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ABSTRACT

This paper focuses on the use of geological and geophysical tools in order to contribute in creating a cultural route from the town of Neapoli to the coastal areas, through the cisterns of Epano Mirabello, Eastern Crete. The first stage of this study involves the restoration and use of the threatened traditional wells and cisterns. In order to achieve this, a detailed geological mapping of the area and a geoelectrical survey were conducted to estimate the thickness of the soil layer (impermeable substrates). The methodology used in this paper provided valuable information regarding the subsoil condition and the sources of the cisterns' water supply system, helping in the proper planning of the cultural route.

Keywords
Karst environment**,** traditional wells, temporary ponds, protection and restoration, Electrical Tomography, Eastern Crete

1. INTRODUCTION

Epano Mirabello region is located in central Crete (Municipality of Aghios Nikolaos), between the touristic areas of Malia and Elounda, south of the national road. Due to the dry sub-humid climate of Crete in general, the water resources management in the past was based on traditional methods such as dry-stone constructions of wells and cisterns. Dry-stone walling was also used in wells distributed in the karst depressions within the metamorphic sequence of the Plattenkalk Group. In the area of Mirabello, groups of drystone cisterns are located in the intersection of geological faults in order to collect groundwater, while the surface rainwater is collected withinn temporary ponds. However, the abandonment of the unagricultuterd land, in combination with the big pressure of the coastal massive tourism needs, have caused the gradual destruction of these human artefacts.

The creation of a cultural route, connecting the most interesting of these historical locations will offer a double benefit: a) the restoration and use of the cisterns, b) an alternative touristical activity capable of creating new work positions. This study is focused on temporary pond located southwestern of Kourounes village, where the local residents have constructed several traditional cisterns, in order to extend water supply through the dry season of year. The lack of maintenance and the abandonment of these traditionally made cisterns, in combination with the soil removal from the pond, have resulted in the gradual deconstruction of the cisterns.

The future existence and preservation of the temporary pond now comes into question, since the surface soil consists of terra rossa, which act as impermeable layer that holds surface water preventing it from migrating downwards through tectonically permeable rocks belonging to the regionally dominant metamorphic rocks of the Plattenkalk Group. This emphasize the necessity of estimating the thickness of the surface soil through a geological/geophysical study.

2. TEMPORARY PONDS

Wetlands are being created and restored with great frequency around the world. The importance of wetland conservation is recognized worldwide, because they represent hot spots of biological richness as well as they are a source of freshwater supply and food. Wetlands are very diverse in their nature, ranging from open water to forested ecosystems or from shallow permanent lakes to temporary ponds. In terms of conservation, some temporary standing freshwater wetlands are considered important habitats for conservation and are recognized by the Ramsar Convention on Wetlands. Furthermore, some are classified as priority habitats by the European Union Habitats Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora (European Commission, 2007).

Temporary ponds, a form of wetland, are shallow water bodies that remain flooded for a sufficiently long period of time during winter and spring. They often occur in shallow depressions with an impermeable ground and have a relatively small catchment area. The depression present a significant variability in size, shape and depth. They usually are endorheic (i.e. closed, with no outflow) but allow the development of (semi) aquatic vegetation and animal communities. Temporary ponds exhibit a self regulating hydrology. The hydrological dynamics of these ponds and the consequent temporary availability of resources are crucial for these habitats' species specificity and diversity (Beja and Alcazar, 2003; Dimitriou et al, 2006; Zacharias et al, 2007; Canals et al, 2011; Pinto-Cruz et al, 2011).

Temporary ponds are globally known under more than 30 different names such as vernal pools, daya's, brumal pools, copular pools, ephemeral waters, etc. and in Greece with different names: *αρόλιθοι*, *ρουσιές* and *κολύμπες*. The use of numerous names indicates the lack of unique classification system for temporary ponds. There is not yet a widely accepted classification system for temporary ponds to characterize them. This has possibly led to the deficiency of information about the main characteristics and differences between the various types of these habitats. In the Mediterranean region there are many types of temporary ponds that vary from small copular ponds (<1 m^2 < 50 cm deep), hollowed out in rocks to almost permanent lakes, which sometimes cover an area of several hectares. In particular, Mediterranean temporary ponds are considered one of the most remarkable and most threatened freshwater European habitats. Mediterranean temporary ponds are poorly understood and highly endangered, suffering widespread degradation and loss due to increases in the area of land under intensive cultivation and urban use (Beja and Alcazar, 2003, Zacharias et al, 2007).

