A preliminary geophysical investigation regarding the possible extension of Alistrati cave in Serres Greece

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Summary

The cave of Alistrati, is located in the Prefecture of Serres, Northern Greece near the foothills of Mount Menoikio, in the area of Petroto. This area is structured by crystalline limestones, where the development of a complex and multilevel karst system is favored. An extensive geomorphological survey was carried out for the accurate mapping of the karst surface above the cave, using UAS. For the investigation of a possible lateral extension of the existing karstic conduit, a detailed surface geophysical investigation was carried out. More specifically, three geophysical techniques were implemented: a) the Electrical Resistivity Tomography (ERT), b) the Ground Penetrating Radar (GPR) technique and c) the Very-Low Frequency (VLF) method. These 13 lines of the three geophysical techniques are fully matched at 4 locations and were join-interpreted, yielding remarkable findings. The comparative results of the above geophysical techniques, as well as their 3D presentation, highlight similar geophysical anomalies, evaluated as different types of karst system structures. Therefore, the combined geophysical survey has indicated the existence and interconnection of the first two karst levels of the area, up to a depth of 50m, as well as the possible extension of the Alistrati karstic conduit to the northeast.

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Introduction

The cave of Alistrati is located in the Prefecture of Serres (Fig. 1), near the foothills of Mount Menoikio, in the area of "*Petroto*". This area is structured by solid, rocky formations and specifically crystalline limestones of the Rhodope Massif. This formation, through fault and fracture systems, favours the underground circulation of water. The precipitation of the water to lower levels triggers the phenomenon of dissolution and erosion, which consequently lead to the development of a complex and multilevel karst system. In the north-eastern part of the cave, a chamber filled with massive rock falls, derived from the cave's ceiling, is found and the further development of the cave is abruptly interrupted (Fig. 1). For the investigation of a possible lateral extension of the existing and accessible Alistrati karstic conduit, a high-detailed surface geophysical investigation was planned and carried out. More specifically, three geophysical techniques were implemented: a) the Electrical Resistivity Tomography (ERT) at 4 parallel profiles of 940m total length, with maximum investigation depth of 50m, b) the Ground Penetrating Radar (GPR) technique at 6 lines of 1330m total length and c) the Very-Low Frequency (VLF) method at 3 parallel lines of 705m total length. Practically, there are three parallel lines where all three techniques have been applied, one more with ERT and GPR data and two other ones with GPR data only (Fig. 1). Therefore, we were able to have a joint interpretation, yielding remarkable results.

