A Geophysical Approach to the Phenomenon of Ground Fissures at the East Thessaly Basin (Greece)

J. Alexopoulos , S. Dilalos , G.S. Mitsika , E. Vassilakis , S.E. Poulos

Summary

The disastrous phenomenon of aseismic ground fissures along the eastern Thessaly basin has deteriorated since 1989. The main reason for these fissures is the over-pumping, which leads to differential vertical compaction of the aquifer system and subsidence on the land surface. In this paper, we present the results of a combined geophysical survey applied in the area (VES and TEM soundings), in order to investigate the subsurface geological conditions. The geological regime of the area is comprised of the alpine basement, transgression formations and finally a package of post-alpine deposits with respectful thickness. A peudo-3D representation of resistivity maps for several depths of investigation was produced. Additionally, a dataset of deep boreholes was used for the calibration of the geophysical data. All the borehole and sounding interpreted data were grouped into three categories in order to produce the Lithology Model of the area. The alpine bedrock was adumbrated only at the southeast and central part of the basin, where we do not observe ground fissures. The absence of alpine bedrock for depths up to 300 meters, the thick and coarse-grained deposits and finally the over-pumping seem to contribute to the creation of the ground fissures.

Introduction

The study area lies within the central part of mainland Greece. It is an elongated, NW-SE trending, flat basin developed between the mountains Mavrovouni and Chalkodonio (Fig. 3). The alpine basement rocks crop out at the eastern and southeastern margins of the eastern Thessaly basin, while the westernmost marginal area is comprised of Neogene continental sediments. There is also a morphological outcrop of the alpine basement, with steep gradients of its margins, inside the basin. The alpine basement consists of metamorphic gneiss, marbles, schists, amphibolites and ophiolitic bodies. The Neogene sediments consist mainly of conglomerates, covering the alpine flysch and limestones. A gradual transition of the alluvial deposits from coarser-grained materials (western and central basin) to fine-grained (eastern basin) is expected, taking into account the available borehole data (Sogreah Grenoble, 1974) and the geological regime. The first Karla Lake was hosted on these fine-grained materials, at the eastern part of the basin (along the foothills of Mavrovouni Mt.), until 1962 when it was drained. The recreation of the artificial Karla Lake (Fig. 3) was completed in 2018.

Figure 1 *Damage caused to the building due to the ground fissure.*

Figure 2 *A ground fissure located in the field, close to village Kileler.*

Extensive aseismic ground fissures, with general orientation WNW-ESE, frequently occur within the eastern Thessaly basin since 1989, causing extensive damage even to buildings of the local society (Fig. 1). Differential vertical compaction of the aquifer system results in different magnitudes of subsidence on the land surface (Jachens and Holzer, 1982). Other causes of differential compaction may include shallow buried bedrock away from the periphery of a basin, faults within the basin-filling sediments (Burbey, 2010) and fault-plane barriers to groundwater flow (Holzer, 1980). Beyond the over-pumping of the basin that is the main cause of the fissures' creations, it seems that the large tectonic structures, buried under the thick quaternary formations (Alexopoulos *et al*., 2013) also contribute to their creation.

Methodology

The effectiveness of coupling hydro-geophysical techniques in hydrological applications has been demonstrated in recent years over multiple scales, from lab to catchment (Binley *et al.,* 2015). A combined geophysical survey took place including TEM and VES in an attempt to collect subsurface data regarding the lithology, hydrogeology and tectonics of the region that could provide further information which could be correlated with the creation of the fissures.

The TEM survey has been widely used in groundwater studies (Auken *et al.,* 2003; Danielsen *et al.,* 2003) and offers a fast and cost-effective way to obtain information, especially for areas with low resistivity values. A dense grid of 71 TEM soundings was carried out with the ABEM WalkTEM system. The field configuration for data acquisition comprises of a 40x40m square transmitter loop (Tx-loop), with two in-loop antennas (the 10x10m RC-200 and the 0.5x0.5m RC-5), each with different receiver areas. The data processing and inversion were carried out with ViewTEM software. The TEM soundings have been interpreted using both multi-layer (20 layers) and few-layer (5 layers) inversion models. Resistivity maps for several depths were produced based on the results of the multi-layer inversions (Fig. 4).