In Greece there are 18 temporary ponds sites, 73% of which are encountered in Aegean islands due to the semi arid climatic conditions that facilitate their existence (Table 1 and Fig. 1). Only 1 out of 18 sites is located in the mainland, whereas the island of Crete has the highest presence of temporary ponds from any other region of the country. The amount of rainfall in these islands rarely exceeds 600mm a year and the prolonged dry period prevents permanent dominance of aquatic vegetation. All sites, except one, are affected by anthropogenic pressures such as, overgrazing, agriculture and hydrological disturbance also comprising the most common threats on temporary ponds throughout Greece. The most common threat of the habitat originates from intensive agriculture which either expands over the temporary ponds or pollutes their water with fertilizers. In some cases, there is also artificial recharge of temporary ponds as a restoration practice, which often results in extended wetting phase and can even make the ponds permanent (Dimitriou et al, 2006, Zacharias et al 2007). The construction of cisterns in the region of Kourounes inside the area where temporary ponds exist might be the reason why this area is not in the catalog of the protected areas of Greece.

SITE CODE	NATURA CODE	SITE NAME	AREA (ha)
Site 1	GR1430004	ETHNIKO THALASSIO PARKO ALONNISOU - VOREION SPORADON, ANATOLIKI SKOPELOS	249145.62
Site 2	GR2440002	KOILADA KAI EKVOLES SPERCHEIOU - MALIAKOS KOLPOS	47547.07
Site 3	GR4110001	LIMNOS: CHORTAROLIMNI - LIMNI ALYKI KAI THALASSIA PERIOCHI	18231.66
Site 4	GR4110002	AGIOS EFSTRATIOS KAI PARAKTIA THALASSIA ZONI	6283.75
Site 5	GR4110003	LESVOS: DYTIKI CHERSONISOS - APOLITHOMENO DASOS	20974.07
Site 6	GR4110004	LESVOS: KOLPOS KALLONIS KAI CHERSAIA PARAKTIA ZONI	18297.82
Site 7	GR4210004	KASTELLORIZO KAI NISIDES RO KAI STRONGYLI KAI PARAKTIA THALASSIA ZONI	1769.68
Site 8	GR4210007	NOTIA NISYROS KAI STRONGYLI KAI PARAKTIA THALASSIA ZONI	4056.74
Site 9	GR4210008	KOS: AKROTIRIO LOUROS - LIMNI PSALIDI - OROS DIKAIOS - ALYKI-PARAKTIA THALASSIA ZONI	10138.24
Site 10	GR4220005	PARAKTIA ZONI DYTIKIS MILOY	5328.25
Site 11	GR4220006	NISOS POLYAIGOS-KIMOLOS	13855.78
Site 12	GR4220007	NISOS ANTIMILOS-THALASSIA PARAKTIA ZONI	1260.76
Site 13	GR4220010	VOREIODYTIKI KYTHNOS: OROS ATHERAS-AKROTIRIO KEFALOS KAI PARAKTIA ZONI	2855.19
Site 14	GR4220014	KENTRIKI KAI NOTIA NAXOS: ZEFS KAI VIGLA EOS MAVROVOUNI KAI THALASSIA ZONI (ORMOS KARADES-ORMOS MOUTSOUNAS)	8668.41
Site 15	GR4340001	IMERI KAI AGRIA GRAMVOUSA - TIGANI KAI FALASARNA - PONTIKONISI, ORMOS LIVADIA-VIGLIA	5781.30
Site 16	GR4340002	NISOS ELAFONISOS KAI PARAKTIA THALASSIA ZONI	271.79
Site 17	GR4340010	DRAPANO (VOREIOANATOLIKES AKTES) - PARALIA GEORGIOUPOLIS - LIMNI KOURNA	4430.51
Site 18	GR4340013	NISOI GAVDOS KAI GAVDOPOULA	6290.59

