2012

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Speleogenesis
and Evolution of Karst Aquifers
online scientific journal www.journal.speleogenesis.info/journal/
Issue 12, 2012

Formation and development of a karstic system below and above sea level in Messinian Mani Peninsula (S. Greece)

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Papadopoulou-Vrynioti, Kyriaki and Kampolis Isidoros. 2012. Formation and development of a karstic system below and above sea level in Messinian Mani Peninsula (S. Greece). *Speleogenesis & Evolution of Karst Aquifers*. 12, 17-21 (http://www.speleogenesis.info/content/)

Abstract: *At the western shores of Messinian Mani Peninsula in South Greece, the composite, integrated karstic system of "Selinitsa" cave and "Drakos" underground river is developed above and below sea-level respectively, in the medium-bedded limestones of the Mani geotectonic unit. The formation and the development of these caves started, most likely, during Middle Pleistocene. Initially, these caves were terrestrial and developed separately. They were connected probably during Holocene through a fissure. The development of this united karstic system is controlled by tectonics. "Selinitsa" cave is older than "Drakos". The sequential base levels of karstification demonstrate the continuous sea-level changes during Pleistocene and Holocene, induced by the relative tectonic activity. This united karstic system is characterized by 'incomplete linkage' to the sea.*
Key words*: integrated karstic system, tectonic control, sea-level changes, karstification.*

Introduction

At the western shores of Messinian Mani peninsula, in south Greece, 49km to south-east of Kalamata city and south of Agios Dimitrios village, an impressive, composite karstic system is developed below and above sea-level (Papadopoulou, 1999). It comprises ''Selinitsa'' Cave and ''Drakos'' underground river, which are located on the shoreline and in + 8 m a.s.l. and -10 m, respectively. This karstic system is over 4 km in length, comprising the fourth longest cave system in Greece. It is developed in limestone benches of Plattenkalk unit tilted at 10°, which are characteristic in the wider area.

''Selinitsa'' Cave has about 3000 m of mapped passages, of which most of passages (about 2000 m) are terrestrial. The cave passages are vadose and phreatic. The cave presents rich speleothemic decorations and has the largest in Hellenic region single collapse chamber of 250x200 m in cross dimensions.

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''Drakos'' underground river has 1232 m in length and is developed entirely below the sea level. Its entrance lies at depth of 10 m but cave passages are developed in three levels, with the deepest parts at -48 m. In the third level and at -28 m depth, ''Drakos'' is connected with ''Selinitsa'' Cave through a chimney-shaped passage of 28 m length. The presence of a big chamber of 50x100 m of cross dimensions and of a big stalagmite in the eastern entrance, is notable, too. Generally, speleothemic decoration in ''Drakos'' is poor. Passages are exclusive phreatic and siphons act as lifting tubes, transferring water drained from ''Selinitsa'', underwater from -28m to -10m (Papadopoulou-Vrynioti and Kampolis, 2011).

The aim of this study is to clarify the formation and development of this composite coastal karstic system.

Geology

The impressive composite karstic system of Messinian Mani is developed into typical white and grayish, medium bedded, limestones of Upper Senonian – Upper Eocene age of total thickness of 300-500 m, which belong to the Mani (Plattenkalk) geotectonic unit (Fig. 1), relative autochthon of Peloponnesus. In the wider area, slightly metamorphic flysch (Upper Eocene – Oligocene) overlies stratigraphicaly the Upper Senonian – Upper Eocene limestones.

Also, limestones of the Vigla series (Upper Jurassic – Cretaceous), silicate schists (Lower – Middle Jurassic) and

