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ALMOPIA SPELEOPARK (PELLA, MACEDONIA, GREECE): MORPHOLOGY-SPELEOGENESIS OF THE CAVES

Georgios LAZARIDIS[1]

Abstract: In the present study the morphology of Almopia Speleopark caves is described in order to discuss preliminarily their speleogenesis in relation to the hydrogeological zones. At least two phreatic phases seem to exist with respect to the observed speleogens. The presence of solution ceilings, cupolas, ridges, pendants, abruptly ending passages and the horizontal morphology of the caves suggest that speleogenesis was due to slowly convecting water bodies. As an exception, some caves contain scallops or other phreatic features that developed by forced flow along a pressure head. The former pattern of speleogenesis was related to the presence of thermal ascending water in the area, while the latter is related to the downcutting of the Thermopotamos stream.

Key words: Almopia Speleopark, Aridea, Macedonia, Greece, speleogenesis, cave morphology.

INTRODUCTION

The Almopia Speleopark is located in the inner-mountain Almopia basin, in Northern Greece (Macedonia), 120 km northwest of Thessaloniki and 2 km from the Kato Loutraki village, on the slopes of the Voras Mt. (2524 m high), one of the highest mountains of Greece. A number of caves, opened by the downcutting of the Thermopotamos River, are situated in the V-shaped Nicolaou valley of the Speleopark (fig. 1).

Speleological research in the Loutra Arideas area started in 1990, when the late speleologist K. Ataktidis reported finding of cave bear bones, that where dug up illegally by treasure hunters in Bear Cave. Due to the great paleontological interest the first excavation cycle was launched in 1992 by the Geology School of Aristotle University, Thessaloniki (AUTH) (E. Tsoukala), under the supervision of the Ephorate of Speleology and Paleoanthropology (ESP) of the Ministry of Culture, and in cooperation with archaeologist Prof. G. Chourmouziadis, and of the late Prof. Eitan Tchernov (University of Jerusalem). The excavations continued in 1993-1994 in cooperation with ESP (Dr. E. Kambouroglou). In 1996 and since 1999 the excavations have been carried out by the AUTH, the ESP, and in co-operation with the Vienna University (Profs G. Rabeder, S. Verginis and their team). The palaeontological specimens from Bear Cave recovered in these excavations can be attributed to *Ursus ingressus* RABEDER, HOFREITER, NAGEL & WITHALM, 2004 and to the associated fauna including spotted cave hyena, lion, leopard, wolf, fox, badger, mustelids, artiodactyles and micromammals, of Late Pleistocene age (TSOUKALA, 1994; TSOUKALA *et al.*, 1998; TSOUKALA *et al.*, 2001; TSOUKALA & RABEDER, 2005; CHATZOPOULOU, 2001; CHATZOPOULOU *et al.*, 2001; PAPPA *et al.*, 2005). There are also caves in both sides of the valley with archeological remains, mainly with Neolithic and Byzantine pottery.

In 1990, the late K. Ataktidis also made the first documentation of the caves and organized the first exploration of the Speleopark. During this expedition preliminary geological (Dr. Tsamandouridis, unpublished data) and paleontological (Tsoukala, unpublished data) results were reported. The late speleologist J. Ioannou, member of the first exploration, noted that the Loutra Arideas area is of high scientific and speleological interest; therefore he suggested that it could be the first speleological park ("Speleopark") in Greece. The next researchers supported his idea and it is well accepted now. In 2005, the speleological research continued. New discoveries and photographic documentation, surveys and observations enlarged the scientific knowledge of the area (LAZARIDIS, 2005). Today the speleological research is progressing well with the aim of completing the previous work as much as possible and to contribute to the palaeontological research in the area.

[1] School of Geology, Aristotle University, 54 124 Thessaloniki, georgelazarides@yahoo.com