TABLE 1 Temporary Ponds site codes, names and size (Source: Natura, 2000 database)

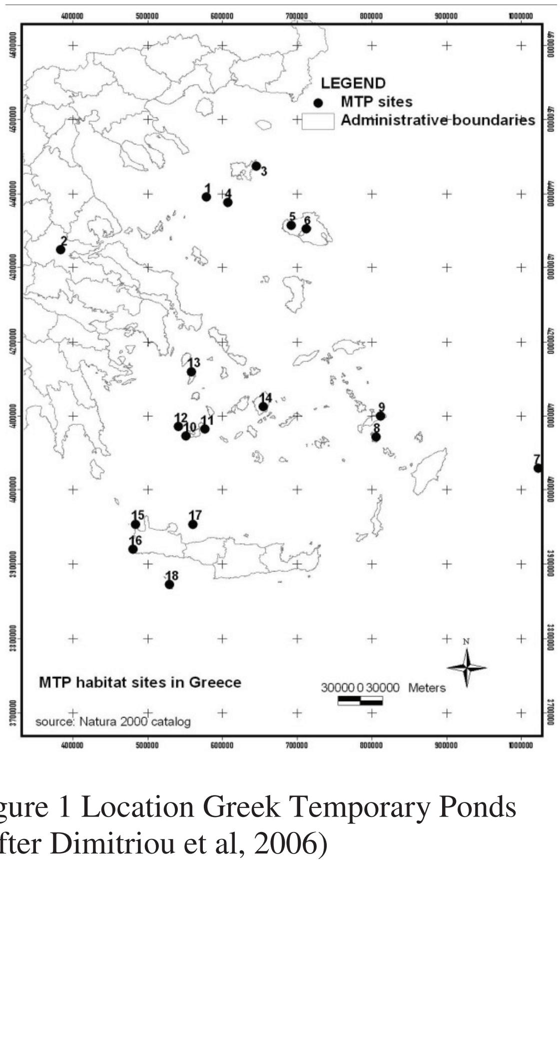


Figure 1 Location Greek Temporary Ponds (after Dimitriou et al, 2006)

3. GEOLOGICAL SETTING

The geological framework of Crete consists largely of nappes of contrasting lithologies and metamorphism that were stacked southwards during an Oligocene to early Miocene N-S compression. Most of the whole nappe stack of continental Greece is recognised in Crete. However, it has a reduced thickness and more important shortening. The nappes are stacked from top to bottom, i.e. from the most internal to external units in the following order: Asterousia nappe, Miamou nappe, Arvi nappe, Pindos-Ethia nappe, Tripolis nappe, Phyllite nappe and Trypali nappe. The Plattenkalk Group represents the lowermost known tectonic unit beneath the nappe pile of Peloponnesus and Crete (Fig. 2) and their formation has been involved in the tectonometamorphic process during the Oligocene-Miocene (Manutsoglu et al, 2003).

Geology of Mirabello Peninsula

Wachendorf et al (1980) published stratigraphic data regarding the Plattenkalk Group of the Mirabello peninsula (Eastern Crete). They described only cherty limestone sequences ("Plattenkalke"), suggesting that the underlying units are not exposed there and the overlying Kalavros formation was tectonically suppressed (Fig. 3). The authors subdivided the rocks lithostratigraphically into three units, according to the amount of cherty layers or horizons of chert nodules embedded, supposing that the sequence was not overturned: The base containing more than three layers of chert per meter (about 200 m thick), a transitional zone with 1-3 chert-layers per meter (about 80 m thick) and an upper unit with less than one chert layer per meter (about 1300 m thick).

