

Preliminary report on granite caves in Greece

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Abstract

In the present paper two different sites with granite caves are described and discussed with respect to their geological settings, cave morphology and petrological data. Both sites are located in Macedonia (northern Greece) where granites of different ages and petrography outcrop.

The first one is a fracture-guided cave named Kanaras Cave that strikes NW-SE. Initial development of the cave took place due to tectonics of the Tertiary NE-SW extension in the area. The final formation took place during the E-W Quaternary extension. Thus, it is considered to be a crevasse cave, which is tectonic in origin. The second site, Loutra Eleftheron, presents caves that can be attributed to side-wall tafoni weathering forms. This is also consistent with the presence of gypsum and hexahydrate, the fracture-guided pattern and the coastal environment of the cave area. It is assumed that salt weathering leads to rock disintegration.

Key words: granite cave, tafoni, crevasse, gypsum, hexahydrate, Vrontou Mt., Loutra Eleftheron, Macedonia, Greece

INTRODUCTION

A great number of karst caves (about 10.000) have been discovered and explored in Greece. Many of them have developed along contacts of carbonate and non-carbonate rocks (contact caves after BÖGLI, 1978). They usually form along contacts of schist and marble such as the Pholia Pothole that is located in eastern Macedonia and developed following the almost vertical dipping of this contact for 150 m. The Melissotripa Cave (Elassona, Central Greece) is an example that is mainly horizontally developed and hypogenic in origin according to VAXEVANOPOULOS (2006). One more or less differently developed cave is the Drakotrypa Cave of Vrasna village that opened in a coarse-grained marble (an intercalated bed in gneiss) in which intrusions of pegmatites are observed. Cave formation is limited at these insoluble veins and the shape of the cave interior depends on their geometry. Fewer examples of caves exclusively opened in non-carbonate rocks are known. Most of them are small littoral ones. Many large and small coastal caves are known in Greece, mainly

developed in carbonate rocks. In general, these caves could have opened in a range of different lithologies (MYLROIE, 2005). Samothraki Island of northern Aegean Sea has littoral caves in felsic rocks and in the broader area of Loutra Eleftheron (East Macedonia, close to the area of the present study) a small sea cave has been formed in conglomerates. A cave is reported by KIRDIS (2000) that has opened in gneiss at Mt. Chortiatis, close to Thessaloniki area. Although there are some examples of caves in non-carbonate lithologies, granite cave speleogenesis in Greece remains little known.

In the present paper two different sites with granite caves are described and discussed with respect to their geological settings, cave morphology and petrological data. Both sites are located in Macedonia (northern Greece) where granites of different ages and petrography outcrop (fig. 1). These plutons are emplaced into the Rila-Rhodope massif that is separated into distinct geological units by major thrust zones (Sidironeron Unit and Pangeon Unit) according to PAPANIKOLAOU & PANAGOPOULOS (1981).



Figure 1. Map of Greece with the location of the granite caves depicted in the Macedonia area.

The first site is located near Fea Petra village, on Mt. Vrontou, close to the Greek-Bulgarian borders, north of Serres (Central Macedonia). The Vrontou Granitoids is an

Oligocene I-type pluton and the rocks are classified as quartz monzonite, granite, granodiorite, monzonite, quartz syenite, diorite and gabbro (SOLDATOS *et al.*, 1998;

KOLOCOTRONI & DIXON, 1991; THEODORIKAS, 1982). In particular, the southern and western parts of the pluton (where the cave is developed) are slightly to intensively deformed by a flat lying shear-system which has led to mylonitic foliation and stretching lineation (SOLDATOS *et al.*, 1998).

The second site is located close to the Loutra Eleftheron (eastern Macedonia) area, where the Kavala pluton outcrops. This pluton consists of metaluminous Alpine I-type granitic rocks; a medium- to coarse-grained porphyritic gneissic granodiorite predominates over a coarse-grained granodiorite (NEIVA *et al.*, 1996). A group of small caves, conduits and holes have developed on the escarpment of an NE-SW striking normal fault and on very steep slopes of small V-shaped valleys that incise the granite. This fault follows the major strike of the bedrock faults of the broader area (TRANOS, 1998) and it is the boundary between the granite and marine sediments of the Pleistocene age that are composed of sandstones, clays and conglomerates. These sediments lie transgressive-

ly on Pliocene marine and brackish sediments, such as sandstone, marls and limestone (KROMBERG & SCHENCK, 1974).