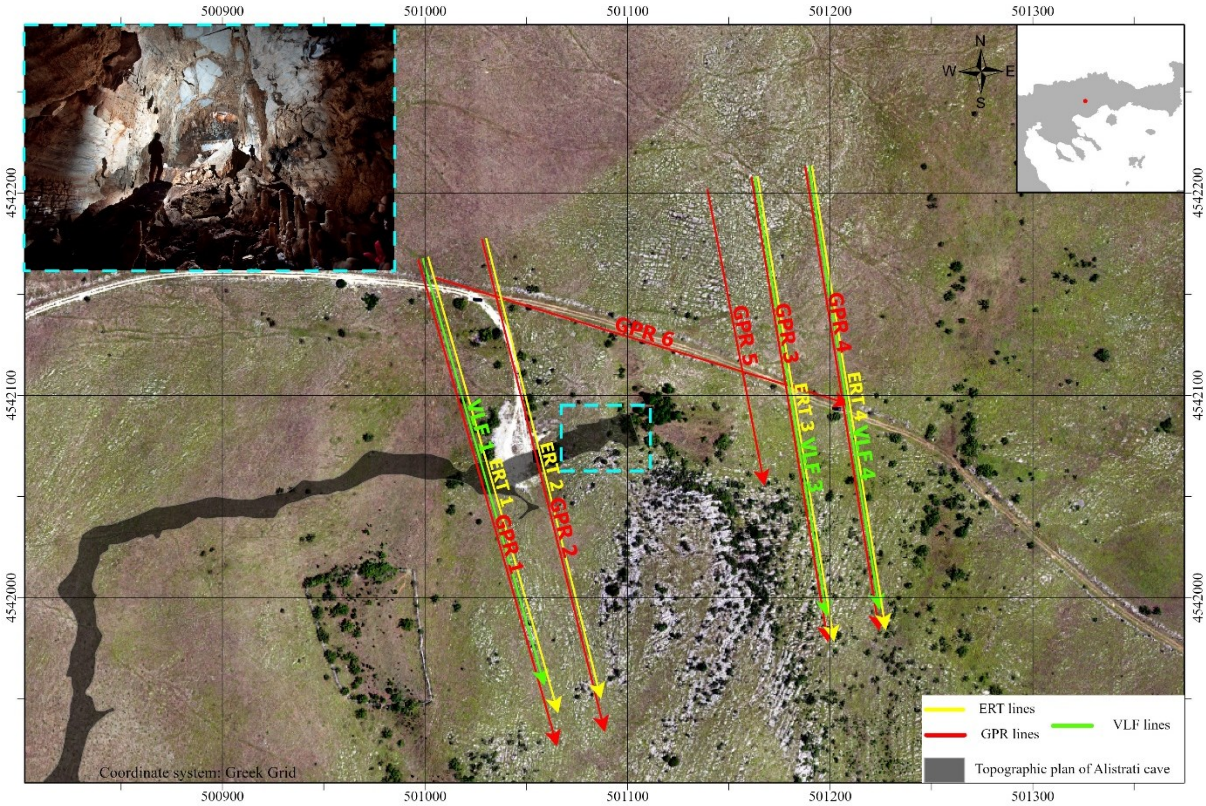

Figure 1 *The geophysical survey lines, above the last hall of the cave with the extensive rockfalls. The embedded image (upper left) is referred to the blue dashed polygon on the map.*

Methodology

For the accurate mapping of the karst surface above the cave of Alistrati an extensive geomorphological survey was carried out initially, using an Unmanned Aerial System (UAS). A 3D dense point cloud, a detailed orthomosaic and a digital elevation model of the area were induced by the photogrammetric processing of the UAS images. Thus, the surface karstic landforms and the morphological structures were detected and represented in detail (Silva *et al.* 2017). Based on this photogrammetric analysis and field observations, the karstic system of "*Petroto*" seems to be developed in three main levels. From these high-resolution photogrammetric products, the detection of the surface karst landforms development was possible. More specifically, karrenfields, dolines and hanging valleys of the study area have been identified (Fig. 5)

For the investigation of a possible lateral extension of the Alistrati karstic void, a detailed surface geophysical investigation was planned and carried out above the chamber with the rockfalls (Fig. 1). More specifically, three geophysical techniques were selected and executed perpendicular to the main direction of the cave development and its possible extension. The ERT was initially selected and applied, to investigate the subsurface resistivity distribution and detect possible high resistivity anomalies caused by karstic voids (Xu *et al*. 2017) The ERT technique was executed at four (4) profiles of 235m each with an electrode spacing of 5m, using the SyscalPro switch 48, unit. Two (2) of the profiles were performed over the existing cave for the calibration of the investigated resistivity values, while the other two (2) were carried out perpendicular to the expected direction of the karstic void (Fig. 1). The 2D inversion and topographic correction of the data was performed with *Res2DINV*, after calculating the coordinates of each section by differential GNSS system. The inversion results indicated the existence of two highly resistive targets (>7000 Ohm.m); a shallow up to 15m depth and a deeper one at a depth of 50m.

Moreover, the GPR technique was applied in order to delineate reflection surfaces and hyperbolas of the GPR pulse, affected by the possible existence of karstic voids in the crystalline limestones' bedrock (Čeru *et al*. 2018). GPR technique was performed at six (6) profiles, using the *Sensors & Software GPR* system, with a 100MHz antenna. A typical filtering procedure, using the *EKKO Project software*, has been applied to process the data, including the Dewow, Background Removal, Band Pass, Sec2 Gain and Migration filters. In addition, topographic correction of the data was performed. The GPR results highlighted strong signal reflection surfaces and typical reflection structures (Fig. 3) often caused by karstic voids. The results seem to reveal the existence of the first karstification system, which is developed at depths up to 15m (Fig. 3).

Subsequently, the electromagnetic VLF method was applied to investigate possible anomalies that may be caused by highly resistive targets (potential air voids) in less resistive environments (crystalline limestones) (Alexopoulos *et al*. 2011). The VLF method has been executed at three (3) of the ERT/GPR profiles, with a length of 235m each, with a measurement spacing of 5m using the *ABEM WADI* VLF system. The data processing, through *KHFFILT* software (Pirttijarvi, 2004), included the application of the Frazer and Karous-Hjelt filters and determined the subsurface distribution of current density. Moreover, the 2D inversion of the VLF data and their topographic corrections were performed in *INV2DVLF* software (Monteiro Santos *et al*. 2006), in order to convert the current density to resistivity distribution. The results of the VLF method (Fig. 2) indicated the occurrence of highly resistive targets probably affected by the existence of karstic voids of the first two karstification levels.