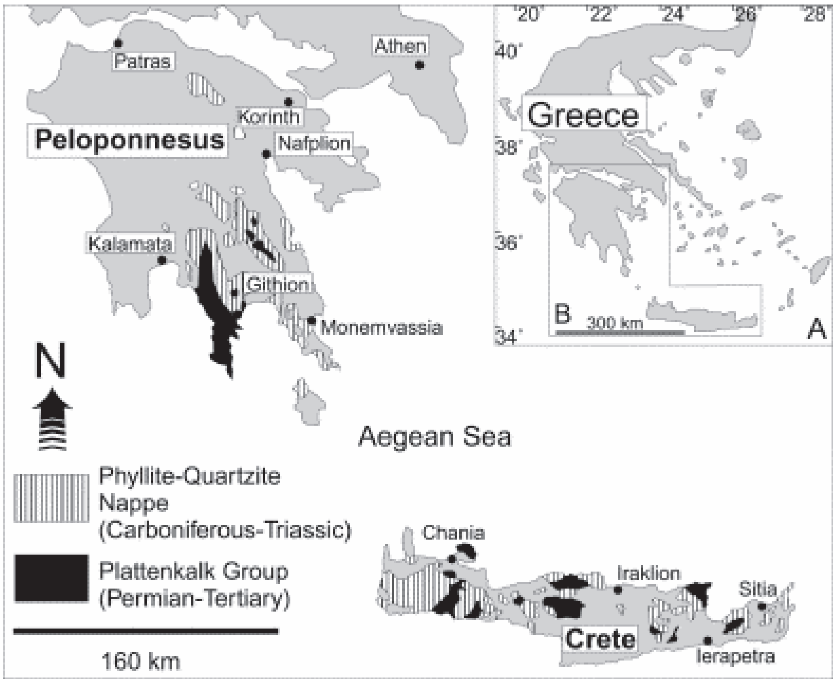


Figure 2: Distribution of the metamorphic Phlyllite-Quarzite Nappe and Plattenkalk Group on Peloponnesus and Crete (after Manutsoglu et al, 2003)

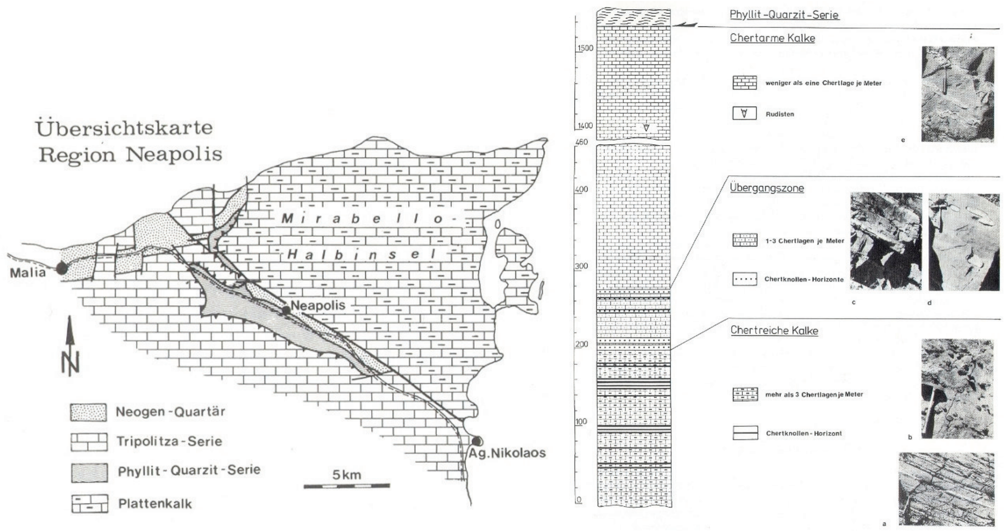


Figure 3: Geological map of Mirabello peninsula (after Wachendorf et al, 1980) with the lithological column

