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Geophysical investigations for aquifer detection in fissured rocks of volcanic origin. A case history

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Abstract: *A combined geophysical survey was conducted to investigate the possibility of detecting aquifer horizons characterized by secondary porosity development due to variations in textural structure. The SE part of Aegina Isl. (Perdika area) which is composed of volcanic rocks, namely of lower seated dacitic lavas overlain by pyroclastic rocks, was chosen for further investigation. Schlumberger soundings carried out along the long axis of the drainage system showed the existence of four geoelectrical layers instead of two which are the basic geological units of the whole area under investigation. This discrepancy is due to the presence of two distinct geological phenomena. The first, in the upper structure, results as a consequence of weathering and fracturing processes and is strongly dependent on lithologic phase changes of volcanic rocks. As a result a phreatic horizon could be developed in areas that are highly weathered and/or fractured. The deeper structure, on the other hand, is tectonically affected showing a great number of discontinuities filled mainly with water. The high transverse resistance value (T>5000 Ohm.m^2), of the layer just above the deepest and conductive layer is attributed to dry dacitic lavas. The deepest conductive layer with intense deformation does not seem to be affected by sea water intrusion even at depths lower than sea level. The top surface of the conductive layer is not regularly spread over the area of investigation showing that the potentially developed aquifer within the fractures depends on the pre-existing topographic relief. The aim of the VLF survey was to detect any vertical or oblique conductive zones that could be associated with large scale tectonic features. Linear elements drawn from aerial photographs are strongly connected with anomaly zones outlined from VLF data. A model of the deep seated aquifer for the area under investigation to explain the recharging mechanism based on geophysical results as well as geologic and tectonic evidence is proposed.*

Key words: *Electrical soundings, VLF, Volcanic Rocks, Aquifer, Aegina, Perdika.*

INTRODUCTION

The exploration of water bearing formations is of vital importance particularly for areas covered by volcanic rocks. The development of a potentially extended aquifer depends mainly on the nature of the rocks, the pre-existing relief of the land and the original family of joints produced during the cooling procedure of magma. The epigenetic joints or fractures due to the tectonic movements are strongly connected with the original family of joints. As a result the statistical processing of all discontinuities shows a random character that can not be applied everywhere. So, the volcanic rocks can potentially become aquifers depending on their joint density and the grade of hydraulic interconnection of the rock discontinuities. The hydraulic and hydrogeological behaviour of lavas and pyroclastic rocks differ substantially.

The hydrogeological regime of a volcanic area is a complicated one, due mainly to the inhomogeneity of the medium, the number and orientation of joints and the presence of large tectonic features running the area.

The phreatic horizon is usually heterogeneous and it is characteristically referred that a wide range of specific discharge values (0.5-8.5 m^3/h) of wells and shallow boreholes has been reported (Stournaras et.al., 1993). The development of deeper aquifers in such environments is of vital importance.

The detection of water bearing formations, by using potential geophysical methods, has started to be elaborated many years ago (Minasian, 1979, Fournier,1989, Medeiros and Lima, 1990, Bernard and Valla, 1990). Most of the literature deals with the detection of deep seated aquifers and little work has been done on the enrichment mechanism that keeps supplied these horizons.

In this paper, the hydrogeological regime of the broad area of Perdika at Aegina island, Greece, is considered and a model of the enrichment mechanism of the deeper horizon is attempted, based on combined geophysical surveys (geoelectrical soundings and VLF measurements).

GEOLOGICAL STRUCTURE

The SE part of Aegina Isl. (area of Perdika) is composed mainly of two types of volcanic rocks i.e. the lower seated dacitic lavas overlain by pyroclastic rocks. Figure 1 shows the geological and tectonic map of the area under investigation. The coastal fluvial deposits cover only a small percentage of the whole area.

Borehole data showed the existence of two water bearing horizons, one phreatic and another deeper that extents locally below the sea level. The discharge values are low as it was expected but potentially enough to solve local watering needs. These aquifers depend on joint density and the grade of hydraulic interconnection of the rock discontinuities (Stournaras, 1989). The hydraulic and hydrogeological behaviour of lavas and pyroclastic rocks differ substantially.