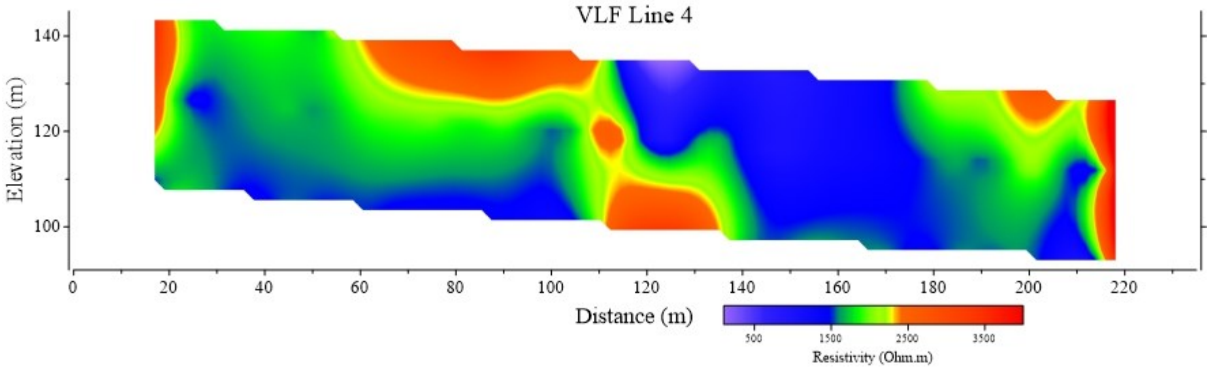

Figure 2 *2D inversion model of the VLF data, for the distribution of the subsurface resistivity, in VLF line 4, after processing with INV2DVLF software.*

Results and Discussion

The comparative results of all the above-mentioned geophysical techniques appear to highlight similar geophysical anomalies. These geophysical anomalies are interpreted as the signature of the first two levels of karstification. From the combined presentation of the ERT and GPR data of Line 4 (Fig. 3), the identification of characteristic structures seems to have been identified from both geophysical techniques. This comparison reveals the correlation between a high resistive target (>10.000 Ohm.m), derived from the ERT and a structure of multiple reflections of the GPR pulse, at depths greater than 8m, at 70m-100m distance. This geophysical anomaly, revealed by both techniques (Fig. 3) can be interpreted as a karstic void of the first, shallow level of karstification. The resistive area (>10.000 Ohm.m), developed at distance between 120m and 150m and at depths greater than 30m, presents similar spatial characteristics with the cave of Alistrati and it is interpreted as its lateral extension to the northeast.

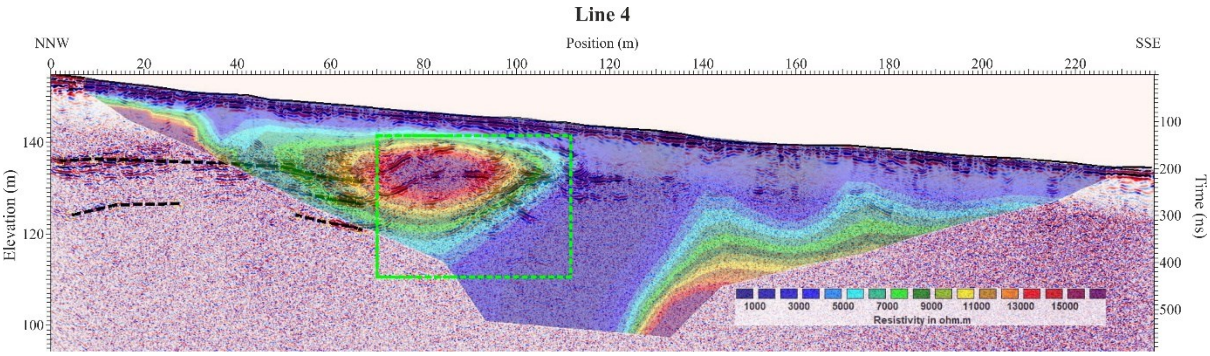

Figure 3 *Combined presentation and interpretation of the ERT and GPR results for line 4. The black dashed lines refer to reflection surfaces of the GPR signal, while in the green dashed rectangle, a structure of multiple reflections can be observed.*

Furthermore, the 3D presentation of resistive volumes (>10.000 Ohm.m), derived from the electrical resistivity tomography technique has been produced with *RockWorks* software. It combines the 3D elevation model and the ortho-photo-mosaic of the area, produced from the photogrammetric analysis of the UAS data. From this 3D model, the development of the first two levels of karstification and their interconnection with surface karstic landforms (Fig. 5) has been adumbrated, as long as the possible extension of Alistrati cave to the northeast, became more obvious (Fig. 4).