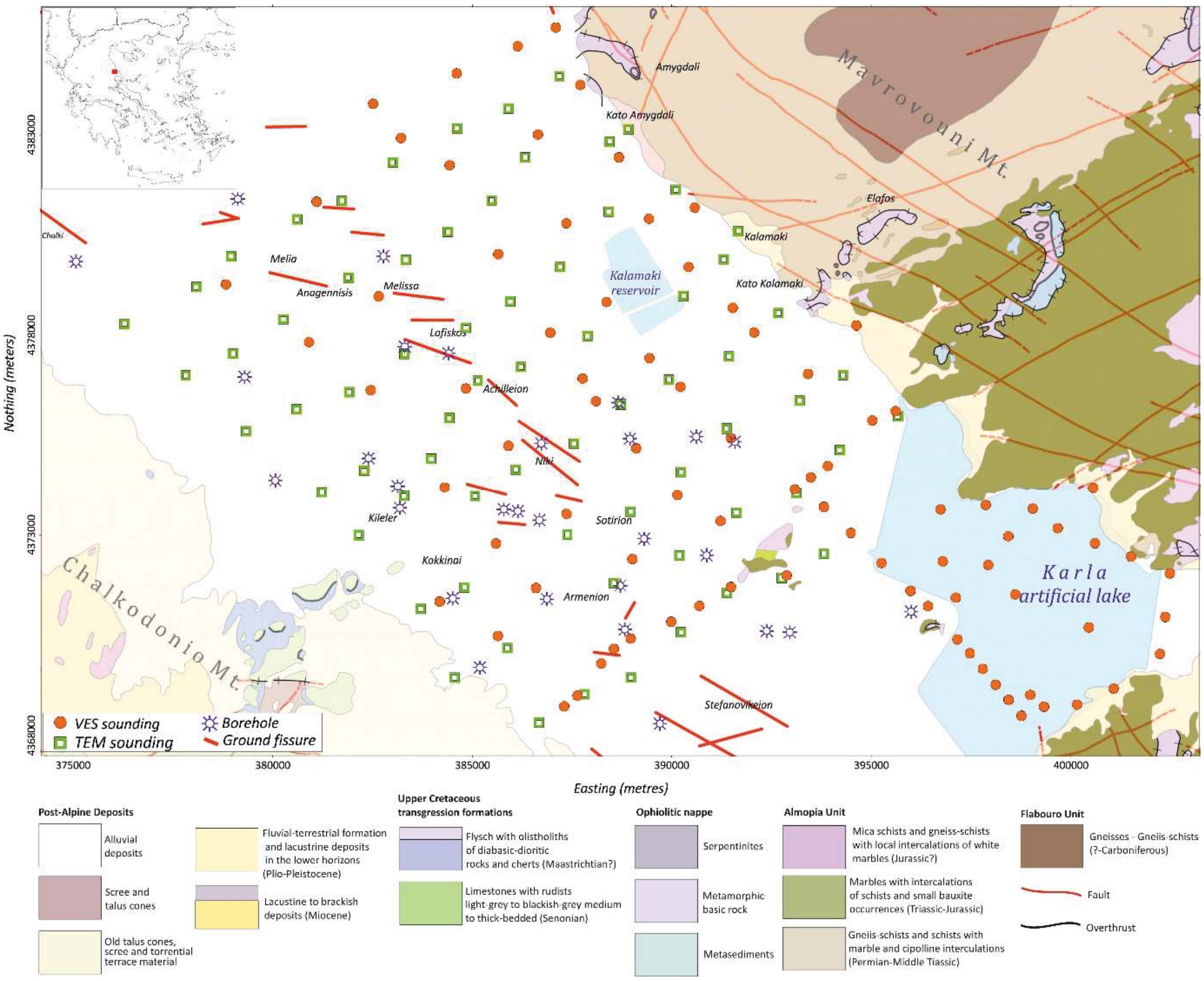

***Figure 3** Geological map of the study area. The locations of the VES and TEM soundings along with the boreholes are also presented.*

The geoelectrical dataset includes a total of 93 VES soundings, carried out with the Schlumberger array and a maximum electrode spacing (AB) equal to 2000m, including soundings carried out by the University of Athens (authors) and re-processed archive data by Kallergis and Papanikolaou (1979) carried out during the period that Karla lake was completely drained. All the geoelectrical data was processed by applying the automatic method of Zohdy (1989), composing a multi-layer model. Beyond this, the commercial software package IX1D of Interpex, was also used in order to calculate the layered model.