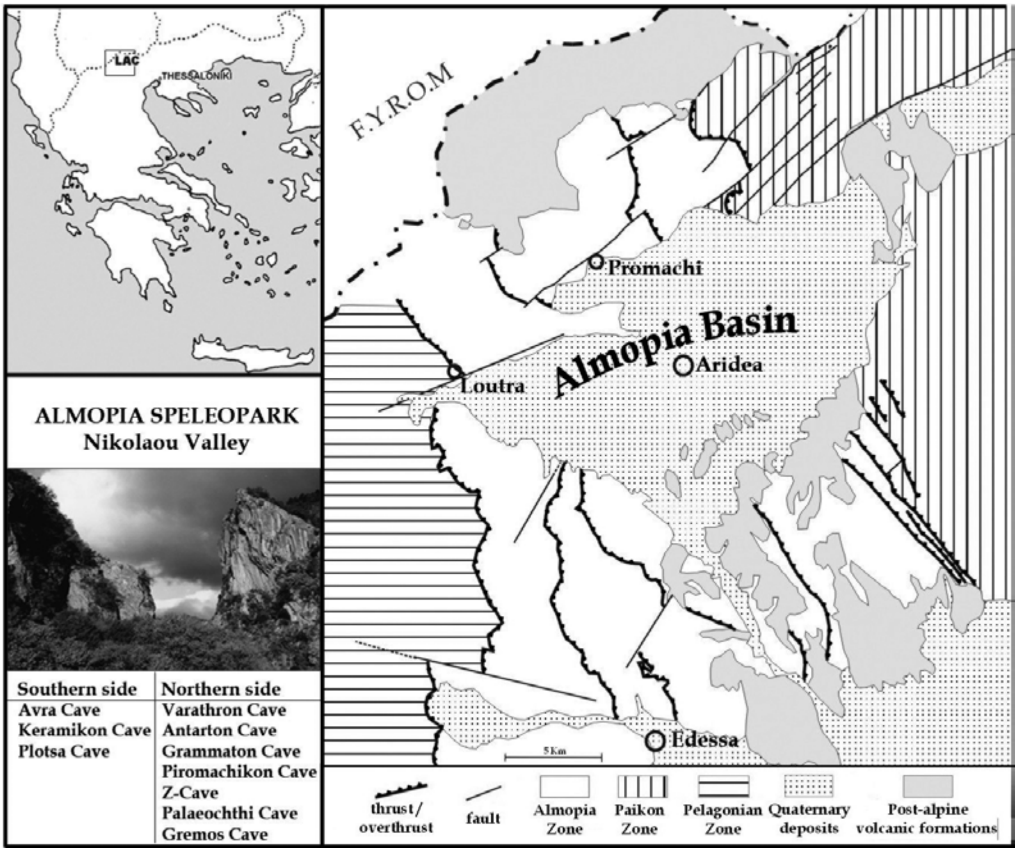


Figure 1. Left: Map of Greece with the Almopia Speleopark (LAC: Loutra Arideas Caves) and a view of the Nicolaou valley with the list of the caves on both sides. Right: geological sketch-map of Almopia (based on Mercier, 1968).

GEOLOGICAL SETTING

The general area is situated near the geological boundary between the Almopia Zone to the east and Pelagonian Zone to the west (Mercier, 1968; Mountrakis, 1976). It consists of Mesozoic metamorphic and sedimentary rocks, and more precisely the Nicolaou valley consists of Maastrichtian limestones of the Almopia zone. A NW-SE striking, ore-bearing fault zone and the ENE-WSW striking Loutraki Fault dominate the general area tectonically. The latter has a length of more than 10 km bounding the Aridea basin against the Voras Mt. (2524 m) (Mountrakis, 1976; Eleftheriadis, 1977; Chatzidimitriadis, 1974).

In the general area of the Almopia Speleopark on the Pelagonian massif, three uplifted denudation surfaces and one or two piedmont surfaces have been identified by Psilovikos & Kanetsi (1989). The former three surfaces were established in periods of a warm and humid climate prior or during the Neogene. The latter surfaces were formed in periods of warm and semiarid climate during the Villafranchian - Villanyian, or in glacial/interglacial climates during the Pleistocene. The entire northern part of the Pelagonian massif (Macedonia) has been uplifted at higher rates than its southern section. Above the caves there is a notable erosional surface, approximately at 700 m a.s.l. where the old Ano Loutraki village is located. According to the description by Psilovikos & Kanetsi (1989) of the erosional surfaces of the Pelagonian massif, this surface is probably an Early Pleistocene paleopediment.

Neotectonic activity of the Loutraki fault uplifted the Voras Mt. and the area of the Speleopark. As a result intense down-cutting of the Thermopotamos River occurred that formed the V-shaped Nikolaou valley and lifted the caves from the phreatic to the vadose zone successively.

Furthermore, a group of thermal springs exists due to the neotectonic activity and to the volcanism in the broader region (Mountrakis, 1976; Vougioukalakis, 2002; Patras, 1990). Mountrakis (1976) states that the origin of the travertine in the Loutra area, as well as at other localities nearby, is also due to these thermal springs either being active today or in the past. Patras (1990) calculated that the water rises from a depth of 600 m and its temperature at this depth ranges from 150 to 180°C. Today springs are located from 360 to 390 m of altitude. Their temperature varies between 30 and 37.5°C. The same researcher states also that the Na^+, K^+ and SO_4^{2-} concentrations decreased in correlation with a lowering of the spring water temperature, because possibly of their precipitation during their mixing with cooler water.