Conclusions

In conclusion, the combined geophysical survey indicated the existence and connection of the first two karst levels of the area and a possible extension of the Alistrati karstic conduit to the northeast at the same level where the existing cave develops (30-50 m depth). The future extension of the investigated area, to the northeast, and the establishment of a denser network of sections of the geophysical techniques, in combination with the extension of the surface karst-geomorphological survey, will highlight in much greater detail the complex karst system of the "*Petroto*" area and the possible lateral expansion of the cave of Alistrati.

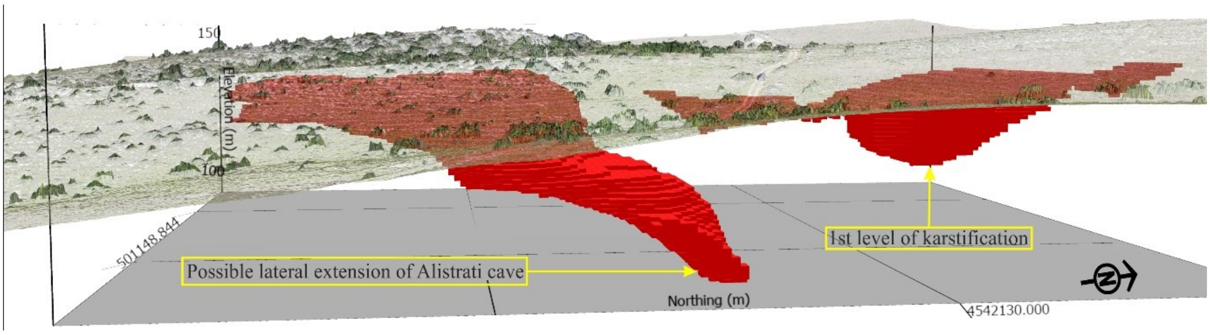

Figure 4 *3D presentation of resistive volumes (>10000 Ohm.m) derived from the ERT results, which highlights the existance of the two first karstification levels. View from East.*

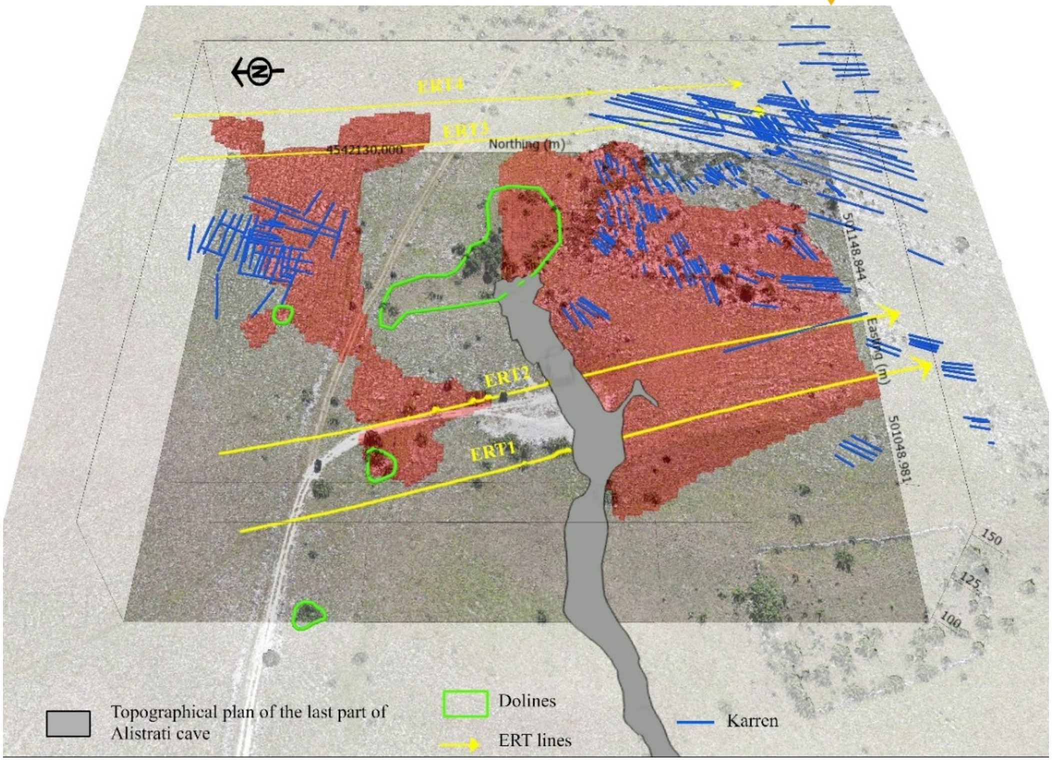

Figure 5 *3D presentation of resistive volumes (>10000 Ohm.m) derived from the ERT results, where the surface and subsurface karstic geomorphs are also presented on the 3D orthomosaic.*

Acknowledgements

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