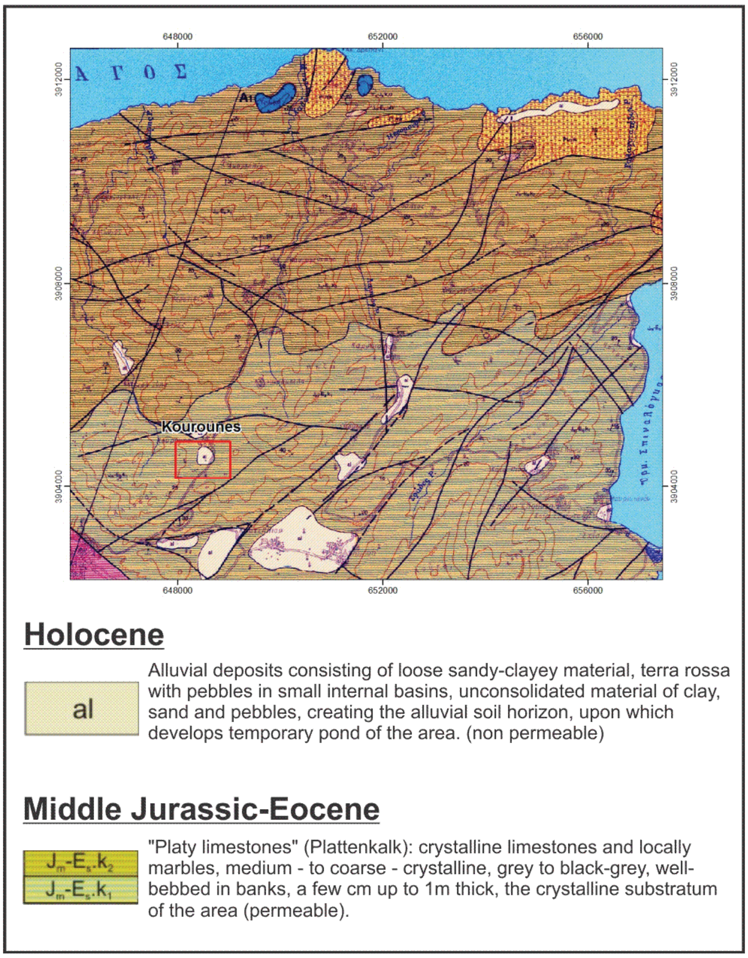


Figure 4: Part of geological map sheet Agios Nikolaos (Knithakis et al 1987) showing the study area

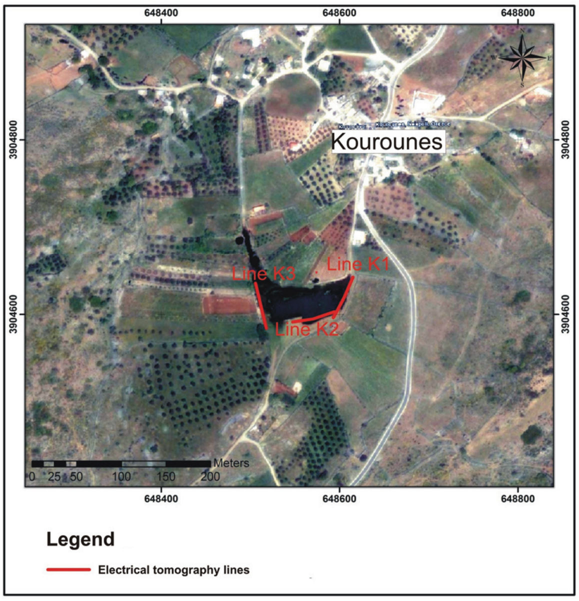
In 1987 the geological map was published in scale 1:50.000, sheet Agios Nikolaos (Fig.4, Knithakis et al 1987) and presented the stratigraphical and lithological columns in the entire area. Later, Soujon et al (1998) presented a lithological correlation between the occurrences of the Plattenkalk

Group of the Talea and the Ida Ori (central Crete) with those of the Lefka Ori (western Crete) and of the Mirabello peninsula (eastern Crete). Following the road from Neapolis to Nofalias (Fig. 4) and leaving Kourounes towards the northern coast, thin bedded limestones with some red or green calcisiltitic horizons and chert-layers are observed at several localities. These very characteristic rocks are also well exposed in the Ornon Oros in eastern Crete. Farther to the north, they trespass into the typical, reddish or greenish calcschists of the Kalavros formation, which are often mylonitised and tectonically overlain by brecciated limestones of the Tripolitza group. The thickness of these members of the Plattenkalk Group can not be estimated exactly, as the outcrops are bad. They suggest only a few metres for each type of rock.

A detailed geological mapping of the area has clearly shown that the temporary pond was formed as a result of karstic erosion, by the enlargement of smaller surface depression (doline) within the metamorphic rocks of the Plattenkalk Group. Doline has a relatively small catchment area, and is located in the Southeastern of an endorheic basin (i.e. closed drainage basin with no outflow) and is covered by a relatively thick layer of soil. Conjugate sets of faults in NNW-SSE and NNE-SSW directions have locally defined the shape of the karstic morphology of the area.

