites had grown on top of the clay deposit (see Chapters 7 and 9) indicating a significant decrease of the flow rate of the Ponor stream during the Postglacial.

Conclusions

The Ponor-Plopa cave system is a typical fluviokarstic network formed by successive captures of the Ponor Stream toward the major regional collector, the Miniş River. The main drainage was roughly NW–SE oriented and may have attracted tributaries coming from the northwest or the endorheic plateau of Plopa. Since karst denudation and collapse processes contributed to the fragmentation of the cave network, the timing and succession of events that led to the formation of the cave system could be assessed only in broad terms. The study of sediments from the upper levels of the system indicates that the Peştera cu Oase acted as a ponor that drained the waters accumulated on the Plopa Plateau toward an already established main drain along the Ponor-Plopa alignment. The sediments preserved on the southern wall of the Puţul indicate at least three depositional events mixing coarse sediments introduced via the upper ponors and fine silts deposited within a water-filled shaft. This hydraulic functioning seems to have ceased during the Tardiglacial and the Holocene.

Part Seven

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