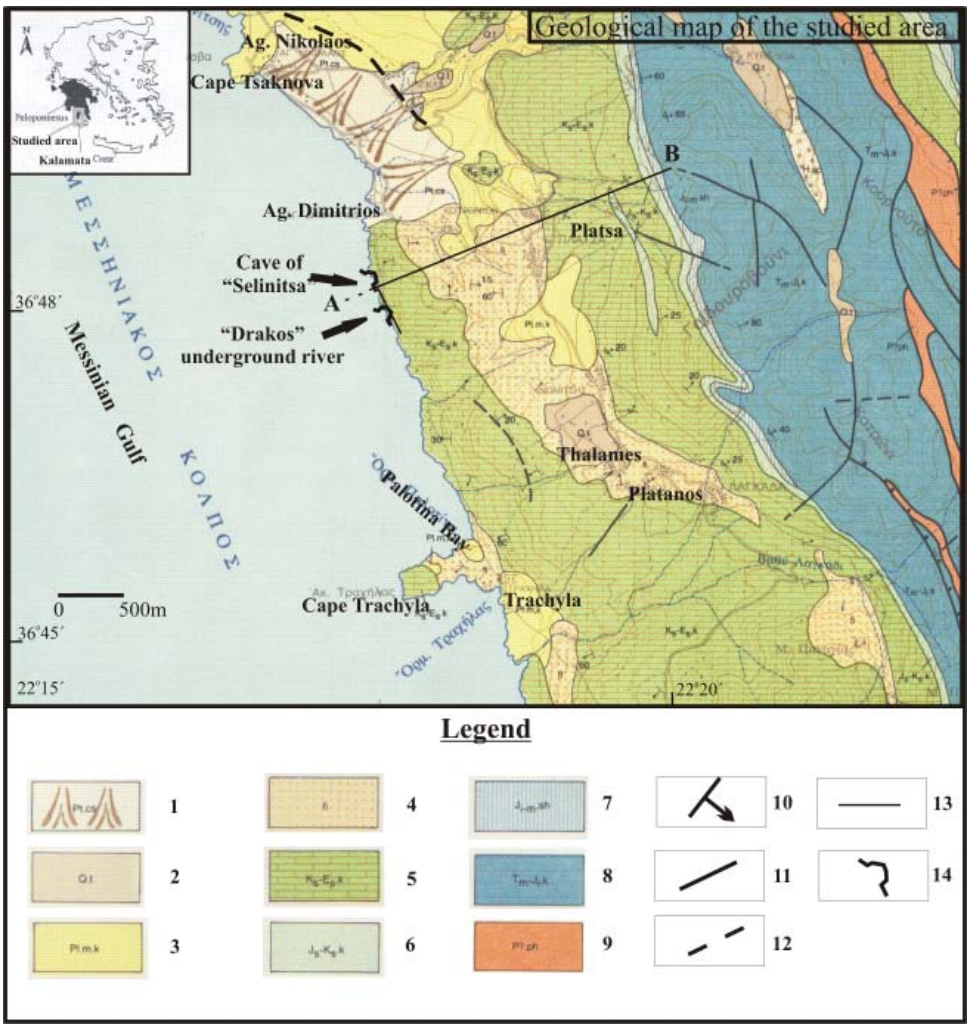

Figure 1. Geological map of the studied area (IGME, 1983). 1 – Old and recent fans (Holocene), 2 – Terrraces consisting of red clays, clayey sand with dispersed angular pebbles and alterations of breccio-conglomerates (Pleistocene), 3 – Marine sediments (Pliocene), Alpine Basement (Plattenkalk / Mani Unit): 4 – Flysch (Upper Eocene-Oligocene), 5 – Limestones (Upper Senonian-Upper Eocene), 6 – Limestones of Vigla series (Upper Jurassic-Cretaceous), 7 – Silicate schists (Lower-Middle Jurassic), 8 – Pantokrator limestones (Middle Triassic-Lower Jurassic), 9 – Phyllitic crystalline basement (Permian (?)-Lower Triassic), 10 – Strike and dip of strata, 11 – Fault, 12 – Fault probable, 13 – Geological boundary, 14 – Cave.

Pantokrator limestones (Middle Triassic – Lower Jurassic) occur at the lower stratigraphic level of the Mani unit (Papanikolaou et al., 1990). Late Cenozoic post-alpine clastic deposits, Pliocene marine marls and Pleistocene clays are observed in unconformity along the coastal zone (Kelletat and Gassert, 1975). Late Pleistocene and Holocene fans cover the plain areas, too.

The tectonism of the wider area is represented by faults with NNW-SSE main orientation and minor E-W orientation, formed mainly during Early Miocene (Mariolakos et al., 1985, 1994), which affects the whole Mani peninsula.

