ΕΛΛΗΝΙΚΗ ΕΠΙΤΡΟΠΗ
ΥΔΡΟΓΕΩΛΟΓΙΑΣ

ΣΥΝΔΕΣΜΟΣ ΓΕΩΛΟΓΩΝ &
ΜΕΤΑΛΛΕΙΟΛΟΓΩΝ ΚΥΠΡΟΥ

HELLENIC CHAPTER OF IAH

CYPRUS ASSOCIATION OF
GEOLOGISTS & MINING
ENGINEERS

11th INTERNATIONAL HYDROGEOLOGICAL CONGRESS
Conference Proceedings

11Ο ΔΙΕΘΝΕΣ ΥΔΡΟΓΕΩΛΟΓΙΚΟ ΣΥΝΕΔΡΙΟ
Πρακτικά Συνεδρίου

ΤΟΜΟΣ 2
VOLUME 2

EDITORS: G. STAMATIS, K. VOUDOURIS, E. VASILEIOU, E.PSOMIADIS, M. DIAKAKIS,
M. POTAMIANOU, I. GRIGORIOU, L. ATHANASIADOU
ΕΠΙΜΕΛΕΙΑ: Γ. ΣΤΑΜΑΤΗΣ, Κ. ΒΟΥΔΟΥΡΗΣ, Ε. ΒΑΣΙΛΕΙΟΥ, Ε. ΨΩΜΙΑΔΗΣ, Μ. ΔΙΑΚΑΚΗΣ,
Μ. ΠΟΤΑΜΙΑΝΟΥ, Ι. ΓΡΗΓΟΡΙΟΥ, Λ. ΑΘΑΝΑΣΙΑΔΟΥ

ATHENS 2017
ΑΘΗΝΑ 2017

ΕΛΛΗΝΙΚΗ ΕΠΙΤΡΟΠΗ
ΥΔΡΟΓΕΩΛΟΓΙΑΣ

ΣΥΝΔΕΣΜΟΣ ΓΕΩΛΟΓΩΝ &
ΜΕΤΑΛΛΕΙΟΛΟΓΩΝ ΚΥΠΡΟ

HELLENIC CHAPTER
OF IAH

CYPRUS ASSOCIATION OF GEOLOGISTS &
MINING ENGINEERS

11th INTERNATIONAL
HYDROGEOLOGICAL CONGRESS

11ο ΔΙΕΘΝΕΣ
ΥΔΡΟΓΕΩΛΟΓΙΚΟ ΣΥΝΕΔΡΙΟ

CONFERENCE PROCEEDINGS
ΠΡΑΚΤΙΚΑ ΣΥΝΕΔΡΙΟΥ

VOLUME
ΤΟΜΟΣ
2

ORGANISED BY/ ΔΙΟΡΓΑΝΩΣΗ:

HELLENIC CHAPTER OF INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS-IAH
ΕΛΛΗΝΙΚΗ ΕΠΙΤΡΟΠΗ ΥΔΡΟΓΕΩΛΟΓΙΑΣ
CYPRUS ASSOCIATION OF GEOLOGISTS AND MINING ENGINEERS
ΣΥΝΔΕΣΜΟΣ ΓΕΩΛΟΓΩΝ ΚΑΙ ΜΕΤΑΛΛΕΙΟΛΟΓΩΝ ΚΥΠΡΟΥ

CO-ORGANISED BY/ ΣΥΝΔΙΟΡΓΑΝΩΣΗ:

AGRICULTURAL UNIVERSITY OF ATHENS
ΓΕΩΠΟΝΙΚΟ ΠΑΝΕΠΙΣΤΗΜΙΟ ΑΘΗΝΩΝ
NATIONAL TECHNICAL UNIVERSITY OF ATHENS
SCHOOL OF MINING &METALLURGICAL ENGINEERING
ΕΘΝΙΚΟ ΜΕΤΣΟΒΙΟ ΠΟΛΥΤΕΧΝΕΙΟ
ΣΧΟΛΗ ΜΗΧΑΝΙΚΩΝ ΜΕΤΑΛΛΕΙΩΝ-ΜΕΤΑΛΛΟΥΡΓΩΝ

EDITORS:
G.STAMATIS, K.VOUDOURIS, E.VASILEIOU, E.PSOMIADIS, M.DIAKAKIS, M. POTAMIANOU, I.GRIGORIOU, L.ATHANASIADOU
ΕΠΙΜΕΛΕΙΑ:
Γ.ΣΤΑΜΑΤΗΣ, Κ.ΒΟΥΔΟΥΡΗΣ, Ε.ΒΑΣΙΛΕΙΟΥ, Ε.ΨΩΜΙΑΔΗΣ, Μ.ΔΙΑΚΑΚΗΣ, Μ.ΠΟΤΑΜΙΑΝΟΥ, Ι.ΓΡΗΓΟΡΙΟΥ, Λ.ΑΘΑΝΑΣΙΑΔΟΥ

ATHENS 2017/ ΑΘΗΝΑ 2017

ISBN: 978- 618- 83393-0-9 (τ.1)

ISBN: 978- 960- 88816-9-3 (τ.2)

ΕΛΛΗΝΙΚΗ ΓΕΩΛΟΓΙΚΗ ΕΤΑΙΡΕΙΑ
ΕΛΛΗΝΙΚΗ ΕΠΙΤΡΟΠΗ ΥΔΡΟΓΕΩΛΟΓΙΑΣ
THE GEOLOGICAL SOCIETY OF GREECE
HELLENIC COMMITTEE OF HYDROGEOLOGY

Contact:
Georgios Stamatis Professor A.U.A., (0030) 210 529 4158
School of Agricultural Production, Infrastructure and Environment
Department of Natural Resources Management & Agricultural Engineering
Laboratory of Mineralogy &Geology
Iera Odos 75, P.C. 11855, Athens, Greece,
E-mail: stamatis@aua.gr

All scientific papers in the proceedings of the Congress have been evaluate and approved for publishing by the Scientific Committee.