On the other hand, the presence of two aquifers inside the body of volcanic rocks requires an internal structural variation of rock mass coherency created possibly by a different joint interconnection texture and dense fractures that were developed through tectonic processes. This variation is actually reflected in the resistivity distribution of the medium as the geoelectrical survey pointed out (Fig. 2).

This structure is extended laterally in a broad area as it is revealed from the Schlumberger soundings carried out along the long axis of the drainage system (Fig. 3 and 4).

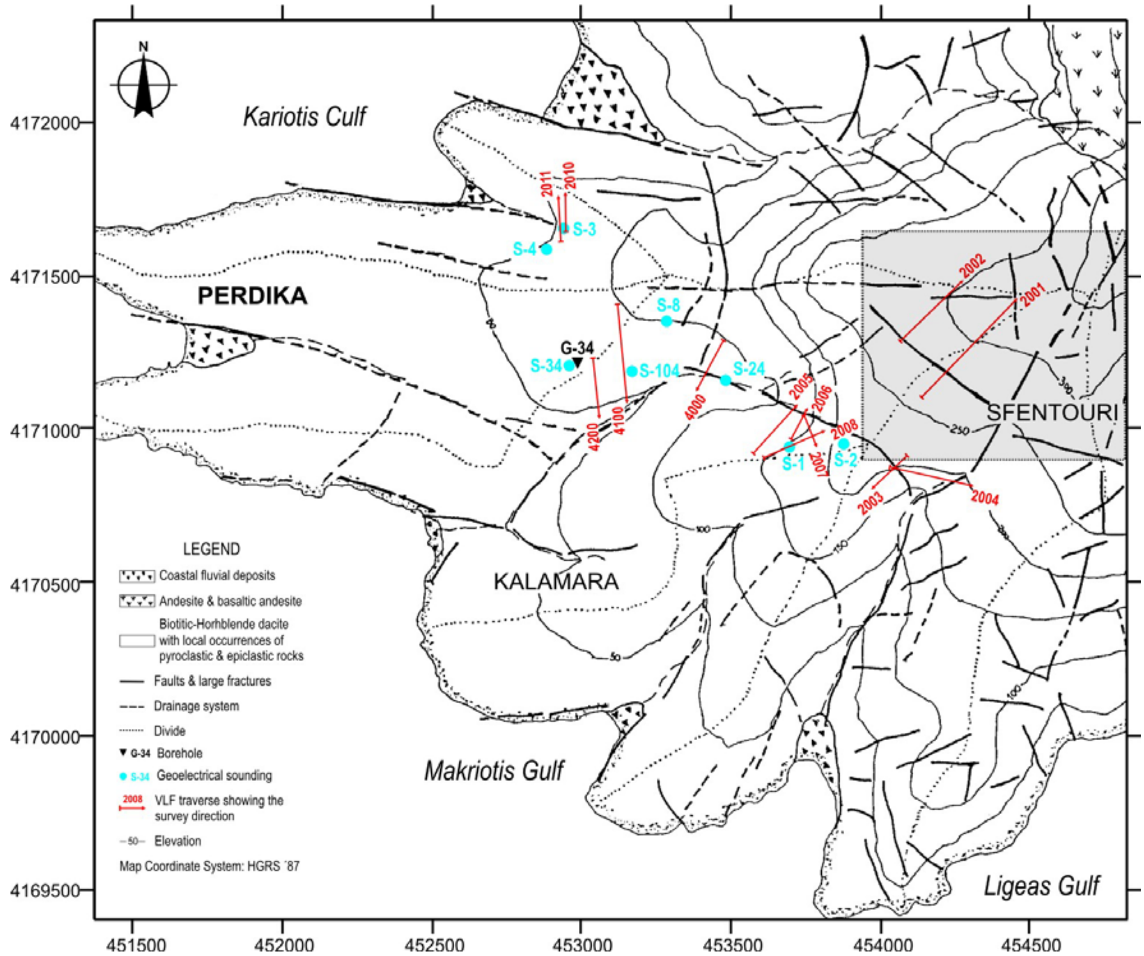


FIG. 1. A map showing the main geologic and tectonic features of the area under investigation. The locations of the geoelectrical soundings and the VLF traverses are also shown.