The petrography of the Kavala pluton has been discussed by KOLOCOTRONI & DIXON, (1991) and of the Vrontou Pluton by SOLDATOS *et al.*, (1998). In the present study, petrography is restricted to a brief summary and the petrographic study is localized to the area of the caves, since only the part of both plutons where the caves occur is of interest. The aim of the present paper is to study the geology of the Kanaras Cave and the Loutra Eleftheron Caves.

THE KANARAS CAVE-VRONTOU GRANITOID

The Kanaras Cave is located on the hill of the same name on Mt. Vrontou. The cave can be described as a single narrow NW-SE striking passage of approximately 15 m of length, 12 m of depth and 2.5 to 0.3 m in width (fig. 2). The cave is of vertical development (fig. 3). Further exploration of the cave is almost impossible due to sediments covering the floor.

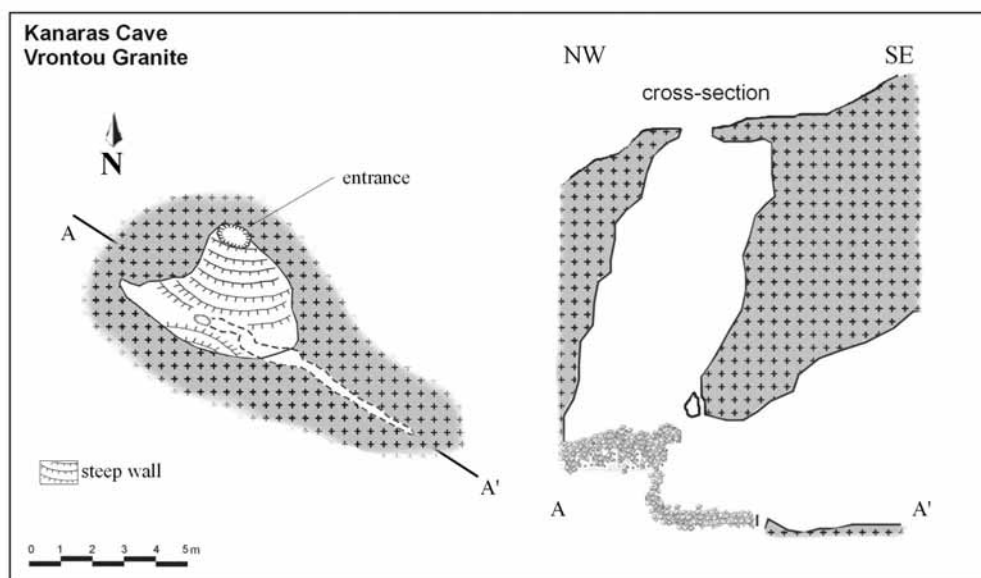


Figure 2. The Kanaras Cave: (left) ground plan, (right) NW-SE cross section.

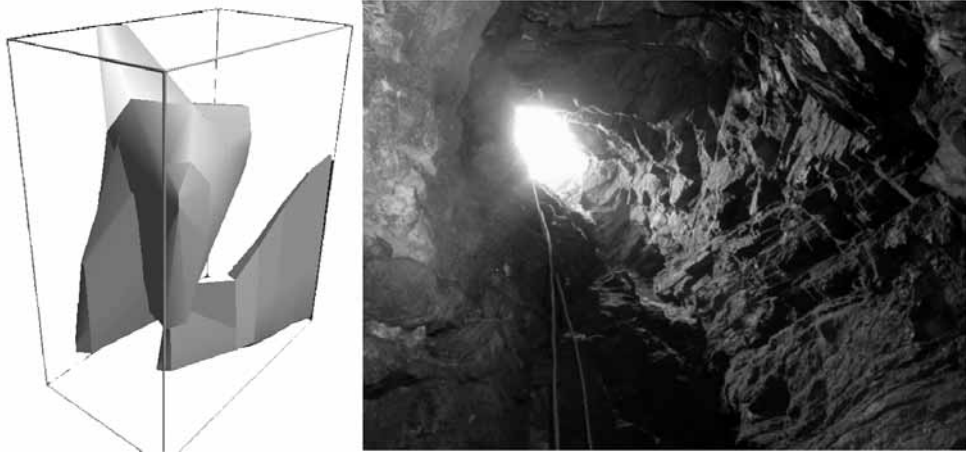


Figure 3. The Kanaras Cave: (left) a SW view of a 3D model of the cave; (right) the interior of the cave at the entrance area that is breakdown modified.