Όλες οι επιστημονικές δημοσιεύσεις στα πρακτικά του Συνεδρίου έχουν αξιολογηθεί και εγκριθεί για δημοσίευση από την Επιστημονική Επιτροπή.

PRELIMINARY RESULTS OF THE APPLICATION OF TRANSIENT ELECTROMAGNETIC METHOD IN THE AREA OF KARLA LAKE (EAST THESSALY BASIN, GREECE)

ALEXOPOULOS J.D., DILALOS S. and MITSIKA G.S.*

National and Kapodistrian University of Athens, Faculty of Geology & Geoenvironment,
Department of Geophysics and Geothermy, Panepistimiopolis, Zografou, Athens, 15784,
jalexopoulos@geol.uoa.gr, sdilalos@geol.uoa.gr, g.mitsika@geol.uoa.gr,

Key words: TEM sounding, subsurface investigation, hydro-geophysics, resistivity maps

Abstract

In this paper we discuss the preliminary results of the Transient Electromagnetic Method (TEM) that was applied in the area of Karla Lake, located in the East Thessaly basin. A grid of 71 TEM soundings was planned and executed in order to investigate the subsurface lithological and hydrogeological conditions of the area. The geological regime of the area is comprised of the alpine basement (marbles, gneisses and schists), ophiolites, transgression formations and finally a package of post-alpine deposits with respectful thickness. Resistivity maps for certain depths of investigation along with a pseudo-3D representation were produced, based on the processed TEM data. The vertical distribution of the resistivity values revealed important information about the lithological succession of the area and the hydrogeological status of the post-alpine sediments covering the basin. Moreover, the limits of the former Karla Lake were delineated and the alpine bedrock was also adumbrated under the thick Tertiary and Quaternary deposits. Finally, taking into account older piezometric maps of 2009 and our geophysical results, we managed to indicate the decline of the groundwater level since then, in the central part of the study area and the broader area of Kileler settlement.

Introduction

The study area lies within the central part of mainland Greece. It is an elongated, NW-SE trending, flat basin developed to the west of Mavrovouni mountain and east of Chalkodonio mountain (Figure 1). For many years, until the 1960's, the historical natural lake called "Karla", existed at the southeastern margin of the East Thessaly basin. The region that was covered by the lake has the lowest elevation. As a result, all the surface water was gathered at that area.

The alpine basement rocks, crop out at the eastern and southeastern margins of the eastern Thessaly basin. The westernmost marginal area is comprised of Neogene continental sediments. The tectonic contact between the metamorphic and non-metamorphic rocks lies buried under the Quaternary fluvial and lacustrine sediments of the basin (Alexopoulos *et al*., 2013). Over-pumping, due to the intense agricultural use, led to significant decrease of the groundwater level and significant shrinkage of the aquifer during the last 30 years.

Time-Domain Electromagnetic (TDEM) or Transient Electromagnetic (TEM) exploration was carried out in order to delineate the subsurface geological and hydrogeological conditions of the area. In general, TEM field surveys require less time and fewer personnel than DC resistivity methods for similar depths of investigation (Albouy *et al*., 2001). The development of a transmitter loop with side equal to 40 meters is less time-consuming than a geoelectrical sounding with large electrode spacing (AB/2 > 500m) that would investigate up to the same depth. Moreover, the TEM method could be used in areas where topography or highly conductive surface conditions severely limit the effectiveness of other geophysical methods (Spies, 1976).

Geological – Hydrogeological Setting

Geological maps of scale 1:50.000 (Institute of Geology & Mineral Exploration-I.G.M.E.), topographic maps of scale 1:50.000 (Hellenic Military Geographical Service-HMGS) and historical maps illustrating the position of the former lake were gathered. These maps were unified, digitized and georeferenced into GIS environment according to the Greek Grid Coordinate System (EGSA '87) as shown in Figure 1. The locations of the TEM soundings (green squares) were planned based on a grid that would cover the study area with high spatial density.