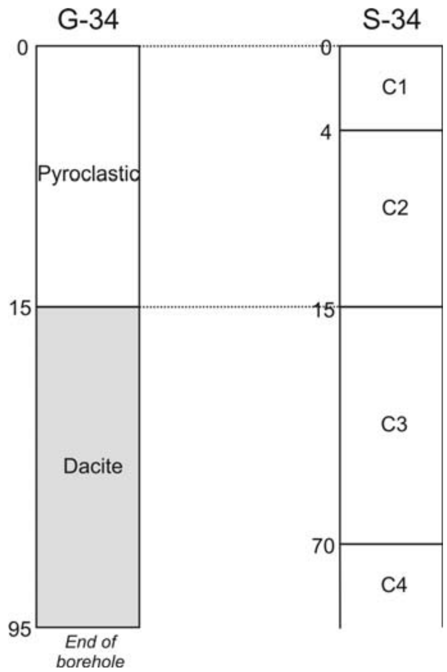


FIG. 2. A comparison diagram showing the broad geological structure of the study area and its correlation with the geoelectrical sounding results. The presence of 4 geoelectrical layers instead of the 2 basic geological units is obvious. C1 presents the dry shallow layer of pyroclastic rock (240 Ohm.m) and C2 presents the layer where a phreatic aquifer is developed (230 Ohm.m), according to the borehole hydrogeological data. The lower resistivity value of C2 layer is attributed to the presence of low water content inside the fissured pyroclastic rock. C3 presents the intermediate dry dacitic rock (450 Ohm.m) and C4 the deeper conductive layer (130 Ohm.m) of the highly fractured dacitic rock.

GEOELECTRICAL SURVEY

A quite number of geoelectrical soundings were carried out in the area of Perdika, to delineate the resistivity distribution of the medium with depth and to detect low and high conductivity layers. The maximum current electrode distance of Schlumberger configuration was 630 m.

The processed data (Zohdy, 1989) are summarised in Figure 3. The cross-section shown in Figure 5 presents the resistivity distribution along the long axis of the drainage area, respectively. This section presents the lateral stratification of the geoelectrical layers and the resistivity variation with depth. The high transverse resistance value (T>5000 Ohm.m^2) of the layer just above the deepest and conductive layer, is attributed to the presence of dry dacitic lavas.

The deepest conductive layer with intense deformation does not seem to be affected drastically by sea water intrusion even at depths below the sea level. The top surface of the conductive layer is not regularly spread all over the area of investigation (Fig. 4), indicating the dependence of a potentially developed aquifer on the pre-existing topographic relief.

VLF MEASUREMENTS

A VLF survey was also carried out to detect any vertical or oblique conductive zone that could be associated with large scale tectonic features. Besides, the existence of such zones would provide a reliable explanation of water enrichment of the deeper aquifers.

Figure 6 shows linear elements drawn from aerial photographs which intersect the VLF profiles. The pseudosections of equivalent current density of the Real component and the associated anomaly zones of higher conductivity, clearly indicate the presence of large inclined fracture zones (Fig. 7b and 8b). Taking into account that the transmission frequency is f=20.3 KHz and an average resistivity value of ρ=400 Ohm.m, the penetration depth of the VLF method is less than 100 meters.

It is remarkable that some VLF anomalies are high enough in both Real and Imaginary components, indicating the presence of very conductive material (Fig. 7a and 8a). Structures associated with high values of Real component and low values of the Imaginary component, are related to the presence of semi-conductive and water bearing fracture zones.