Since Middle Pleistocene, the stresses have been reversed in the area, became extensional in WNW-ESE direction, and faults of the same direction have been formed. The NE-SW directions of fractures which observed during the field work, south-east of "Drakos" underground river, must be relatively younger tectonic structures, as a NW-SE to NNE-SSW fault interrupts and displaces a NW-SE fault of Miocene age in Kotroni hill (Fig. 1). Also, due to an anticlinal structure, reversed strata have been observed in the wider area.

Due to the anticlinal structure and the dips in the area of caves, the flysch and the silicate schists , act as barrier of impermeable lithology (Pavlakis et al., 1989). These comprise the regional karstification base levels (Fig. 2) of the studied karstic system. For this reason, the karstic system is characterised by 'the incomplete linkage' to the sea (Mijatovic, 1975, 1977).

Based on the rose diagram analysis (Figs 3 and 4) which results from 105 measurements of joint directions from the marbles area above "Selinitsa" and "Drakos", it is apparent that: joints around "Selinitsa" have a NNW-SSE to NW-SE principal direction, consequently they must correspond to the Miocene tectonism. On the contrary, joints around "Drakos" have a NE-SW principal direction corresponding to a younger tectonism.

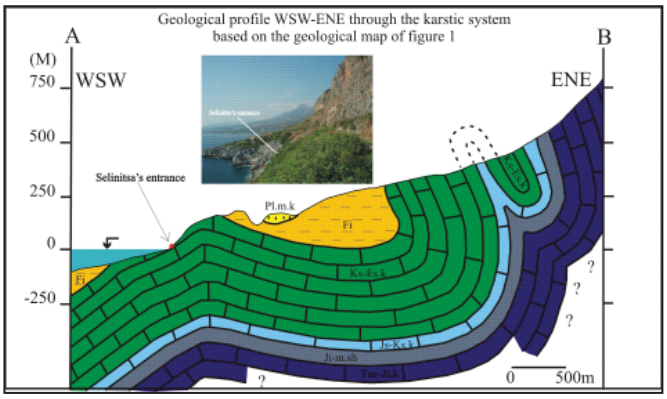

Figure 2. Geological profile WSW-ENE through the karstic system based on the geological map of figure 1 and photo of "Selinitsa's" entrance.

Formation and development of "Selinitsa - Drakos" karstic system

In "Selinitsa" Cave, the larger part of its passages demonstrate NW orientation, and a small part has E-W orientation (Fig. 3), as follows from the mapping analysis of "Selinitsa" and the respective rose diagram (Papadopoulou-Vrynioti and Kampolis, 2011).

The large chamber of the cave with 250x200m cross-dimensions is developed along two main axes of NW-SE and E-W directions, respectively. Also, "Selinitsa's" passage, through which it is connected with "Drakos", has NE-SW direction. Small branches are developed in N-S direction, too.

"Drakos" passages are developed mainly in NE-SW directions, and minor passages are of E-W directions, as the majority of passages present a general NE orientation and only a small part a WSW orientation (Fig. 4). Small branches are developed in NW-SE and NNW-SSE direction, too.

With comparison of rose diagrams of passage directions of both "Selinitsa" and "Drakos" and respective rose diagrams of joints directions (Figs. 3 and 4), a great similarity between them is evident. This is due to the fact that the development of the studied composite karstic system has been controlled by tectonics.

Further analysis suggests that "Selinitsa" development is influenced mainly by NW-SE, NNW-SSE faults of Miocene, whereas "Drakos" is controlled by NE-SW faults of younger age. The fact that both caves have passages in WNW-ESE direction, controlled by tectonics of Middle Pleistocene, means that the development of those caves is most likely to have started during Middle Pleistocene.

During Pleistocene glacial periods, the sea level fluctuated from -120m to -40 m, below the present one (Lambeck, 1996). Considering the relative tectonic activity, this level must have been the base level of karstification. In this way, initially both "Selinitsa" and "Drakos" caves were developing above sea level, having a terrestrial character. The terrestrial character of "Drakos" Cave is also ascertained by the presence of the big stalagmite at the eastern entrance, at -10 m depth, and by the existence of stalactites and stalagmites in the third level, at a depth of approximately -30 m.