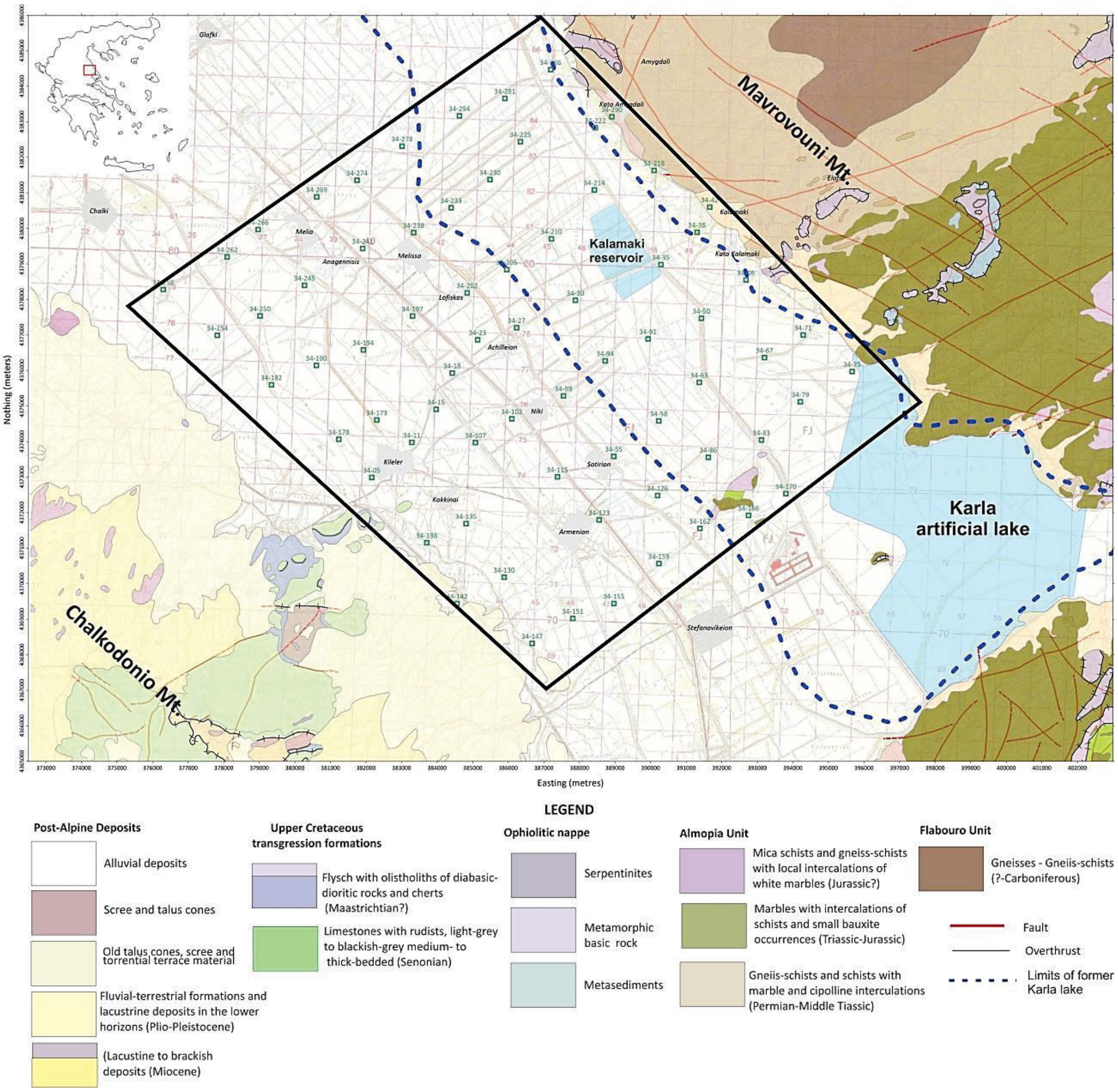

Figure 1. Geological map of the East Thessaly basin (modified from geological maps of "Ayia-Panayia Ayias", "Platycampos", "Velestinon" and "Volos" sheets of I.G.M.E). The rectangle encloses the study area. The locations of TEM soundings are illustrated with green squares.

Regarding the structural regime, the area is tectonically controlled by NW-SE and NE-SW faults. The main fault systems, with NW-SE direction, are considered the main ones, controlling the development of the East Thessaly basin and the Karla lake depression as well. An asymmetric extensional basin is formed, the active margin of which is dipping to the SW. The western margin is back-tilted towards the east, along a major tectonic contact, which is covered by the recent post-alpine sediments. Nevertheless, several dextral strike slip tectonic structures of WSW-ENE direction can be identified across the eastern marginal range (Alexopoulos *et al.*, 2013). These are possibly related to the northern branch of the active North Aegean Trough.

The descriptions of the geological formations in the following section are mainly based on the Ayia-Panayia Ayias, Platycampos, Velestinon and Volos Sheets of I.G.M.E.

Pre-Alpine formations

The Pre-Alpine formations observed in the area belong to Flabouro Unit, found on a large area of Mavrovouni. It consists of mica ortho- and para-gneisses, gneiss-schists with amphibole schists and amphibole intercalations. Aplite-pegmatite bedded sills locally occur, while there is a total absence of carbonate sediments. These crystalline basement formations are metamorphic in various facies and hydrogeological are characterized as hard fractured rocks of low permeability.

Alpine formations

The Alpine formations observed in the area belong to Almopia Unit (Pelagoniki s.s.).

- **Permo-triassic sequence:** Metamorphic rocks of various facies: Mica schists, gneiss-schists, amphibole schists, epidote-amphibole schists, amphibolites, prasinites and metadiabases dominate in these rocks, alternating laterally and vertically. Coarse-crystalline marble and cipolin intercalations of small thickness (up to 50m) and various colors often occur, mainly in their upper members. Their total thickness can be more than 800 meters.
- **Upper Triassic – Middle Jurassic marbles**: They constitute the regular upwards development of the previous mentioned formations. They are medium-bedded, locally thick-bedded to unbedded, intensively karstic, of blue-grey to black-grey color, bituminous, with intercalations of dolomitic marbles and crystalline dolomites mainly in their lower members. In their upper parts, they are mainly thin-bedded, of grey color, detached into plates, locally with mica schists intercalations or small bauxite deposits found.
- **Gneiss-schists, schists:** Light-colored, leucocratic, sometimes augen forming, microcrystalline. Locally in these rocks, thin-bedded marble intercalations of small thickness (up to 80m) are observed.

The Upper Triassic-Middle Jurassic marbles formation, the marble and cipolin intercalations of the gneiss-schists, the schists and the Permo-triassic sequence, due to the dissolution of the carbonate minerals are characterized as karstic formations of high permeability, due to their secondary porosity.

Metamorphic ophiolitic complex accompanied by metasediments

Due to an overthrust, the metamorphic ophiolotic complex lies tectonically on the Upper Triassic-Middle Jurassic marbles or the overlying gneiss-schists. It consists of serpentinites, metamorphic basic rocks and metasediments, which can be distinguished in amphibolites, prasinites and amphibolitic-epidotic-chloritic schists.