The cave has developed along the striking of the main group of joints in the nearby area (fig. 4). It is a fracture-guided cave with respect to a comparison between the orientation of the cave and the rock fractures, either

joints or foliation. Additionally, the dip-angle of foliation is more or less a low one facilitating the collapse of boulders from the cave roof that is only some meters thick. The entrance probably opens by upward stoping.

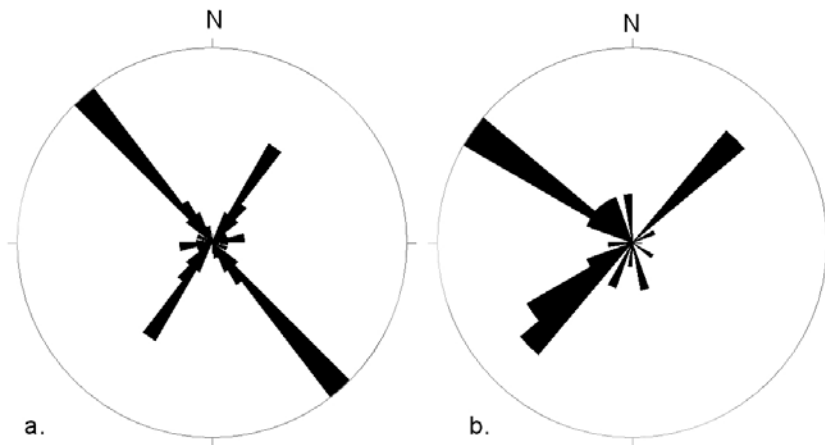


Figure 4. The Kanaras Cave: rose-diagram of the rock fractures: a. of striking; b. of dip-angle.

Petrographic characteristics of the Kanaras Cave, Mt. Vrontou

The rock of the Vrontou cave is intensively deformed, fractured, sheared and appears to be quite weathered.

Even though it was difficult to prepare the thin sections for the petrographic study, they provide useful information concerning the degree of deformation of the rock.

The rock is a medium- to coarse-grained granodiorite and displays a gneissic texture. The most abundant mineral remnants are hornblende and plagioclase while biotite, k-feldspars and quartz are missing in some samples or are broken-down. In some thin sections, feldspars display an unusually anomalous extinction (fig. 5a) which is interpreted as the result of intensive stress and deforma-

tion. The essential minerals are hornblende, biotite, plagioclase, quartz and microcline and the accessory minerals are opaque titanite, apatite and zircon. The secondary minerals are sericite, epidote, chlorite, and undefined iron oxides. Microcline is perthitic and anhedral. Plagioclase is subhedral to euhedral, with myrmekite occurrence along its borders and sometimes altered to sericite or epidote. Quartz is anhedral, deformed and rounded (fig. 5b). Biotite is subhedral and hornblende is subhedral to euhedral with cracks appearing and there being absence of some parts of the crystals (fig. 5c & 5d). To finish the macroscopic observation and petrographic study indicate that the granodiorite had been subjected to an intensive mechanical deformation as a result of stress similar to the one described by SOLDATOS *et al.* (1998).

