# THE TECTONIC CONTROL OF AN UNDERGROUND RIVER NETWORK, AGIA TRIADA CAVE (KARYSTOS, GREECE)

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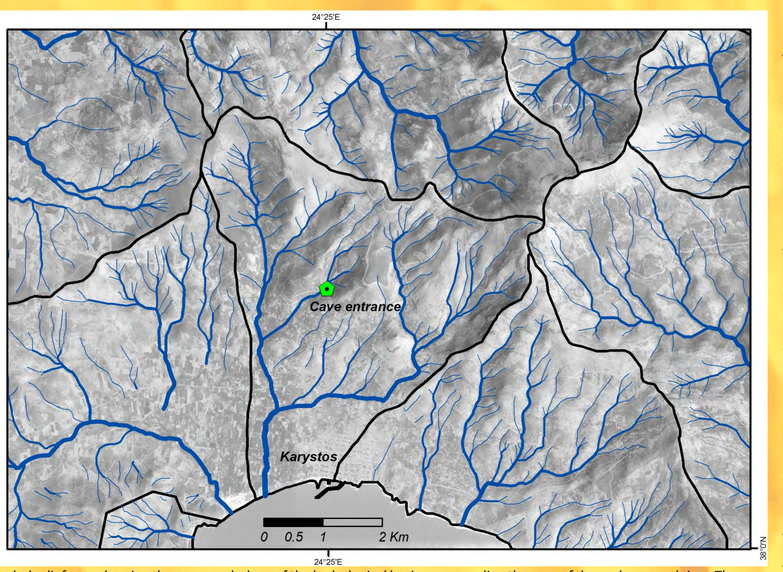
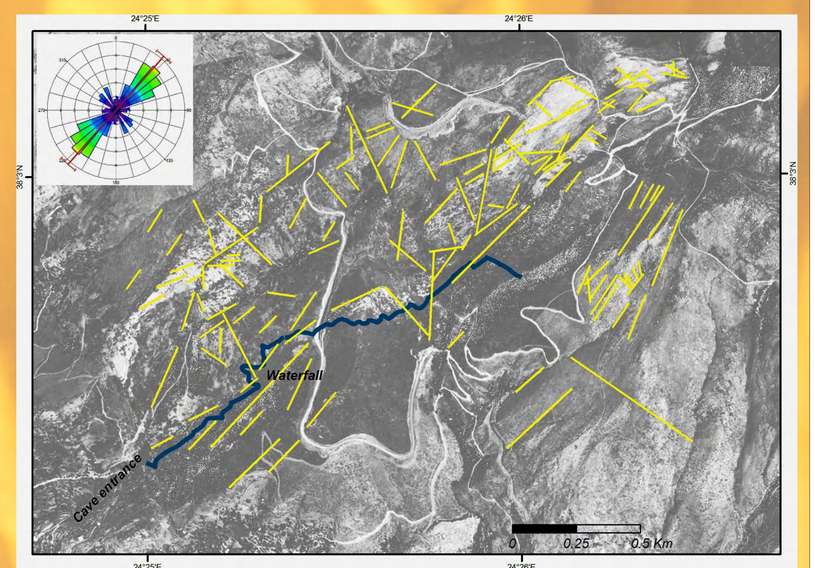


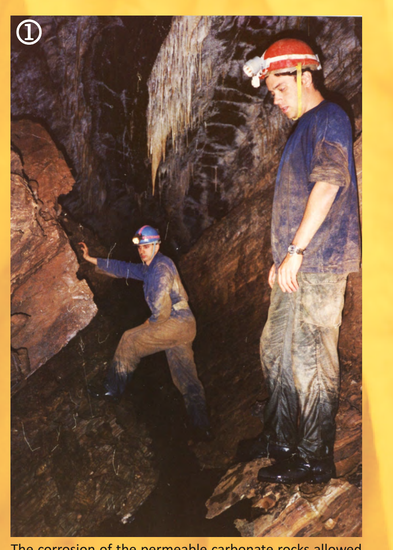

Shaded relief map showing the geomorphology of the hydrological basins surrounding the area of the underground river. The cave is located in a hydrological basin which covers an area of about 20 km$^2$ discharging most of the WSW slopes of Ochi Mt. since its watershed reaches the highest peak of the mountain at nearly 1,400 m of elevation. The drainage network reaches the 5$^{th}$ order of Strahler classification. It comprises of two 4$^{th}$ order branches, which divide the triangular shaped basin into two asymmetrically developed sub-basins. The westernmost main branch flows almost parallel and in a relatively small distance from the watershed margin, as well as the easternmost branch flows next to the eastern margin of the basin.