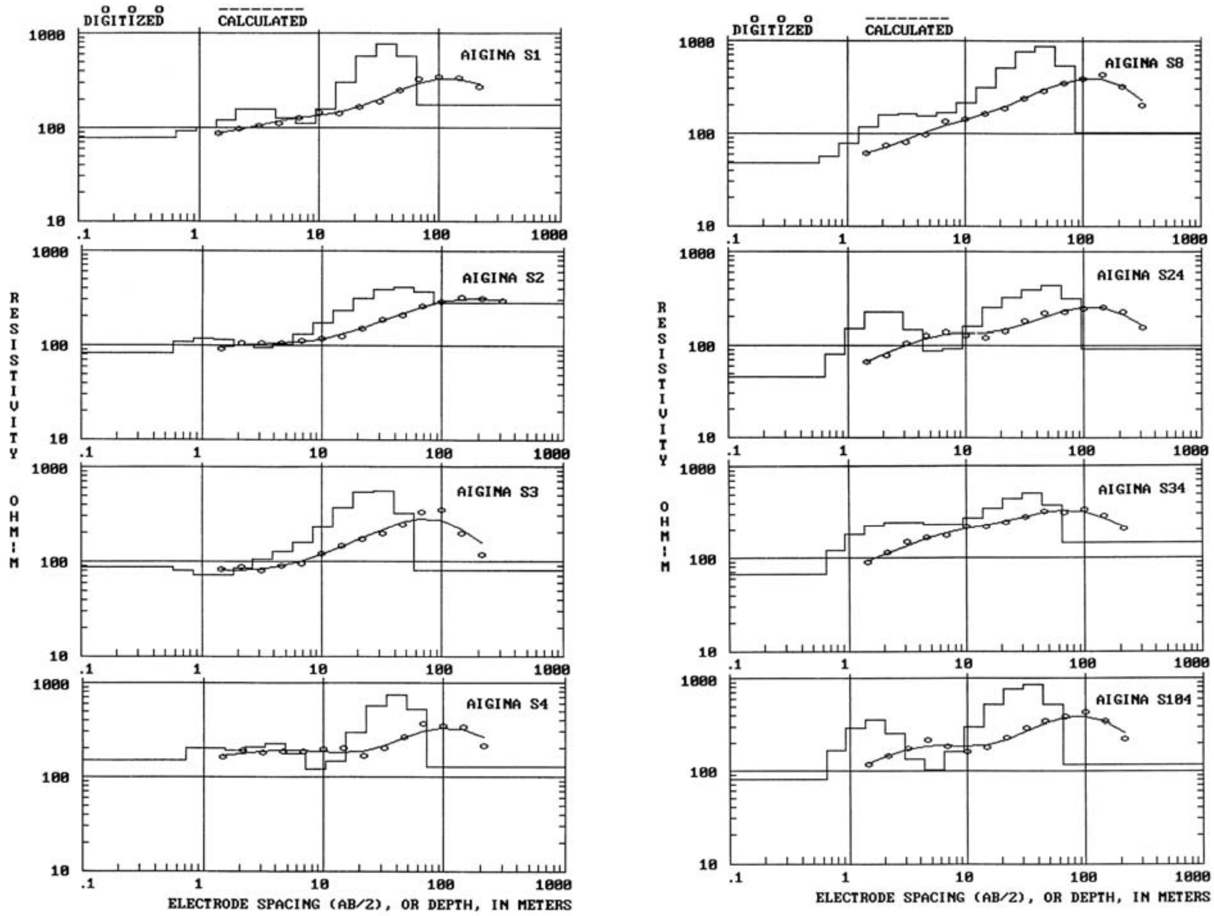


FIG. 3. Graphical presentation of the results after processing of VES (Zohdy, 1989).