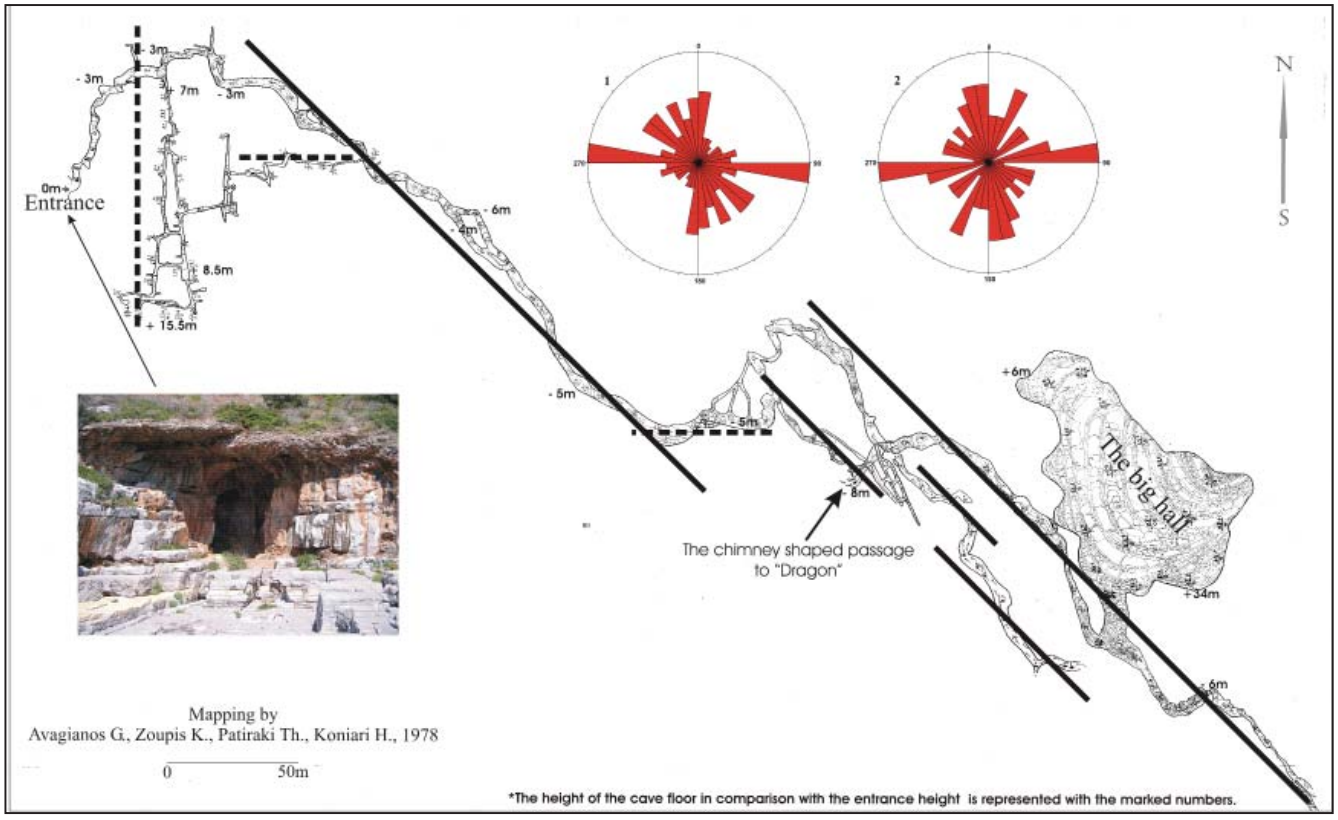

Figure 3. A map of "Selinitsa" cave and rose diagramms of its passage directions (1) and joints above and around its entrance (2).