## ABSTRACT

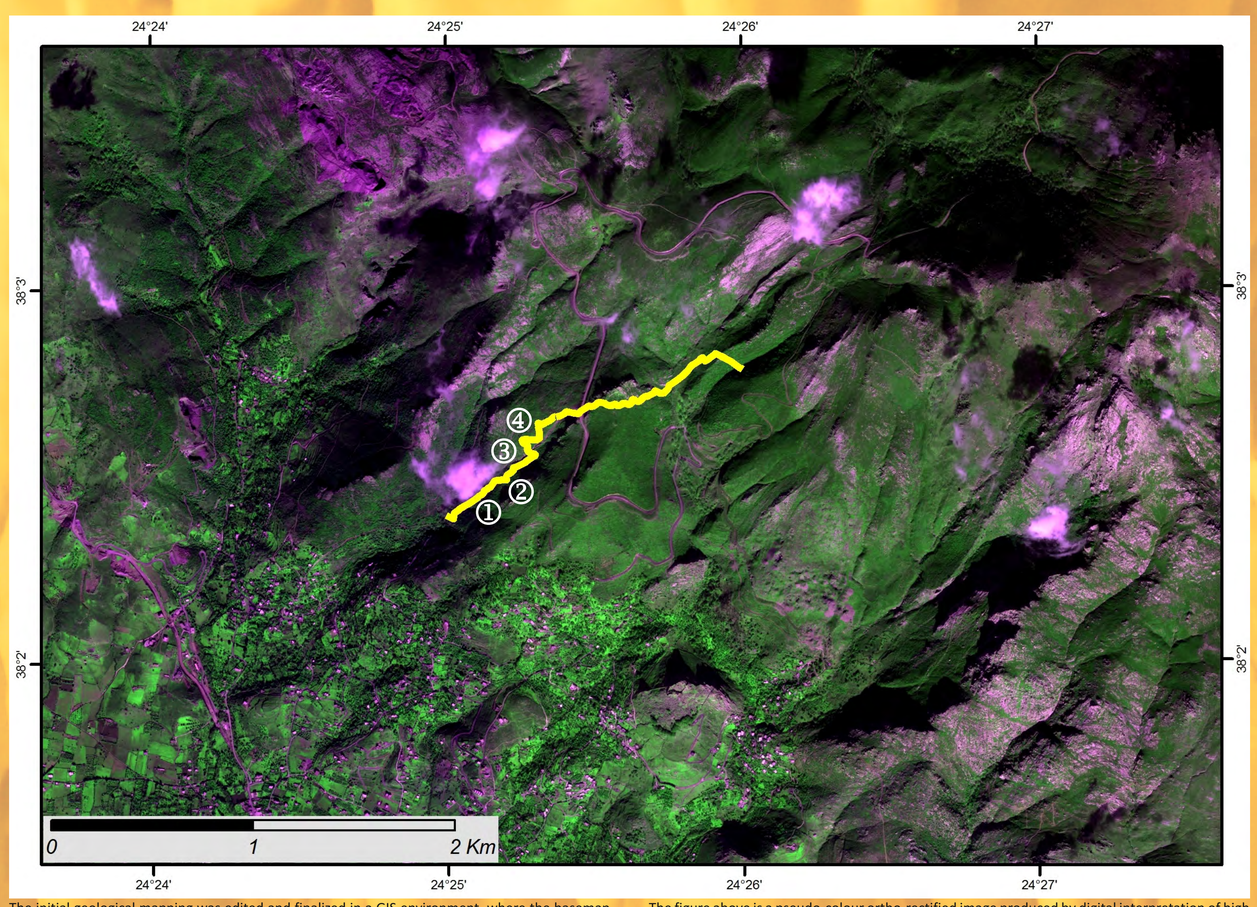
The water pathways of the underground river of Agia Triada (Karystos, Greece) and their generation are examined in this study. One of the longest caves explored in Greece is formed at heavily deformed metamorphic rocks and the suggested combined methodology, which includes traditional geological mapping, speleological exploration and remote sensing image interpretation, led us to the conclusion that the water flows along the hinge of a NE–SW-trending mega-fold trending NE-SW. A number of faults that have been activated after the generation of the underground river, have altered its pathway by creating "knick-points" which host impressive subsurface waterfalls, the largest of which is about 20 meters high. The extraction of morpho-lineaments from ortho-rectified satellite images revealed the importance of structures that were identified on the open surface mainly by high-resolution remote sensing data interpretation and are related to the cave development. This was made feasible with the use of the Geographic Information Systems as all the collected data were converted into layers for further interpretation. It proved to be very useful as the projection of the cave trace on the ortho-rectified data revealed the underground linkage between two adjacent hydrological basins and also explained the unusual large quantities of water discharged by the Agia Triada spring.