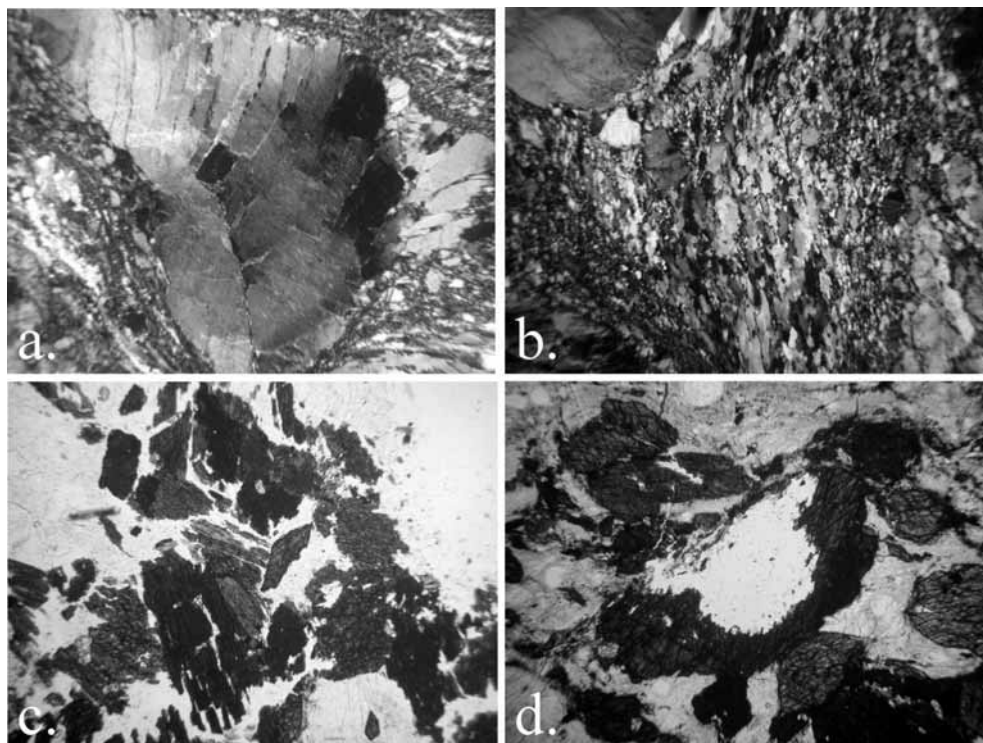


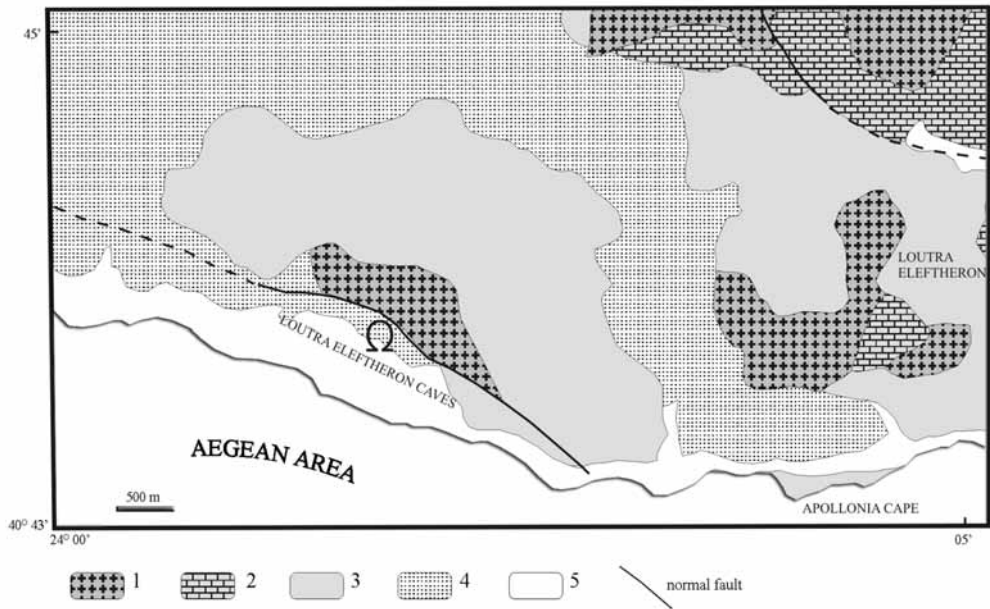
Figure 5. Thin sections of the Kanaras Cave: a) Feldspar displaying anomalous extinction; b) Characteristic form of the quartz component of the rock; c,d) Broken-down hornblende crystals.

The Loutra Eleftheron Caves, Kavala Pluton.

A group of small caves, conduits and hollows have developed on the escarpment of an NE-SW striking normal fault and on the very steep slopes of small V-shaped valleys that incise the granite (fig. 6 & 7). This fault follows the major strike of the bedrock faults of the broader area (TRANOS, 1998) and it is the boundary between the granite and marine sediments of the Pleistocene age that is composed of sandstones, clays and conglomerates. These sediments lie transgressively on Pliocene marine and brackish sediments, such as sandstone, marls and

limestone (KROMBERG & SCHENCK, 1974).