MORPHOLOGY AND SPELEOGENS OF THE CAVES

The Almopia Speleopark consists of six caves and four rock-shelters of similar morphology, the altitudes of which ranges between 460 m to 560 m a.s.l. (pl. 1). Additionally some small "isolated" chambers and many karst conduits occur as well. Presently they are "dry caves" in the vadose zone.

The caves described here as rock-shelters (pl. 2.1) are remnants of karst caves intersected by surface erosion. For this reason they developed as small chambers with many small conduits. Usually they contain a lot of breakdown boulders.

The larger caves have a maze-like pattern, structurally guided by joints. Maze caves can develop only if the growth rate is similar along many alternate flow paths. The maze pattern in general presents a variety of types. Six different types of linestone caves are differentiated: two branching types (curvilinear, rectilinear) and four maze types (anastomotic, network, spongework, ramiform) (Palmer, 2000; 2005). The plan morphology of the Almopia Speleopark caves reminds of ramiform mazes. This kind of plan pattern is due to local boosts in the water aggressiveness. Generally angular connections dominate where joints and faults are the principal structural guides of the conduits in contrast to curvilinear connections that dominate where the conduits develop primarily along bedding planes (Ford, 2000). The Almopia Speleopark caves present angular connections that indicate the significance of fracture control. However, they also show a ramiform pattern that illustrates the importance of the bedding partings in contrast to network types that show fracture control. The former refers mainly to the major passages of the caves. The latter is noticed in some large halls, in some small passages and in places where boneyard morphology (pl. 2.10) is observed. Generally the caves that developed on the northern slope represent large halls, except for the linear passages along joints, in contrast to the caves of the southern slope where large halls are absent. Large halls, connected by small "windows" are predominant in Bear Cave, Antarton Cave, Gremos Cave and Varathron Cave.

The predominant strike of the cave passages is NW-SE and NE-SW. The majority of the caves have more than one entrance developed by intersections of passages by surface erosion.

Cave genesis in general can occur either below the ground water table (i.e. in the phreatic zone) or in the unsaturated zone above the water table (i.e. in the vadose, where cavities are mostly filled with air). Both zones leave characteristic micro- and mesoscale morphological elements known as speleogens, that can be used to reconstruct the speleogenetic history of a cave or a cave area. In the case of the Almopia Speleopark, morphological indicators suggest that the bulk of the cavities developed under phreatic conditions and that vadose processes later altered the initial morphology.