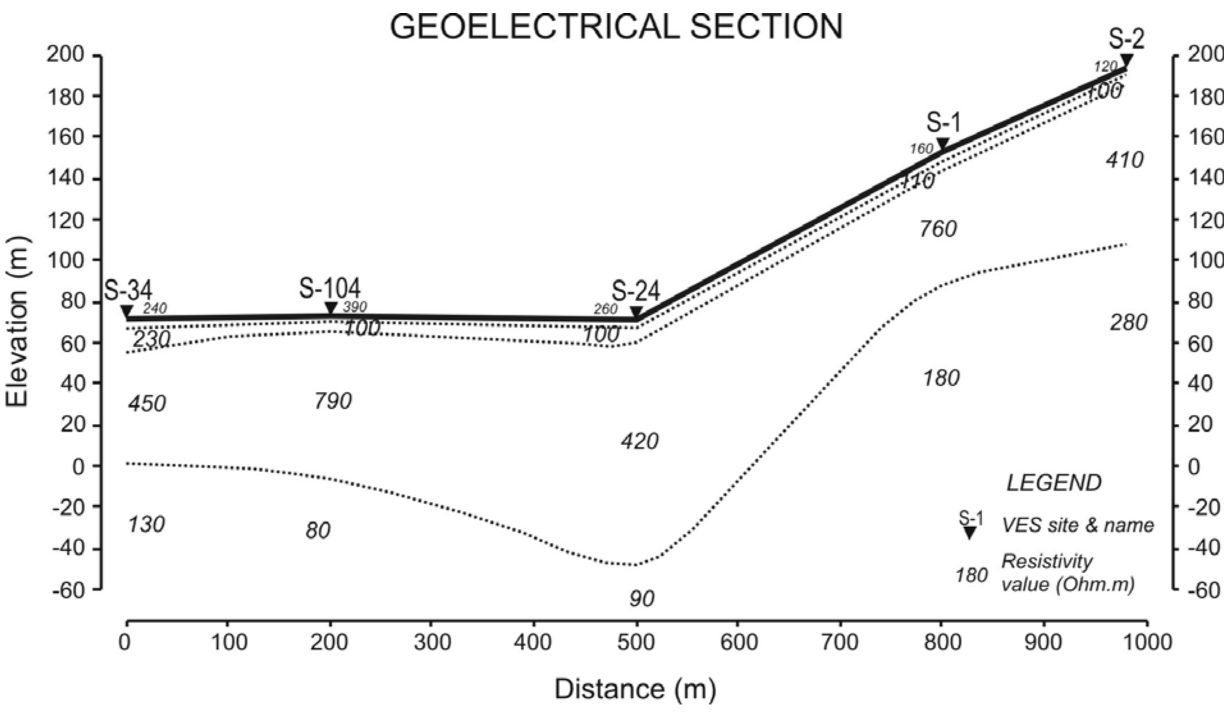


FIG. 4. A geoelectrical cross-section based on the interpretation scheme indicated in Figure 3. Three discontinuities are present along the whole length of the profile, showing a stratified structure.