Results and Discussion

The 'horizontal' resistivity maps of 4.5m, 7m, 10m, 15m, 20m, 30m, 45m, 70m, 100m, 150m and 200m investigation depth were produced based on the processing results of the TEM data. A pseudo-3D representation was produced (Fig. 4), where these horizontal resistivity maps are presented in order to have a better visualization of the subsurface resistivity distribution, both vertically and laterally. At the eastern area of the resistivity maps, we observe low resistivity values (<5-10 Ohm.m) at relatively small depths (<20m), changing to relatively high resistivity values (>300 Ohm.m) in greater depths. This could be a result of the lithological succession of the area, which is gradually changing from clay dominated to more sandy, overlaying the alpine basement (Alexopoulos *et al.,* 2017).

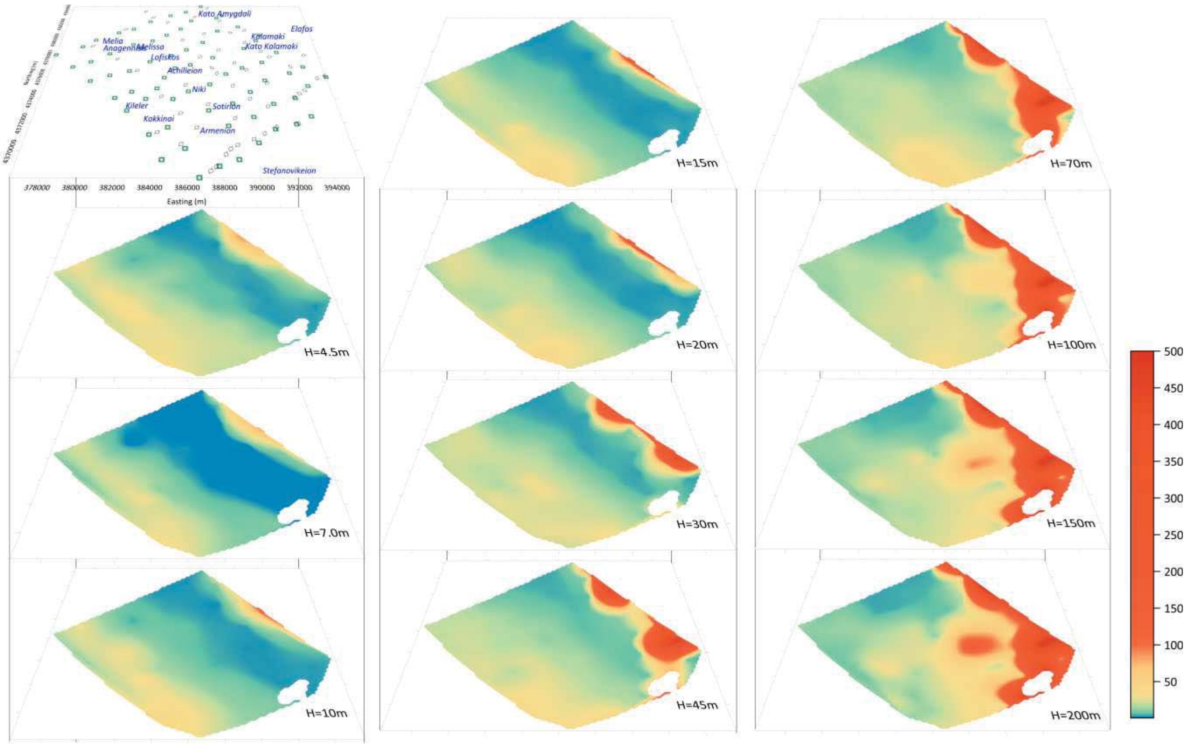

Figure 4 *Pseudo-3D resistivity imaging of the subsurface constructed with the 'horizontal' depth slices. The white area southeast corresponds to area with no information.*