All the Serpentinites, the metamorphic basic rocks and metasediments are characterized as hard fractured rocks of low permeability.

Sediments of Upper Cretaceous transgression

These sediments lie uncomfortably over the Triassic-Jurassic formations or the ophiolitic complex-metasediments. They consist of grey limestones of Senonian age, medium to thick-bedded, crystalline, locally dolomitic, characterized by high permeability due to secondary porosity and flysch of Maestrichtian age with fine-to medium-grained sandstones, with intercalations of pelites in places laminated, conglomerates and sandy conglomerates. In the lower parts, olistoliths and olistostromes of various lithological composition are present. It is characterized as formation of very low permeability.

Post-Alpine sediments

The sediments of Quaternary and Neogene age consist of:

- **Alluvial deposits**: Light-grey to brownish-grey unconsolidated material of clay, sand, pebbles and fluvial-lagoonal materials. There is a gradual transition from the coarse materials of the margin to the fine-grained ones, towards the central part of the basin.
- **Scree and talus cones:** Loose rock fragments of various size and lithological composition with fine-grained material between them, occurring at the margins of the alluvial basins.
- **Old talus cones, scree and torrential terrace material (Pleistocene-Holocene)**: Coarse -grained material with pebbles and fragments of various sizes, cemented usually by carbonate material. Terraces height about 20 meters.
- **Fluvial-Terrestrial formations (Plio-Pleistocene)**: Red clays, clayey sandy material of low cohesion, with dispersed rounded and angular pebbles or coarser-grained elements of various lithological composition. Their lower parts are consisted of lacustrine-terrestrial facies with considerable amount of marly material and constitute the upward gradual transition of the underlying Miocene deposits of the area.
- **Lacustrine to brackish deposits (Miocene)**: Grey to whitish friable marls, in beds of 5-20cm thickness and in places laminated, sometimes argillaceous, greenish. In places and mainly in the upper parts, hard marls and marly travertinoid limestones occur of whitish yellow color. They are porous formations of very low permeability (almost impermeable). Their effective porosity is practically considered zero.

The Quaternary deposits (alluvial deposits that consist of clay, silt, sand and pebble alternations, fluvial-lagoonal materials, scree and talus cones) and the Plio-Pleistocene formations consist of porous formations of fluctuating permeability.

Geophysical Survey

Over the last three decades the TEM method has become increasingly popular for environmental and groundwater investigation (Auken *et al*., 2003; Kalisperi *et al*., 2009). TEM surveys are used for hydro-geophysical applications (Christensen *et al*., 1998; Danielsen *et al*., 2003) and for the determination of the subsurface geological structure. The basic distinction in the hydro-geophysical investigations of unconsolidated sediments is between clayey and sandy formations (Christensen *et al*., 1998). The TEM method offers excellent images of deep-seated low-resistive layers and is capable of resolving geological structures and layers in the overlying succession (Jorgensen *et al*., 2005). Moreover, the Transient Electromagnetic method has been applied for identifying, mapping and temporal monitoring of the fresh-saltwater interface (El-Kaliouby *et al*., 2015, Kontar E. K. *et al*., 2006, Qahman *et al*., 2001).

During the field measurements, a direct current is transmitted through an ungrounded loop. This results in a primary magnetic field. Then, the current is shut off abruptly, which based on Faradays Law, induces an electrical field in the surroundings. This induced electrical field will produce electrical currents in the ground, called ‘eddy currents’ because of their form. These ‘eddy currents’ will generate a secondary magnetic field now. During the measurement, the change of the secondary field is measured while the primary field is absent, eliminating the difficulties we meet with frequency domain methods. The TEM method is highly sensitive to low-resistivity layers since a larger amount of the current flows in these layers. The diffusion speed depends on the resistivity of the layers, therefore the diffusion speed will be high for high-resistivity layers and low for low-resistivity layers (Christiansen *et al*., 2009).

A dense grid of 71 TEM soundings was carried out covering the entire basin area (Figure 1). All the soundings were performed with the ABEM WalkTEM Time Domain Ground EM system. The ABEM WalkTEM instrument has a built-in GPS, which automatically records the position and stores it along with the collected data. A Windows XP Pro platform is incorporated into the ABEM WalkTEM unit, supporting the measuring interface.

A typical field configuration for data acquisition, along with the WalkTEM, comprises of a 40m x 40m square transmitter loop (Tx-loop), with two in-loop antennas (the 10m x 10m RC-200 and the 0.5m x 0.5m RC-5), each with different receiver areas as shown in Figure 2. The RC-5 receiver is optimized for high resolution, shallow soundings while the RC-200 is suitable for deeper soundings. With this field setup, a depth of almost 200 meters can be investigated. The data processing and inversion were carried out with ViewTEM software, developed by The HydroGeophysics Group of Aarhus University, Denmark.

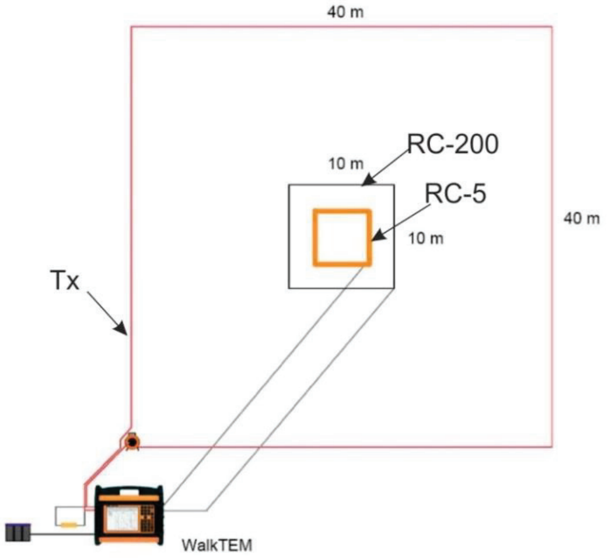

Figure 2. A typical TEM field configuration (Modified from ABEM instruments, 2016).