Morpho-lineament map at a buffer zone of 1 km upstream the cave trace (blue line). The statistical interpretation of 282 lineament features is shown at the inset rose-diagram. The morpho-lineaments are surface expressed lineament features, which might be either geological or geomorphological structures or neither of both. In any case these can be related to more or less significant structures that have affected the study area and left their imprints on the surface. The lineament features, which were identified on the produced pseudo-colour and true-colour remote sensing images, show the exact main orientations with the field observations and measurements. It is more than clear by reading the rose diagram that the main orientation of the lineaments is along NE-SW. Nevertheless, a secondary trend of NW-SE is also identified. Even though both of the main calculated orientations are identical to those revealed by the field observations, it is clear that the remote sensing data interpretation altered the significance of the recorded orientation, by promoting the NE-SW trend as the most significant.




The corrosion of the permeable carbonate rocks allowed the water to create a relatively high tunnel with a naturally created passage above the subsurface flow. The underground river flows beneath the naturally created passage along the first few hundred meters after the cave entrance (Photo by Emm. Vassilakis).



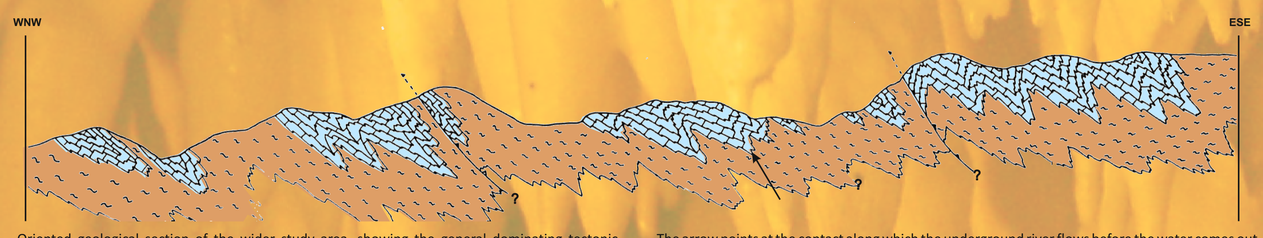

The initial geological mapping was edited and finalized in a GIS environment, where the basemap consisted of the four-spectral-band IKONOS image (three bands in the visible and a fourth in the infrared spectra). Different band combinations led to the production of several true- and pseudo-colour digital map compositions, aiming to reveal formations of similar mineral composition and especially the contacts between the various rock outcrops.

The figure above is a pseudo-colour ortho-rectified image produced by digital interpretation of high spatial resolution (1m) IKONOS satellite image (2,4,1/R,G,B). The yellow line represents the projected cave trace on the surface. The green colours represent the vegetation cover whilst the bluish colours represent the uncovered rocks. The purple colours at the top represent an open excavation field for decorative stones (Plaka Karystou). The numbers refer to the locations of the photos around the plate.


Diversion of the main underground river where diving equipment is necessary. It is a very small and narrow passage next to the formed lake which can be used after climbing on a 6 meters high wall. It is an older branch of the river which used to be active during the early stages of the cave generation and it was filled up with sandy material later (Photo by Emm. Vassilakis).

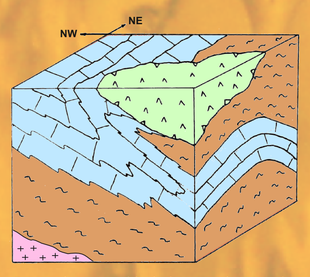

The impressive 20 meters high subsurface waterfall forms a shallow lake, one of the many that are formed along the underground river of Agia Triada. The water flows on the knick-point which is formed normally to the folding axis that can be identified on the wall behind the two speleologists (Photo by Emm. Vassilakis).


Petrified waterfalls with a large asbestite cover of 3 meters wide and 6 meters high above the contemporary water flow, show a more recent migration of the underground river water path at a lower level (Photo by Emm. Vassilakis).