Their size does not exceed several meters. A common characteristic of the morphology of the caves in this area is that their entrances are always wider than they are at their deepest place. They seem to be fracture-guided (fig. 7) with elliptical to circular shape of cross section. Additionally, they are not distributed in the area in a restricted way, either hypsometrically or horizontally. The floor of the caves does not typically show any marked weathering. This is due to protection by weathered material deposited from above.



1. Kavala Pluton; 2. marbles; 3. marine and brackish sediments of the Pliocene age; 4. marine sediments of the Pleistocene age; 5. terrestrial sediments of the Olocene age (based on KROMBERG & SCHENCK, 1974).

Figure 6. Geological sketch of the Loutra Eleftheron area with the location of the caves depicted.



Figure 7. Characteristic view of the Loutra Eleftheron Caves.



Figure 8. The Loutra Eleftheron Caves: small conduits in granite along fractures.

Petrographic characteristics of the Loutra Eleftheron Caves.

Macroscopically, the samples show a low degree of alteration with no evidence of intense weathering. Several fractures occur in the area of the caves, filled with a white weathering material originating from the granite. A number of fractures are filled with hexahydrate or gypsum. The latter, covers partially cave walls and it is contained in weathering material from the granite. The mineral composition of the material from fractures was recognized with powder XRPD analysis. Powder XRPD analyses were obtained on a PHILIPS PW1820/00 X-ray diffractometer of the department of Mineralogy-Petrology-Economic Geology, School of Geology, A.U.TH, carrying a PW1710 micro-processor. The operating conditions for all samples were 35 kV and 25 mA using Ni-filtered CuK α radiation. The 2-theta scanning range was between 3° and 63° and the scanning speed was 1.2°/min. Refinements were done with the PC-APD software and the identification of the samples was made with the JCPDS-ICDD 2003 database. Silicon was used as external data.

The microscopic study of thin sections of the rock shows that the sample is a coarse-grained, porphyry monzogranite with perthitic phenocrysts often displaying a poikilitic texture enclosing small crystals of plagioclase and biotite, and sometimes myrmekite occurs along their borders. The essential minerals are quartz, microcline plagioclase and biotite and the accessory minerals are opaque, zircon, titanite, apatite and allanite. The secondary minerals sericite, saussurite, chlorite, undefined iron oxides presence is limited. Microcline phenocrysts are euhedral and shortly perthitic. Sericite and clay alteration occurs as patches form in microcline. Plagioclase is euhedral to subhedral altered to sericite and saussurite. Biotite is also euhedral and rarely subhedral (fig. 10a & 10b) containing sometimes chlorite. Euhedral zircon and apatite occur as inclusions in feldspars. In conclusion, the petrographic study indicates no evidence of alteration of the wall rock of the Loutra Eleftheron Caves but the numerous fractures of the granite reflects that the granite was subjected to a direct stress event.

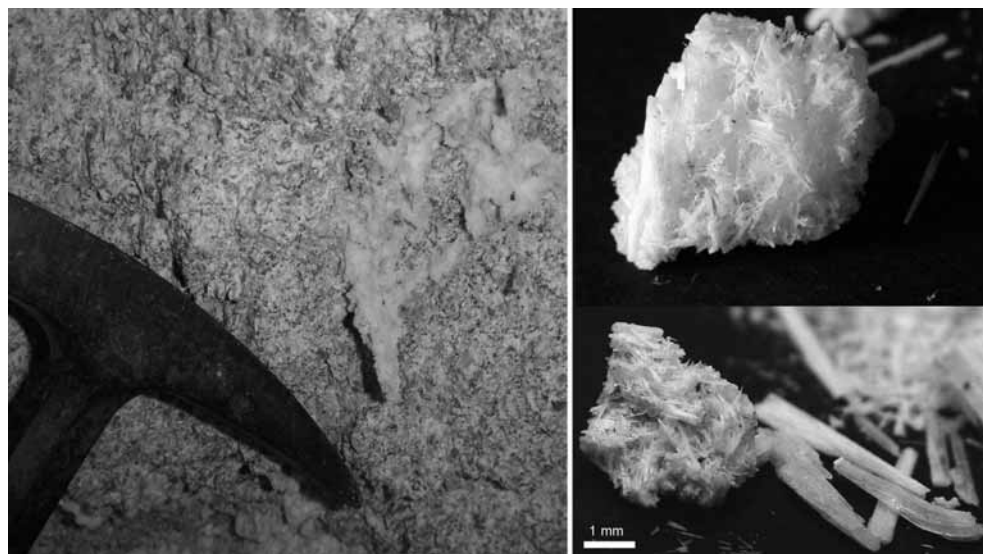


Figure 9. The Loutra Eleftheron Caves: close-up a) of the gypsum that covers the cave walls; b) of the hexahydrate that fills fractures of the granite.