Results and Discussion

The TEM soundings have been interpreted using both multi-layer (20 layers) and few-layer (5 layers) inversion models. Resistivity maps for certain depths of investigation were produced based on the results of the multi-layer inversions. The ‘horizontal’ resistivity maps of 4.5m, 7m, 10m, 15m, 20m, 45m, 70m, 100m, 150m and 200m investigation depth were produced. For the spatial interpolation of the resistivity values of all the TEM soundings the Natural Neighbor gridding method (Sibson, 1981) was used. A pseudo-3D representation of the subsurface was produced (Figure 3) with all the depth resistivity maps in order to have a better visualization of the resistivity distribution, both vertically and laterally.

At the eastern area of the resistivity maps (Figure 3), 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 explained due to the lithological succession of the area, which is gradually changing from clay dominated to more sandy, overlaying the alpine basement. Small decrease in resistivity values of the coarse sediments is observed (~15-20 Ohm.m) in the west, mainly after the first 100 meters depth.

According to Archie’s law (Archie, 1942) the resistivity of the sediments is inversely proportional to the ion content of the pore water. Hence, aquifers are expected in areas with relatively small resistivity values.

More specifically, Figure 4 depicts the resistivity map of 15 meters depth. The high conductivity zone (<5 Ohm.m) located in the north and northeast, delineates the limits of the former lake due the fine grained materials containing high amount of clay that was deposited there. The presence of this conductive zone around ‘Petra’ outcrop, which consists of gneiss-schists and marbles, is a sign of the steep gradient of its margins. This morphological outcrop of the alpine basement is delimited, probably, by normal faults.

In the north-west and south, the resistivity values are higher (10-40 Ohm.m) probably due to the existence of unsaturated, coarse grained, shaly-sand sediments. In the area of Kalamaki and Kato Kalamaki, relatively high resistivity values (80-120 Ohm.m.) have been revealed, probably due to the thick deposits of old talus cones and scree, cemented usually by carbonate material.

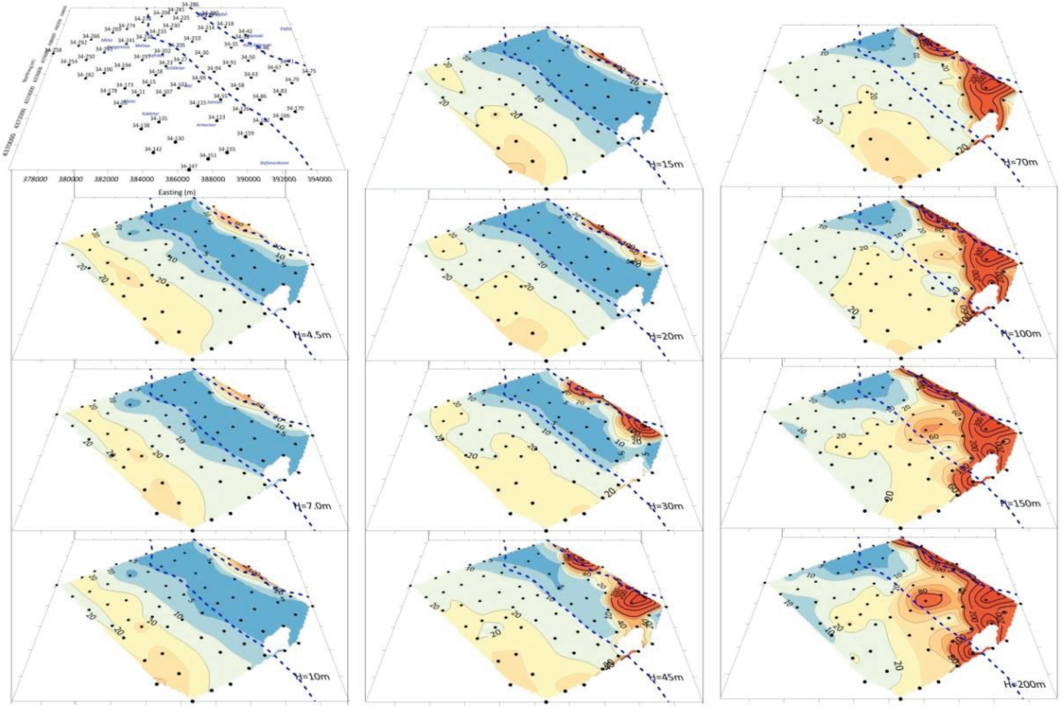

Figure 3. Pseudo-3D resistivity imaging of the subsurface, based on the depth resistivity maps. The blue dashed line represents the limits of former Karla lake.