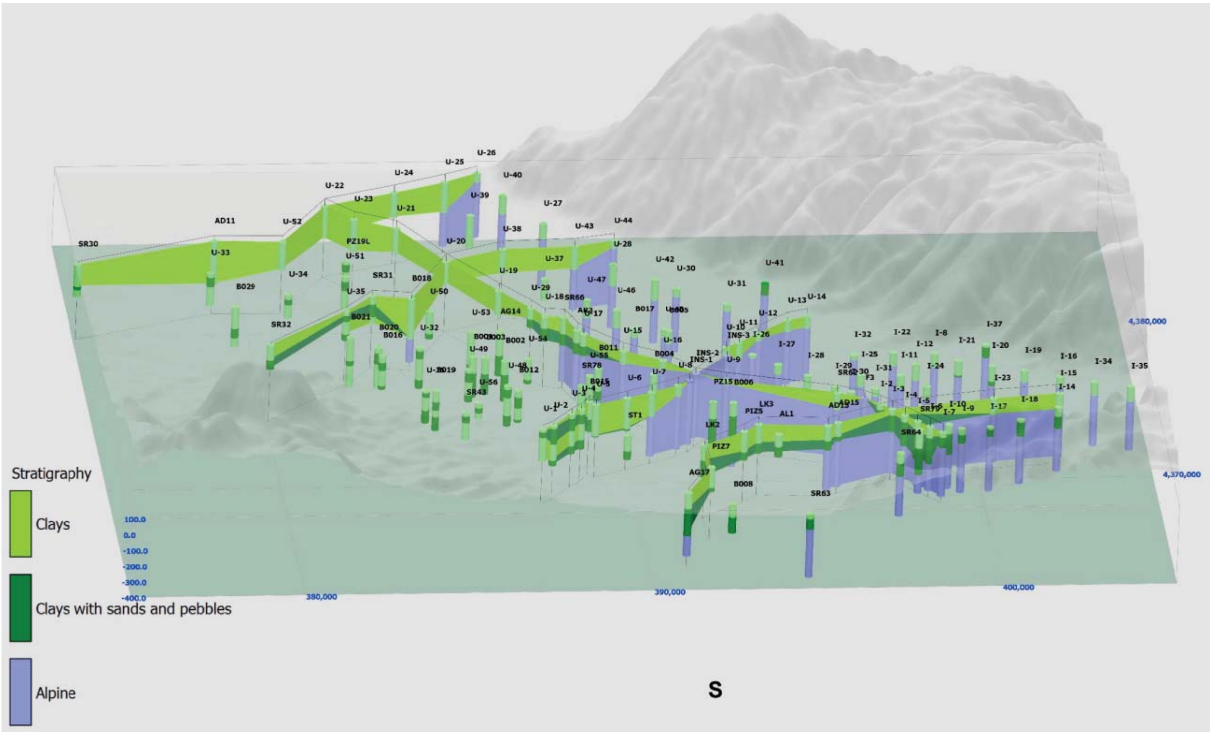

Figure 5. *Lithology Model of the study area. A Vertical Exaggeration equal to 5 has been selected for better visualization.*

The drilling data of 56 deep boreholes by Sogreah Grenoble (1974) was collected in order to validate and calibrate the geophysical data. All the borehole and VES interpreted data was grouped into three (3) categories: i) Clays, ii) Clays with sands and pebbles and iii) Alpine formation in order to construct the Lithology Model of the study area (Fig. 5).

Conclusions

The TEM and the VES methods were applied along the East Thessaly basin providing important information for the subsurface geological regime for depths up to 200 meters. As it is illustrated in Figure 5, the alpine basement has been detected at the southeast part of the basin, while at the northwest part it has not been detected, even from boreholes of 320 depth of investigation. The ground fissures (Fig. 3) are located at the latest part of the basin where the alpine bedrock has not been identified. Moreover, at that area the alluvial deposits are thick and coarse-grained. All these factors, along with the over-pumping of the basin cause the continuous creation of the fissures.

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