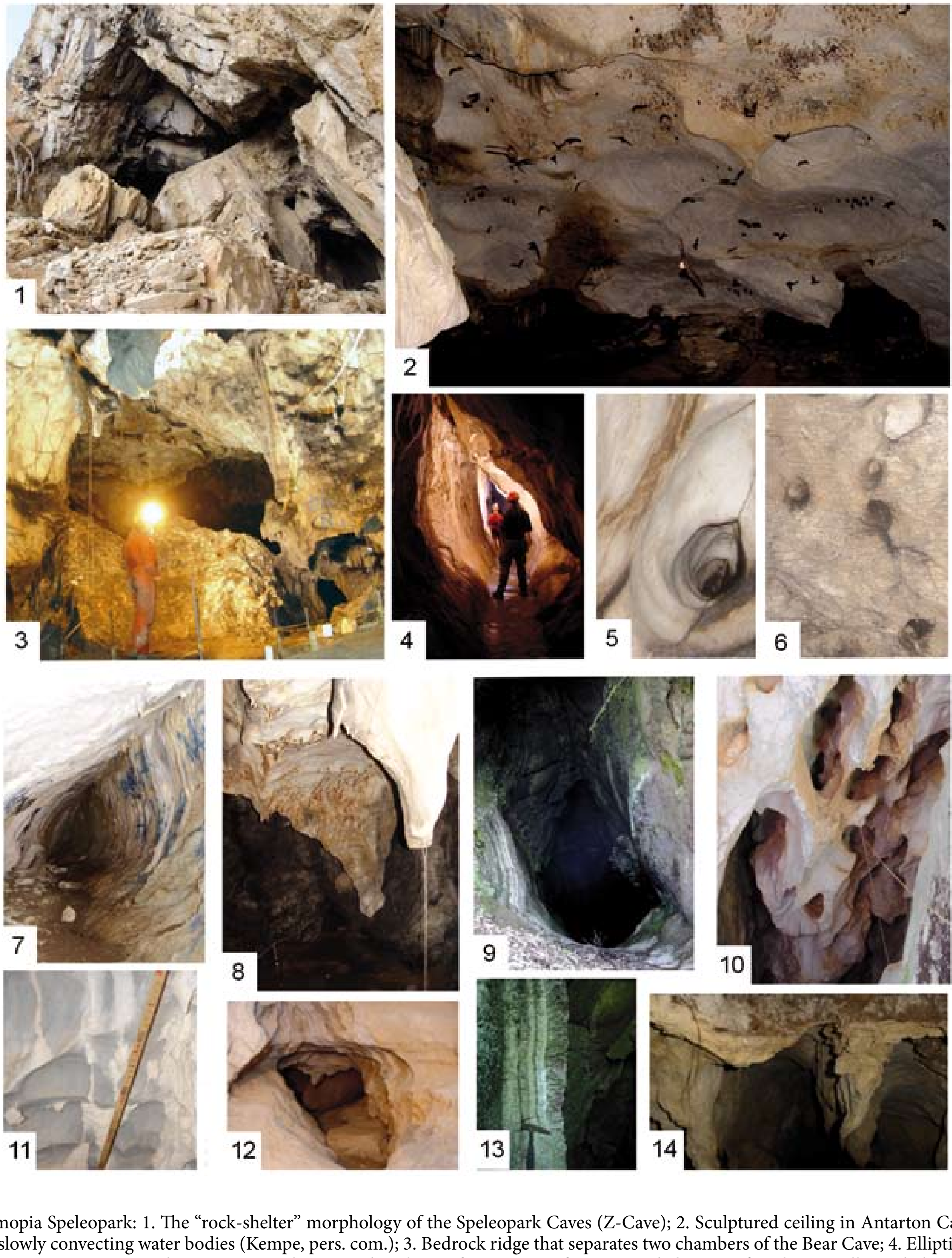
The phreatic origin of the caves (Kempe, pers. com.) is indicated by the following morphological elements (according to Kempe, 1970; Kempe *et al.*, 1975; Bögli, 1978; White & Deike, 1989; Lauritzen & Lundberg, 2000; White & White, 2000; Lundberg, 2005; Kempe *et al.*, 2006):

1. Solution ceilings (Laugdecken) either flat or concave formed by slowly convecting water bodies (pl. 2.2).
2. Walls sculptured by cupolas that grade downward into sloping side walls (facets) (pl. 2.2).
3. Bedrock ridges that separate the halls or interrupt the passages (pl. 2.3).
4. The presence of elliptical (lenticular) and symmetrical cave passages (in cross sections) that are controlled by high angle joints or by the intersection between two planes respectively (pl. 2.4; 2.7 and 2.9).
5. Many solution pockets that are present at the roof of some caves of the Speleopark; these are created by mixing corrosion along joints where water emerges into a passage filled with water of a different chemistry (pl. 2.5 and 2.6).
6. The presence of ceiling half-tubes, i.e. a channel in the ceiling of descending elliptical passages with a semi-circular cross-section.
7. Scallops on ceilings and walls that develop by solution in a turbulent flow of groundwater filling the passage (pl. 2.11). They are absent in Bear Cave, Antarton Cave and Gremos Cave, while there is one passage with scallops in Varathron Cave. On the other hand, the caves of the southern slope contain abundant scallops that indicate a S-N flow direction from the caves outward to the river. On the contrary the scallops of Varathon Cave and Pyromachikon Cave show the same flow direction but from the river inward to the mountain.
8. Pendants that are remnants from removal of intervening rock through eddy dissolution (pl. 2.8 and 2.14).

Plate 1

Almopia Speleopark; surveys of the caves. Ground plans: 1a. Varathron Cave; 2. Antarton Cave; 3. Pyromachikon Cave; 4. Grammaton Cave; 5. Gremos Cave; 6. Z-Cave; 7. Bear Cave (based on Kampouroglou & Chatzitheodorou, 1999); 8. Avra Cave; 9. Plotsa Cave; 10. Keramikon Cave; 1b. Cross section of the main chamber of Varathron Cave.