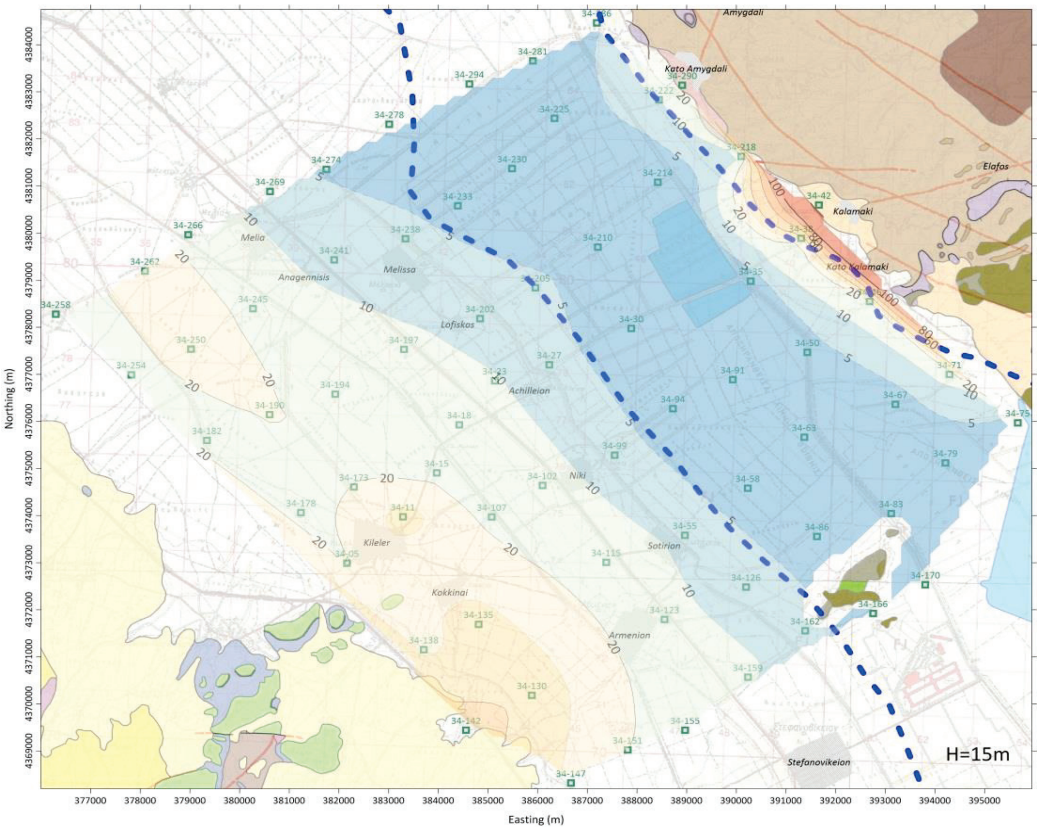

Figure 4. Resistivity map for the depth of 15m. The blue dashed line represents the limits of former Karla lake.

In Figure 5 the resistivity distribution for the depth of 70 meters is presented. The high conductivity (<5 Ohm.m) zone that was observed at the 15-depth slice has been restricted to the north area only. The resistivity regime of the western margin of the basin shows a similar pattern, with locally small variations. In the central part of the study area, the resistivity values vary from 10 to 20 Ohm.m. Nearby the ‘Petra’ outcrop, high resistivity values have been revealed (>100 Ohm.m), probably due to its alpine margins. The alpine basement seems to extend up to ‘Barouti Magoula’ area, where the TEM sounding 34-67 was carried out. It is located in the north-east and along the margin of Mavrovouni Mountain. The resistivity values at this area exceed the 400 Ohm.m. Unfortunately, the discrimination between the different alpine lithologies of the area is quite difficult, based only on the geophysical data.

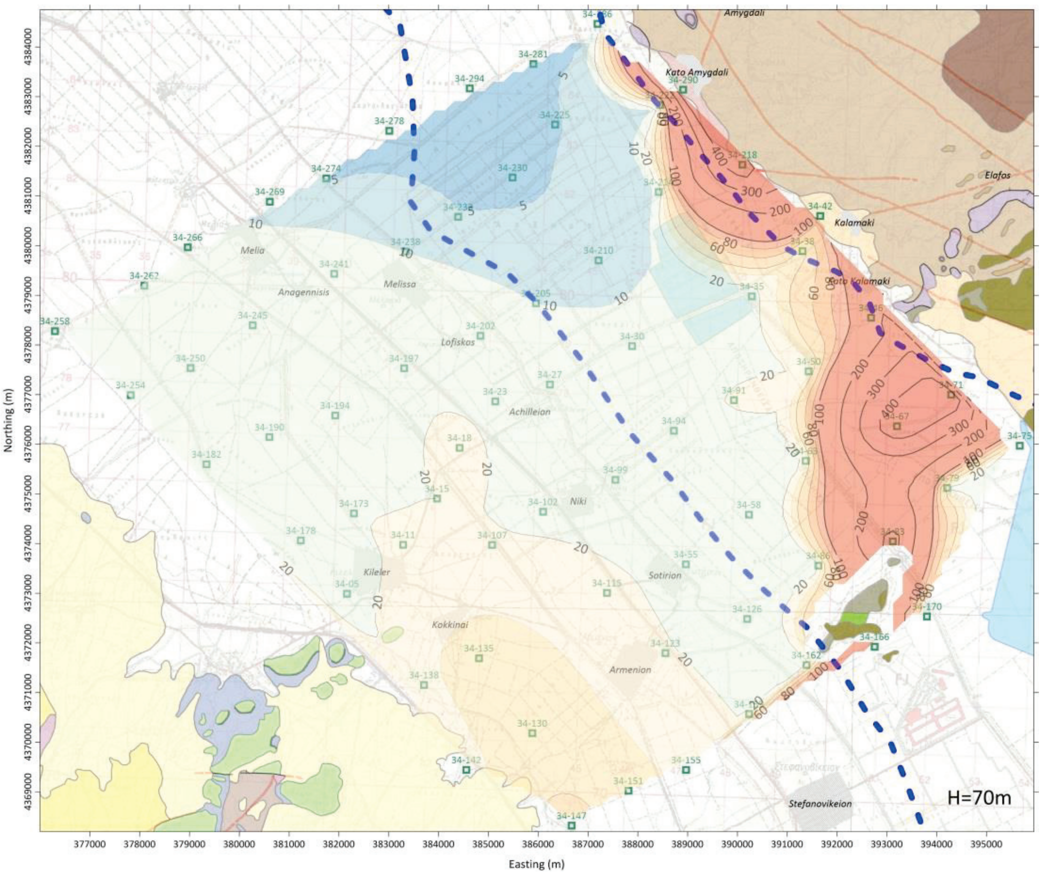

Figure 5. Resistivity map for the depth of 70m. The blue dashed line represents the limits of former Karla lake.