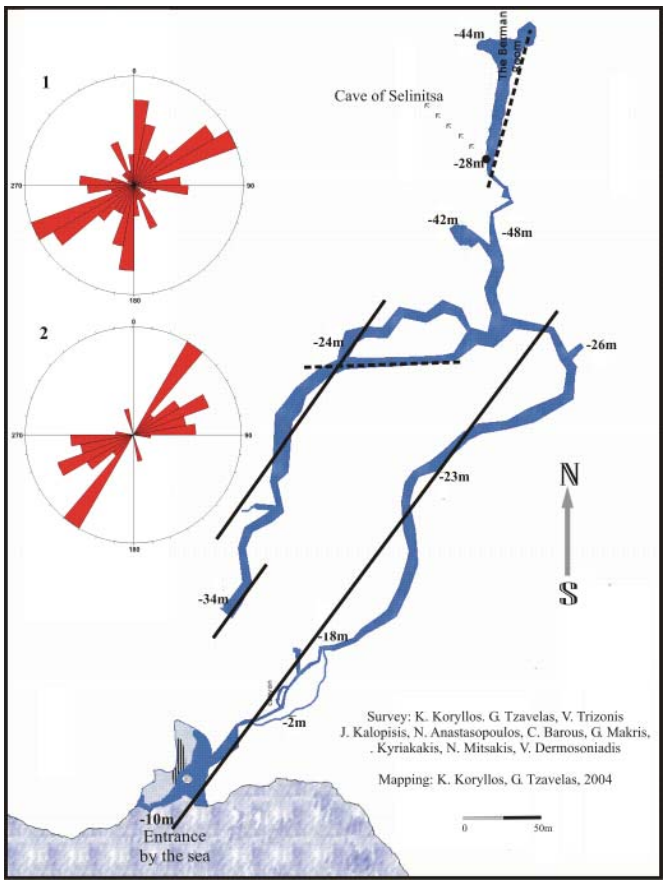

Figure 4. A map of the "Drakos" underground river and rose diagrams of its passage directions (1) and joints above the cave (2).

The location of the connection point of the caves, the smaller length of ''Drakos'' Cave in comparison with ''Selinitsa'' Cave, and the limited speleothemic decoration of "Drakos" are evidence of the short time period during which ''Drakos'' Cave was located above sea level. By the end of the last glacial period of Pleistocene, sea level began to rise gradually. This can be ascertained by the high frequency of karst tubes in -25 m to -20 m and in -12 m to -8 m, which are responsible for the submarine discharges in the Vlychada Cave area located to south of the studied area (Giannopoulos, 2000) and probably for the submarine spring in Stoupa Bay, north of the studied area (Stamatis et al, 2011). Also, a small number of widened conduits is observed in altitudes -45m to -40m. It is likely that these ranges reflect the gradual sea level rise and the presence of temporary sea level stands within them.

Initially, the two caves developed separately. This is suggested by the fact that their connection is through a narrow chimney-shaped passage, which is developed along a NE-SW tectonic discontinuity, corresponding to the younger tectonism. The width of that passage also, reflects the recent age of development. Consequently, ''Selinitsa'' and ''Drakos'' connection and the integration of the karstic system must have taken place recently, probably during Holocene.

Conclusions

The ''Selinitsa'' Cave and the underground river of ''Drakos'', developed below and above sea level respectively, are now united.

Initially both of these caves were developing above sea level but ''Drakos'' has remained above sea for a short time period.

Initially, the two caves developed separately. They were probably connected during Holocene, through a fissure with NE-SW direction in -28 m depth, creating an integrated karstic system.

The tectonism has strongly influenced the development of the studied karstic system that can be characterized as directed by tectonics.

The tectonic control of ''Selinitsa'' is NW-SE whereas that of ''Drakos'' is NE-SW.

''Selinitsa'' cave is older than ''Drakos'' because ''Selinitsa'' is located in a higher position related to ''Drakos'', the most passages of ''Selinitsa'' are above the present sea level and has almost three-fold length of passage development.

The development of both caves is most likely to have started during Middle Pleistocene.

The older base level of karstification of this composite karstic system is in -48 m. Also, widened conduits from -12 to -8 m, observed in the underground river of ''Drakos'', corresponds to the most recent base level of karstification.

The above mentioned levels demonstrate the continuous sea level changes during Holocene induced by the relative tectonic activity.

The studied karstic system is characterised by 'incomplete linkage' to the sea.

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