4. GEOPHYSICAL SURVEY

The geophysical survey was employed to estimate the thickness of the surface soil, and give any additional information regarding the geology of the temporary ponds subsurface. It comprises of three electrical resistivity tomography (ERT) lines in selected locations within the pond (Fig.5, Table 2). The Wenner – Schlumberger array was preferred, due to its high signal-to-noise ratios and sensitivity to vertical changes in the subsurface, in order to define the transition of terra rossa to metamorphic limestones of the Plettenkalk Group. A total of 55 electrodes, with 1 m electrode spacing, were employed to give a sufficient resolution for an accurate estimation of the thickness of the soil layer. The StingR1/ Swift AGI system was used for the acquisition of the resistivity data.



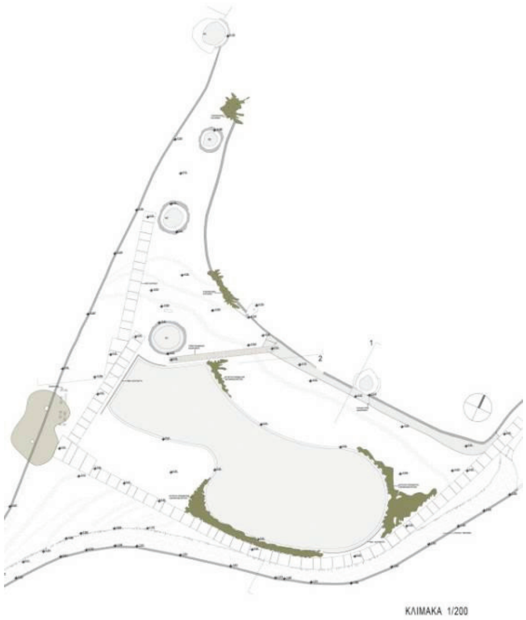


Figure 5: Satellite image of study area in Kourounes village (Google Earth) showing the position of electrical tomography lines and a proposal sketch map showing the position of the cisterns around the temporary pond

The inversion of the apparent resistivity data was carried out using the RES2Dinv software (Loke and Barker, 1996). The L1 norm-method was employed (Clayerbout and Muir, 1973) in order to enhance the sharp boundaries between the soil and the rock formation. According to inverted resistivity sections (Figs. 6-8), two different geoelectrical layers were observed in each line. The first one comprises values less than 40 Ωm, covering the largest part of the sections and is interpreted as terra rossa deposits. The other comprises values between 90-300 Ωm, covering the minor part of the deepest zone of the sections and is as attributed to karstified limestone rocks.

TABLE 2: Geophysical survey characteristics

LINE	Direction	Length	Maximum Depth	Resistivity range	
				Upper layer	Lower layer
K1	NE-SW	54m	12m	<40 Ωm	90-200 Ωm
K2	SW-NE	54m	12m	<40 Ωm	90-200 Ωm
K3	NW-SE	54m	12m	<40 Ωm	90-300 Ωm

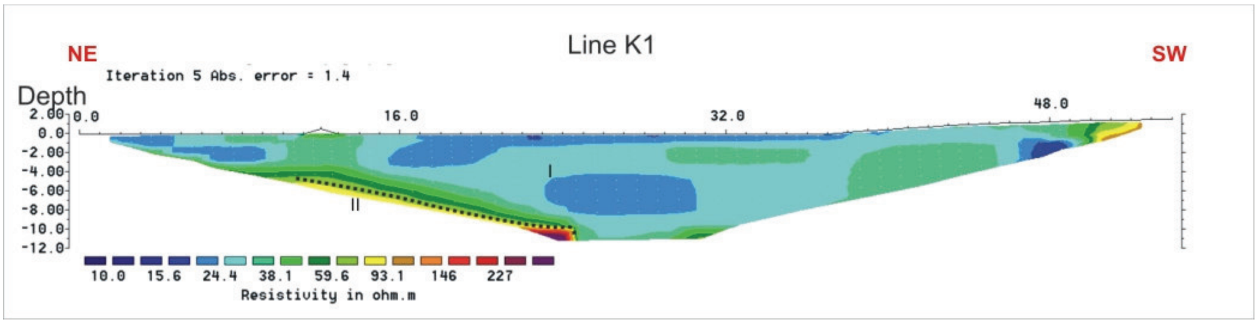


Figure 6: Geoelectrical section Line K1 by the use of norma L1 and Wenner-Schlumberger array. The direction of line is from northeast to southwest. Dashed black line separates Terra Rosa (I) from limestone (II)