At the horizontal map of 200 meters depth (Figure 6), the extent of the resistive area (>200 Ohm.m) has been increased. Except the east margin of the basin and around ‘Petra’ outcrop, there is an area of high resistivity values, northeast of Niki village, where TEM sounding 34-94 had been carried out. This could be evaluated as the occurrence of the alpine basement. Despite the big depth of investigation (200m.), the zone of high conductivity in the north has been enlarged. Moreover, another conductive zone has been revealed (10 Ohm.m) in the west margin of the basin.

Taking into account piezometric maps of 2009 (Dimopoulou, 2011), there are no aquifers located in the study area until the depth of 20 meters. This information indicates that the delineated highly conductive zone in the north is a result of the layers’ alternations consisting of clay and sand. These layers cannot be adumbrated individually due to their very small thickness. The absolute elevation of the groundwater level for the broader area of Kileler settlement (west part of the study area) was -8 meters, based on the piezometric maps of 2009, which corresponds to a depth of approximately 80 meters. The decrease in the resistivity values in that area, that could indicate the existence of aquifer, starts generally after the 100m depth. This could be justified by the continuous decline of the groundwater level during the last 7 years.

In the central part of the study area (Figure 3), low resistivity values (10 Ohm.m) correspond possibly to the existence of a porous aquifer and not to the presence of clay (<5 Ohm.m) that begin at the depth of approximately 50-60 meters. According to the piezometric maps of 2009, the groundwater level at that region was located at a depth of 40 meters. Therefore, a decline of the groundwater level is also observed in this area.

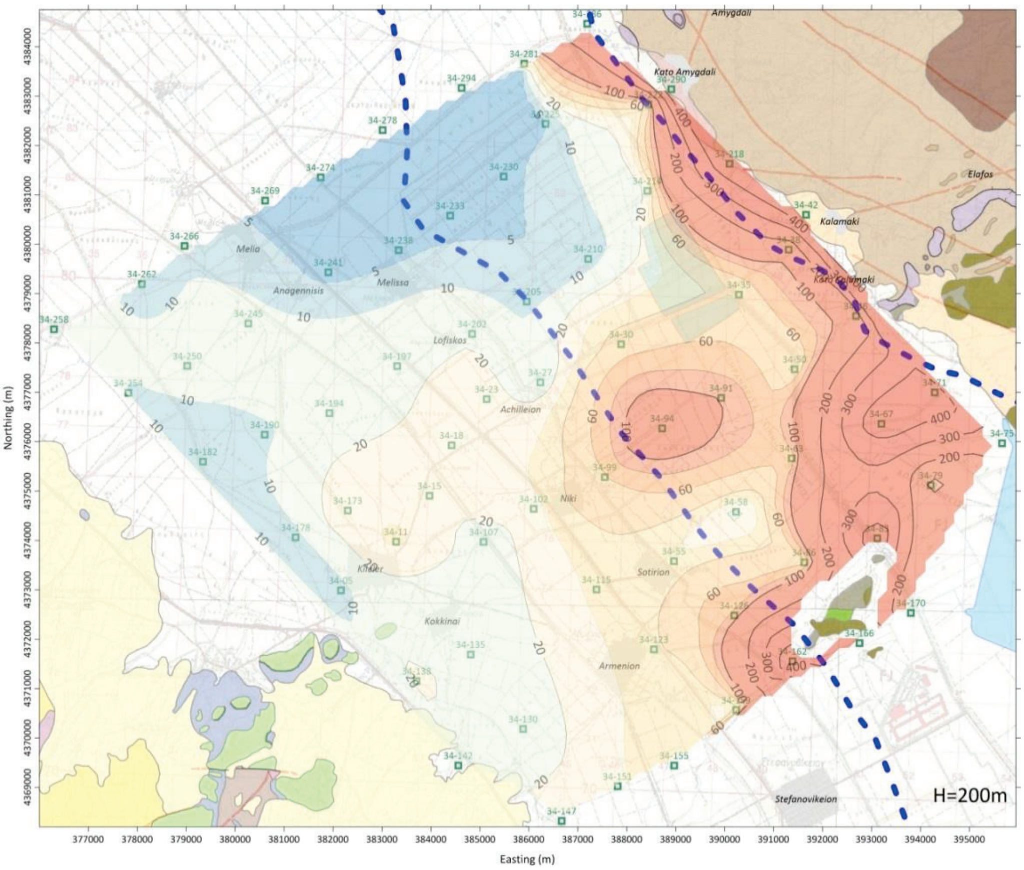

Figure 6. Map of distribution of resistivity in depth of 200m. The blue dashed line represents the limits of former Karla lake

Conclusions

The Transient Electromagnetic (TEM) method applied in the Karla lake basin, provided important information for the geological and hydrogeological subsurface status. The depth of the post-alpine sediments and the locally adumbration of the alpine bedrock in the investigated area was determined for depths up to 200 meters. Additionally, regarding the hydrogeological status, a decline of the groundwater level of 15-20 meters was estimated, since 2009, in the central part of the study area and the broader area of Kileler settlement. This information verifies the over pumping problem that seems to exist in the area, which seems to be the reason for the existence of severe surface cracks, all over the area, that even cause damages to the houses of the villages.