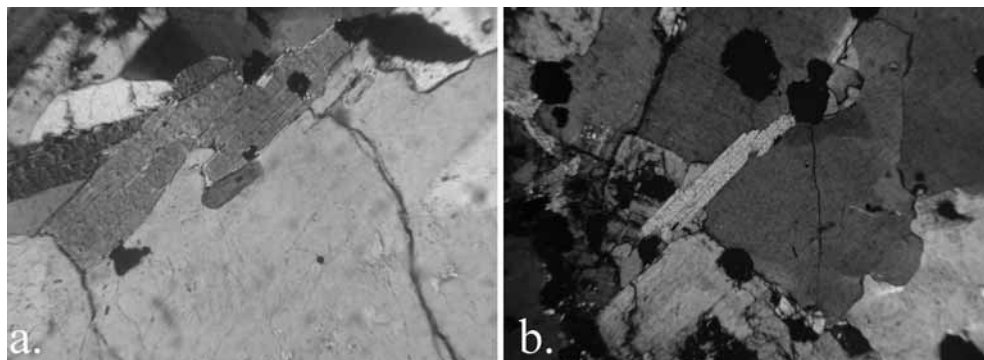


Figure 10. Thin sections of the Loutra Eleftheron Caves rocks: a, b) Orthoclase phenocrysts and subhedral biotite (N+).

DISCUSSION

Speleogenesis in non-carbonate lithologies, except gypsum and salt, involves an initial chemical weathering of the rock to create zones of friable rocks, which then are removed by piping. Subsequently, the flowing water results in further conduit enlargement due to mechanical erosion. This process concerns the quartzite caves and the essential conditions are as follows: a) a long period of phreatic level stability, followed by uplift; b) a large difference between local and regional base levels; c) rock layers specifically susceptible to piping, or impermeable layers (CORRÊA NETO, 2000). WILLEMS *et al.*, (2002) reports an example of karst in granitic rocks in the sense that dissolution plays an essential role in the genesis of the cave. They also summarize the following processes of granite cave development: regolith between residual boulders; mechanical weathering along altered fracture zones or along easily dissolved siderite veins under warm climates; coalescence of tafoni; simple widening of fractures under cold climates. The granite caves of Pontevedra (Galicia, Spain) are classed in several different types such as granite caves formed by flowing water (caves evolved by gorge erosion; boulder fragment

caves; coast caves) and caves not formed directly by water (weathering caves; caves related to the periglacial Würm effects) and other granite caves including boulder caves and fissure caves (VAQUEIRO, 1999). Crevasse and cryogenic granite caves have been reported from Slovakia (BELLA, 1998). Granite landforms, except for the major forms, include also minor forms (many of these are cavernous forms), such as gnammas, tafoni, gutters, grooves, flared slopes, rock levees and rock doughnuts (CAMPBELL, 1997; TWIDALE, 1986). Only the discernment of exogenous and endogenous, either of primary or secondary type of granite landforms, allows the complete understanding of the geomorphological history of the area in which they occur (VIDAL ROMANI & YEPES TEMIÑO, 2004).

The Kanaras cave is a strongly fracture-guided granite (granodiorite) cave. The cave rocks are intensively deformed, fractured, sheared and sufficiently weathered. A stopping process forms the entrance area and inside the cave no speleothems or characteristic erosional forms by water have been noticed. Furthermore, it could be attributed to a crevasse cave according to its morphology. A NE-SW extension during Tertiary has been noticed at the west Rodhope massif of the

Hellenic hinterland (KILIAS & MOUNTRAKIS, 1990, KILIAS & MOUNTRAKIS, 1998, KILIAS *et al.*, 1999). This extension could be the cause of the NW-SE striking Kanaras Cave. Furthermore, the opening probably took place during an E-W extension of Quaternary. Thus, a tectonic origin fits better the Kanaras Cave.