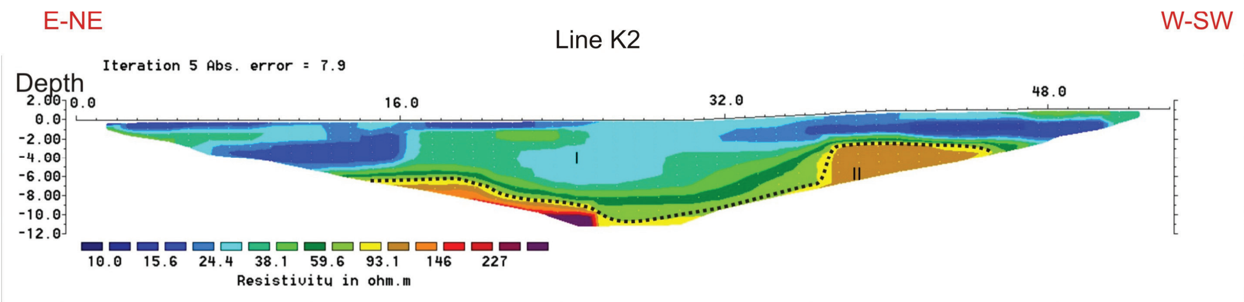


Figure 7: Geoelectrical section Line K2 by the use of norma L1 and Wenner-Schlumberger array. The direction of line is from southwest to northeast. Dashed black line separates Terra Rosa (I) from limestone (II)

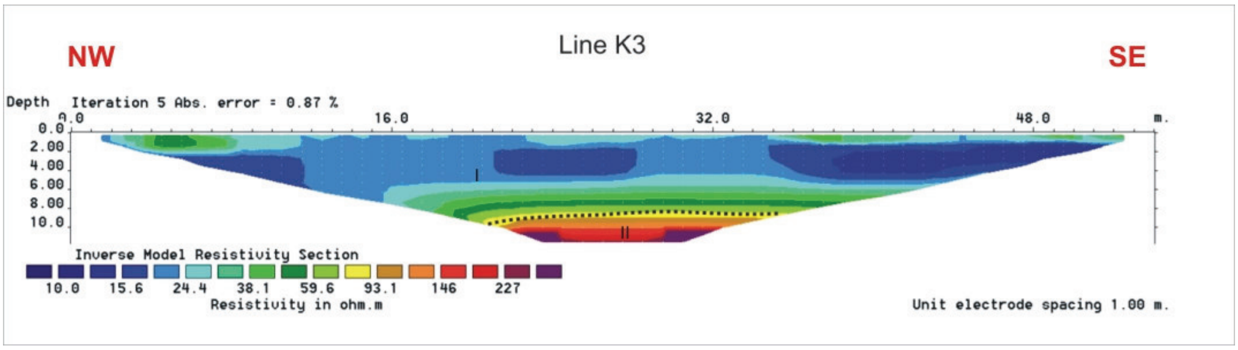


Figure 8: Geoelectrical section Line K3 by the use of norma L1 and Wenner-Schlumberger array. The direction of line is from northwest to southeast. Dashed black line separates Terra Rosa (I) from limestone (II)

Fig. 9 shows a spatial representation of the Geoelectrical sections. The thickness of the terra rossa deposits can be estimated around 9-12 m at the North-eastern part of the investigated area, while it decreases towards the South-western parts, where it is estimated around 6m. This gives valuable information about the pattern of the limestone roof underneath the soil deposits.