Furthermore, the TEM survey should be expanded in the future to the southeast margins of the basin, in order to investigate the possible hydraulic communication between the alluvial deposits and the karstic marbles. Reports of salination (Dimopoulou, 2011; Papakosta, 2010; Skordas, *et al.,* 2012) of the karst and consequently of the alluvial aquifer, reveal the need for identifying, mapping and temporal monitoring of the fresh-saltwater interface as the intrusion of seawater is a potential source of groundwater pollution.

6. Acknowledgements

The authors would like to thank Kalampoki E., Mavroulis S., Kaplanidi H. and Farangitakis P. for their valuable contribution during the field work campaigns.

7. References

ABEM Instruments (2016). WalkTEM User Guide: 42

Albouy, Y., Andrieux, P., Rakotondrasoa, G., Ritz M., Descloitres, M., Join, J. L., Rasolomanana, E. (2001). Mapping Coastal Aquifers by Joint Inversion of DC and TEM Soundings-Three Case Histories, Groundwater, 39: 87-97

Alexopoulos, J., Vassilakis, E., Dilalos, S., Pantelis, C., Papadopoulos, T. (2013). Identification of buried active structures with preliminary geophysical and morphotectonic analysis, at eastern Thessaly basin, Greece, 4th International INQUA Meeting on Paleoseismology, Active Tectonics and Archeoseismology (Eds. Grützner C., Rudersdorf A., Pérez-López R., Reicherter K.), 9-14, Aachen, Germany

Archie, G. E. (1942). The electrical resistivity log as an aid in determining some reservoir characteristics, Trans. AIME, 146: 54–67, 280

Auken, E., Jorgensen, F. and Sorensen, K.I. (2003). Large-Scale TEM Investigation for Ground-Water. Exploration Geophysics, 33: 188-194

Christensen, N.B. and Sorensen, K.I. (1998). Surface and Borehole Electric and Electromagnetic Methods for Hydrogeological Investigations. European Journal of Environmental and Engineering Geophysics, 3: 75-90

Christiansen, A.V., Auken, E. and Sorensen, K. (2009). The transient electromagnetic method Groundwater Geophysics. A Tool for Hydrogeology, 2nd ed., Springer-Verlag Berlin Heidelberg

Danielsen, J.E., Auken, E., Jorgensen, F., Sondergaard, V.H. and Sorensen, K.I. (2003). The Application of the Transient Electromagnetic Method in Hydrogeophysical Surveys. Journal of Applied Geophysics, 53: 181-198.

Dimopoulou, M., (2011). Hydrogeological survey in the area of ground fissures in Karla East Thessaly, M.Sc Thesis, National & Kapodistrian University of Athens (*in Greek*).

El-Kaliouby, H. and Osman, A. (2015). Application of time-domain electromagnetic method in mapping saltwater intrusion of a coastal alluvial aquifer, North Oman. Journal of Applied Geophysics, 115: 59-64

Jorgensen, F., Sandersen, P.B.E., Auken, E., Lykke-Andersen, H. and Sorensen, K. (2005). Contributions to the Geological Mapping of Mors, Denmark-A Study Based on a Large-Scale TEM Survey. Bulletin of the Geological Society of Denmark, 52: 53-75

Kalisperi, D., Soupios, P., Kouli, M., Barsukov, P., Kershaw, S., Collins, P., Vallianatos, P. (2009). Coastal Aquifer Assessment using Geophysical Methods (TEM, VES), Case Study: Northern Crete, Greece, 3rd IASME / WSEAS (GES'09), Cambridge, UK, 158-164

Katsikatsos, G., Vidakis, M. and Migiros G., (1981). Geological Map of Greece, scale 1:50.000, sheet Platycampos, IGME, Greece

Katsikatsos, G., Mylonakis, I., Triantaphyllidis, E., Papadheas, G. and Psonis, C. (1983). Geological Map of Greece, scale 1:50.000, sheet Velestino, IGME, Greece

Katsikatsos, G., Vidakis, M., Hecht, J. and Papadheas, G. (1986). Geological Map of Greece, scale 1:50.000, sheet Volos, IGME, Greece

Kontar, E.K., Ozorovich, Y. R. (2006). Geo-electromagnetic survey of the fresh/salt water interface in the coastal southeastern Sicily, Continental Shelf Research, 26: 843–851

Migiros, G. and collaborators, (2008). Record – Evaluation of hydraulic works proposals of the area Kato Olympoy-Ossas-Mavrovouniou. Technical Report: 282

Migiros, G. and Vidakis, M., (1984). Geological Map of Greece, scale 1:50.000, sheet Ayia-Panayia Ayias, IGME, Greece.

Papakosta, E., (2010). Hydrologic and hydrogeological conditions of the hydrologic Karla basin and planning of rational water source management. M.Sc Thesis, Agricultural University of Athens (*in Greek)*

Qahman, K.A. and Zhou, Y. (2001). Monitoring of Seawater Intrusion in the Gaza Strip, Palestine, First International conference on Saltwater Intrusion and Coastal Aquifers Monitoring, Modeling, and Management. Essaouira, Morocco

Sibson, R., (1981). A brief description of natural neighbor interpolation, in V. Barnett, ed., Interpreting Multivariate Data: John Wiley & Sons: 21–36

Skordas, K., Kosmidis, D., Liapis G., Tzamouranis N., Vafidis, D., (2012). The likely effect of underground waters level fall of S.E. Thessaly because of salinity of lake Karla. 10th Panhellenic Symposium of Oceanography & Fisheries. Athens: 8

Spies, B.R., (1976). The Transient Electromagnetic Method in Australia, BMR Journal of Australian Geology & Geophysics, 1: 23-32.