In the Loutra Eleftheron area the granite suffered a short stress event but there is no evidence of chemical alteration so far. The caves are fracture-guided and they rapidly decrease in size inside. The latter is a typical morphology of the piping process (SELF & MULLAN, 2005). An essential difference between local and regional base levels can be explained by the presence of the fault that uplifts the granite massif. This uplifting could result in the drainage of the granite through its fractures and the removal of loose material. Additionally, higher fractured rocks are more susceptible to weathering than those in which the fractures are absent, whether widely spaced or tightly closed (CAMPBELL, 1997). Marine and brackish sediments of the Pliocene age lie transgressively to the granite showing that at least one phreatic level was preceded. Water is the key of granite weathering (TWIDALE, 1986). So, the above-mentioned essential conditions for speleogenesis in non-carbonate rocks more or less occurred during the geomorphological history of the area except the alteration of the rock. Further, many fractures are filled with weathering material.

The morphology of the Loutra Eleftheron caves is similar to side-wall tafoni. This means hollows and caverns developed on the steep bounding slopes of residuals (TWIDALE & BOURNE, 1975). Generally, tafoni occur in arid and semi arid lands in cold and arid Antarctica as well as in coastal environments (CAMPBELL, 1997; HUININK *et al.*, 2004). They have been commonly attributed to subaerial processes, but subsurface initiation of tafoni is also possible (TWIDALE & BOURNE, 1975). Salts are widely recognized

as an important cause of rock weathering formations. Although some explanations demand chemical modifications of the rock, cavernous structures have been found in rocks that have not shown any sign of mineral alteration (HUININK *et al.*, 2004). Tafoni have been considered to result from salt weathering due to crystallization pressure or stresses induced by crystal hydration or differential thermal expansion of salts. Possible processes of salt weathering are case hardening, core softening, increased air circulations that cause higher drying rates or a model of growing controlled by the drying behaviour of the rock (further discussion in HUININK *et al.*, 2004). MATSUKURA & TANAKA (2000) have noticed the effect of rock hardness and moisture content on salt weathering. In many tafoni the common salts are gypsum and halite (Antarctica: halite, gypsum and mirabilite (ANDRÉ & HALL, 2005); Korea (Mount Doeg-Sung): gypsum (MATSUKURA & TANAKA, 2000); Finland: gypsum (KEJONEN *et al.*, 1988); USA, (Utah, Crystal Peak): calcite, aragonite, halite, gypsum, polyhalite, (from tafoni developed in rhyolite ash-flow tuff, MCBRIDE & PICARD, 2000)). Fractures and ceilings of the Loutra Eleftheron caves are filled or covered by hexahydrate and gypsum deposits that can cause salt weathering and granite disintegration.

CONCLUSIONS

The Kanaras Cave and the Loutra Eleftheron Caves are described here for first time in Greece. Furthermore, they are the only known granite caves in Greece.

All macroscopic observation and petrographic study of the Kanaras Cave indicate that the granodiorite was subject to an intensive mechanical deformation as a result of stress similar to the one described by SOLDATOS *et al.* (1998).

The petrographic study of the Loutra Eleftheron Caves indicates no evidence of

alteration of the rock but the numerous fractures of the granite reflects that the granite was subjected to a direct stress event.

The Kanaras Cave is a fracture-guided cave that strikes NW-SE. Initially, development of the cave took place due to tectonics of the Tertiary NE-SW extension in the area. The final formation took place during the E-W Quaternary extension. Thus, it is considered to be a crevasse cave which is tectonic in origin.

Based on the morphology and the petrography the Loutra Eleftheron Caves can be attributed to side-wall tafoni weathering forms. This is also consistent with the presence of gypsum and hexahydrite, the fracture-guided pattern and the coastal environment of the cave area. It is assumed that salt weathering leads to rock disintegration. Furthermore, many fractures are filled with weathering material and no gypsum, or filled with hexahydrite. This may be a result of phreatic level due to sea transgression during the Pliocene

and the Pleistocene. Possibly the fault facilitates the draining of the granite through its fractures and the removal of the loose material that comes from salt weathering.

The occurrence of hexahydrite in caves according to HILL & FORTI (1997) is rarely reported and this is the first time that hexahydrite has been referred to in a Greek cave.

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