5. CONCLUSIONS

This project focuses on creating a cultural route from the town of Neapoli to the coastal areas, through the most interesting locations of the inland (Skoutelis et al, 2011). The first stage of this study involves the restoration and use of the threatened traditional wells and cisterns. Circular dry-stone cisterns are presented with nearly vertical masonry walls and with no major structural problems except in specified areas and also a larger non circular cistern with greater wall inclination to the vertical, exists which wall has largely collapsed. The physicochemical chatacterization both of the surrounding soils and the construction materials of the various cisterns can be considered as an important tool towards the classification of the conservation state and the consequent decision making of the appropriate interventions.

After a detailed geological mapping of the area, a geoelectrical survey was conducted in order to estimate the thickness of the soil layer (impermeable substrates) at Kourounes Mirabello, where five wells are located. More specifically, three electrical tomography sections aided to define the terra rosa layer, whose thickness ranges from 7m to 12m. Thickness variations of soil cover in combination with morphological observations (smooth slopes of the surrounded cliffs) lead to the conclusion of a preexisted dissolution doline which has been covered by soil layer. In such situations water supply might be from two different sources. Apart from surface drainage, water might come from subsurface aquifers in a periodical or occasional manner. Any change in soil thickness from anthropogenic reasons could have irreversible consequences regarding soil preservation and hydraulic equilibrium of the doline.

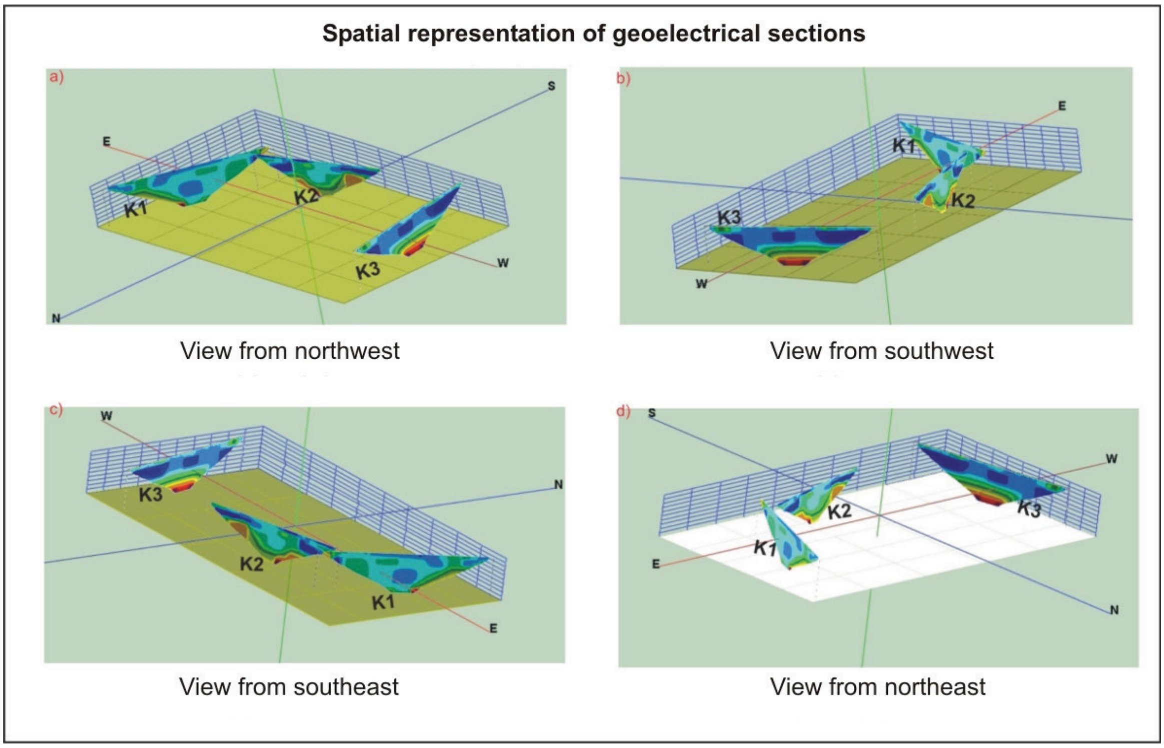


Figure 9: Spatial representations of the geoelectrical sections. (a) View from northwest, (b) view from southwest, (c) view from southeast and (d) view from northeast

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