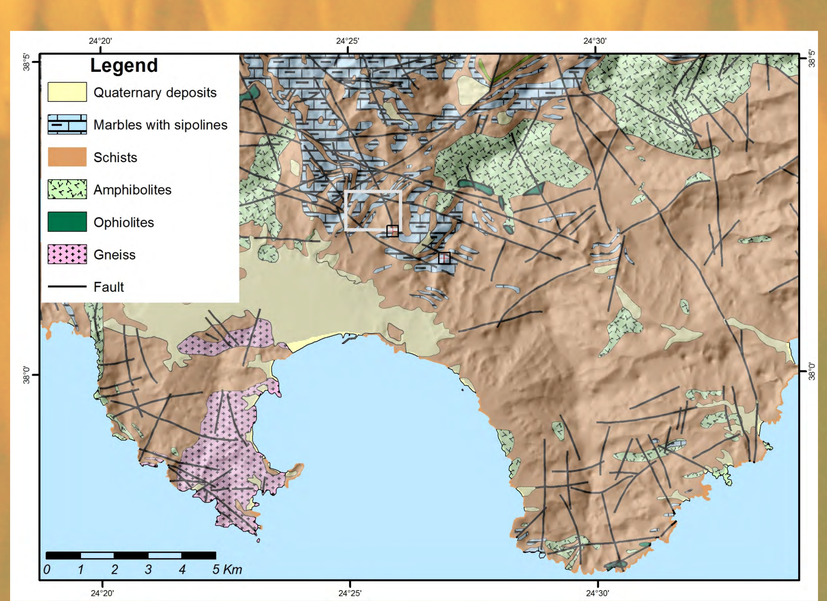

Oriented geological section of the wider study area, showing the general dominating tectonic structures of the Ochi unit, which are the isoclinal folds and the upthrusting parallel to the folding.

The arrow points at the contact along which the underground river flows before the water comes out to the open surface through Agia Triada karst spring.

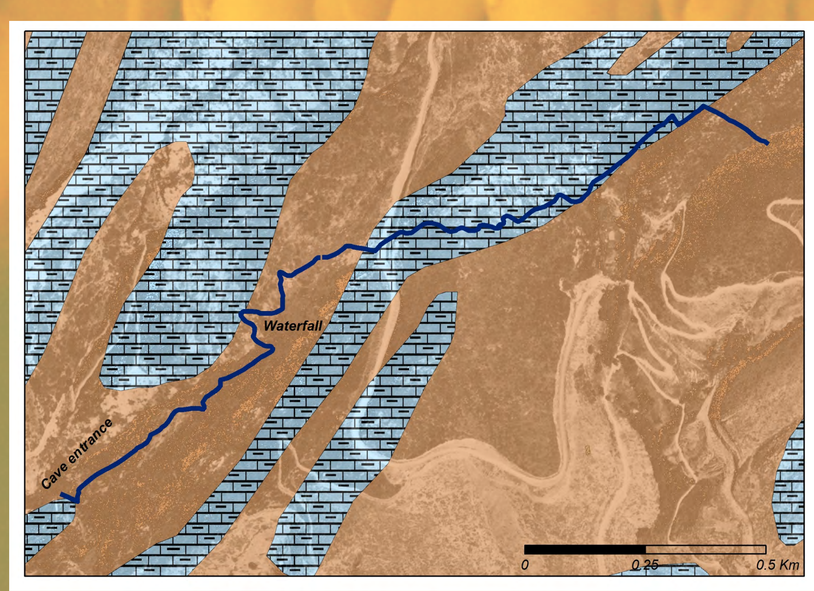



Oriented tectonic block diagram showing the general structure of the area of South Evia.
The geological and structural mapping revealed that the entire area has been folded during the alpine period (late Jurassic - early Cretaceous). Most of the folds that are observed in all kinds of scales have axis trending generally along the NE-SW orientation. This orientation is compatible with deep ductile deformation. It is expressed with isoclinal, overturned and recumbant folds with many orders of folding.
A second deformation incident seems to have happened after the previous one as folding of the already folded rocks is observed. It is expressed by open folds with almost vertical axial plane and NNW-SSE axis trending. The most likely age of this deformation is during Oligocene.

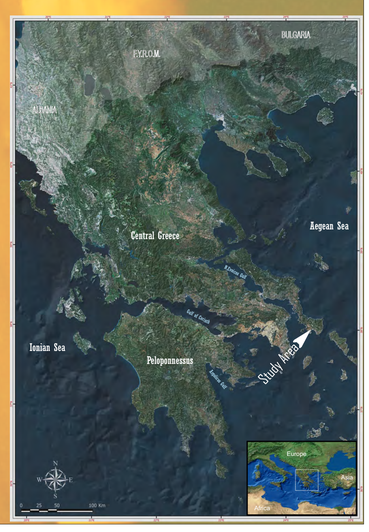
Folded sipoline rocks were identified throughout the area around the cave trace at all scales.




Simplified geological map of southern Evia on a transparent shaded relief. The white box shows the magnified area (shown at the right plate).The area comprises mainly of metamorphic rocks, members of the Ochi unit. Intercalations of marbles with sipolines and mica schists have been observed throughout the entire area and are geotectonically placed between a series of ophiolitic rocks and amphibolites on top and the basement rocks comprised of gneiss. Three main systems of faulting were identified throughout the wider area of southern Evia. Most of the faults trend NW-SE but there is also a large number of faults trending either NE-SW or ENE-WSW.




Magnified geological map around the surface projection of the cave trace (blue line). The cave entrance and the waterfall locations are also noted. A slight transparency was given to the panchromatic ortho-rectified remotely sensed image which was used as a basement layer throughout the field work for geological mapping and tectonic measurements.

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