Plate 2



Almopia Speleopark: 1. The “rock-shelter” morphology of the Speleopark Caves (Z-Cave); 2. Sculptured ceiling in Antarton Cave by slowly convecting water bodies (Kempe, pers. com.); 3. Bedrock ridge that separates two chambers of the Bear Cave; 4. Elliptical phreatic passage in Varathron Cave; 5. Solution pocket along a fracture; 6. A fracture guided group of pockets; 7. Elliptical phreatic passages that end abruptly (Avra Cave); 8. Pendants of more than 1.5 m length (Bear Cave); 9. Phreatic passage at the higher entrance (520 a.s.l.) of Varathron Cave; 10. Boneyard morphology (Bear Cave); 11. Scallops; 12. Keyhole passage (Keramikon Cave); 13. Detail of the phreatic coating that cover the passage of the higher entrance of Varathron Cave; 14. Pendants of approximately 0.5 m of length in Avra Cave.

Table 1
Almopia Speleopark. Morphology and location of the caves. Summary table.

	Bear Cave	Antarton Cave	Varathron Cave	Avra Cave	Keramikon Cave	Piromachikon Cave	Grammaton Cave	Gremos Cave	Palaeocthi Cave	Cave Z	Plotsa Cave
Southern (S) or Northern (N) slope	N	N	N	S	S	N	N	N	N	N	S
Altitude (m)	540	540	500-520	460	494	536	541	560	540	537	570
Entrances	1	2	3	2	4	1	2	3	1	1	1
Solution ceilings	+	+	+	-	-	-	-	-	-	-	-
Facets	+	+	+	-	-	-	-	-	-	-	-
Bedrock ridges	+	+	+	-	-	-	-	+	-	-	-
Elliptical & symmetrical passages	+	-	+	+	+	+	+	+	+	-	-
Ceiling half-tubes	-	-	-	-	+	-	-	-	-	-	-
Scallops	-	-	+	+	+	+	-	-	-	-	-
Pendants	+	+	+	+	-	-	-	-	-	-	-
Keyhole passages	-	-	-	-	+	-	-	-	-	-	-
Phreatic speleothems	-	-	+	-	-	-	-	-	-	-	-
Breakdown	+	+	+	-	+	-	-	+	-	+	-
False-floors	+	+	-	-	+	-	-	+	-	-	-

According to the presence or absence of these morphological elements, the initial development of the caves occurred in the phreatic zone. Once the caves drained because of the regional uplift, changes in the vadose zone followed:

1. The deposition of the speleothems as a process that takes place in airfilled caves. The inclined passage of the higher entrance of Varathron Cave is the only place at the Speleopark caves, where phreatic speleothem coating on the passage walls has been observed (pl. 2.9 and 2.13).
2. The filling of the caves with fluvial sediments. These sediments are well studied in Bear Cave. The dominant presence of Ca-Mg rich metamorphic minerals (clinozoisite, tremolite, talc, chlorite/vermiculite) in the fine-grained sediments of the cave floor is indicative of the composition of the weathering products of the parent rocks of the broader drainage basin, which have been weathered. The absence of smectite and kaolinite indicates that the sediments have not been transported a long distance (Tsirambides, 1998). The allochthonous origin of the cave sediments is recognised in general by the presence of non-carbonate pebbles.
3. Keyhole passages occur only in Keramikon Cave that represent the shift from the phreatic to the vadose conditions. This type of passages results in the combination of a symmetrical phreatic tube and a vadose canyon (pl. 2.12).
4. Post-phreatic breakdown modified walls and ceilings that lose their smooth surfaces, replacing it with a more angular morphology, and obstructing the floor by large blocks, diminishing the cross section of the cave.

DISCUSSION - CONCLUSION

At least two phreatic phases must have occurred because of the observed morphology and the presence or absence of the corresponding speleogens (tab. 1). The presence of solution ceilings, cupolas, bedrock ridges, pendants, abruptly ending passages and the overall horizontal development of the caves suggest the dominant phase of speleogenesis was due to slowly convecting water bodies in the phreatic zone. This morphology is characteristic for Bear Cave, Antarton Cave, Gremos Cave and Varathron Cave. Thermally ascending water most probably was responsible for the formation of the caves at this location. Additionally, all caves occur in a relatively small area, where even today thermal springs occur. As an exception some of them contain abundant scallops or some other phreatic features that are developed by forced flow along a pressure head. Only these caves or passages might correlate with a base level of the incising valley.

For the reason these two conditions above never happen simultaneously, a degeneration of the caves is possible. The development by convection is a deep-seated method of speleogenesis that may have taken place before the neotectonic activity in the area; therefore it probably took place before the formation of the erosional surfaces. While downcutting, took place near-surface groundwater or surface water could have entered the caves, thereby by passing the surface stream under pressure and re-sculpturing some of the walls under turbulent flow.

The predominant vadose modifications are the filling of the caves by sediments and the breakdown. Furthermore, the solutional or erosional vadose features present a minor development.

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