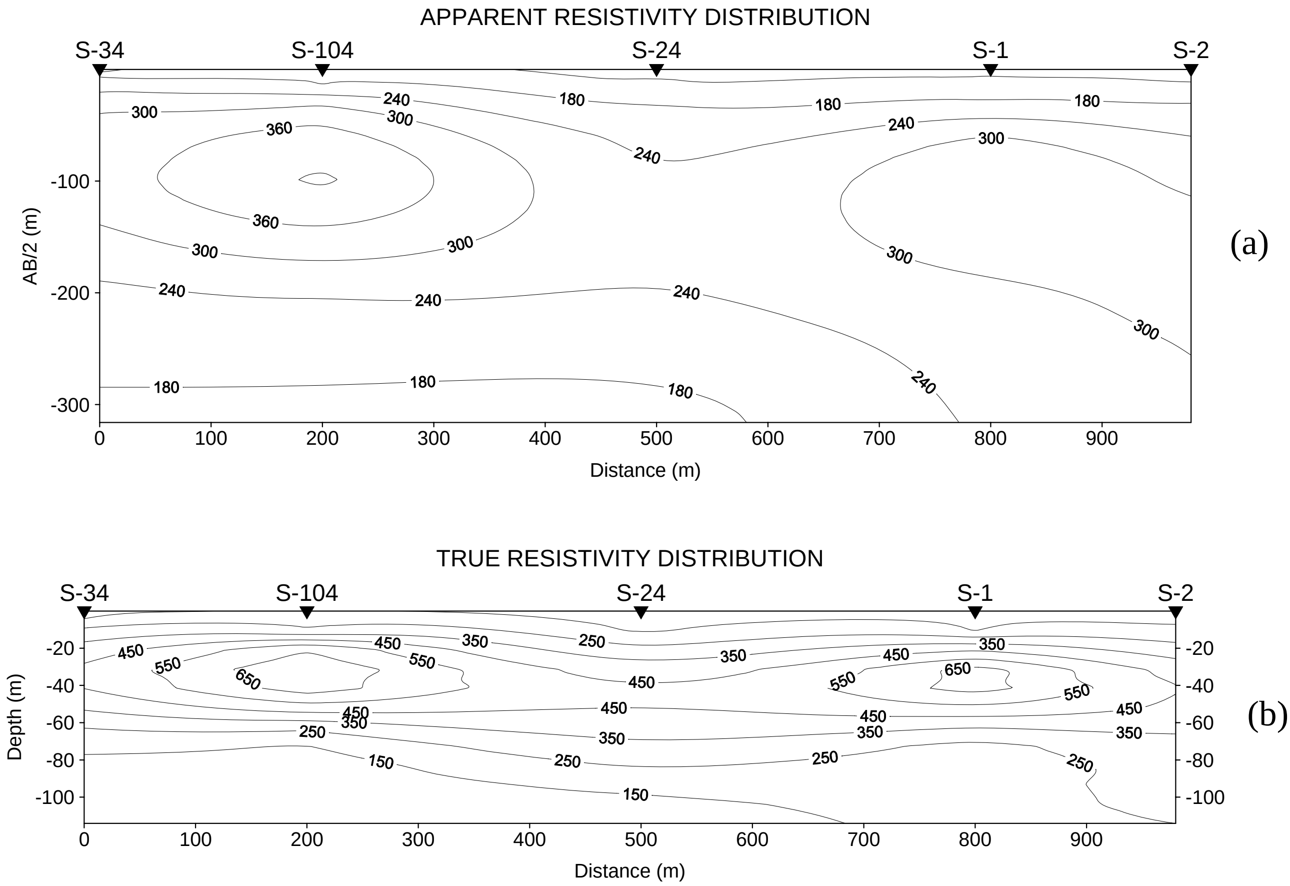


FIG. 5. Geoelectrical cross-sections parallel to the elongated and large topographic feature of the area under investigation, showing a) the apparent resistivity lateral distribution and b) the true resistivity distribution.

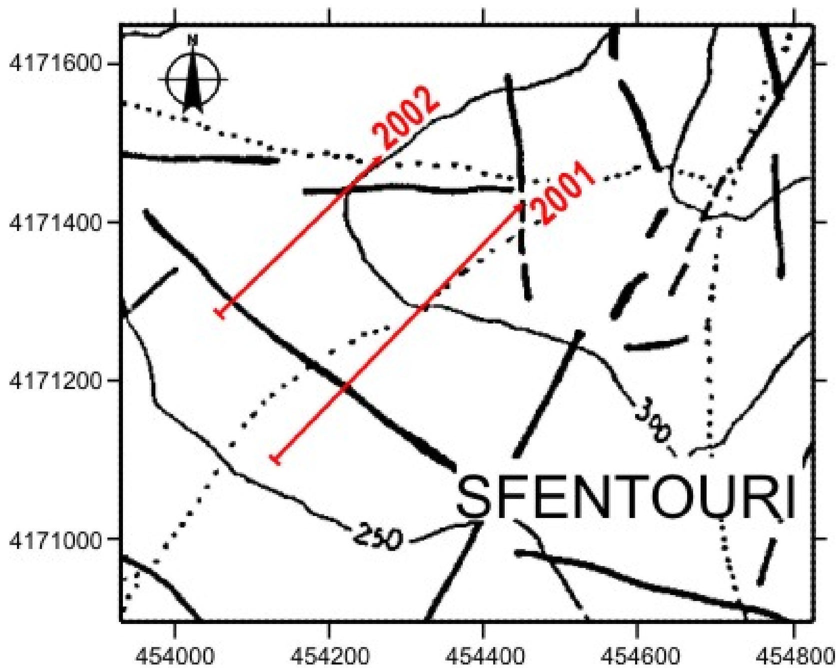
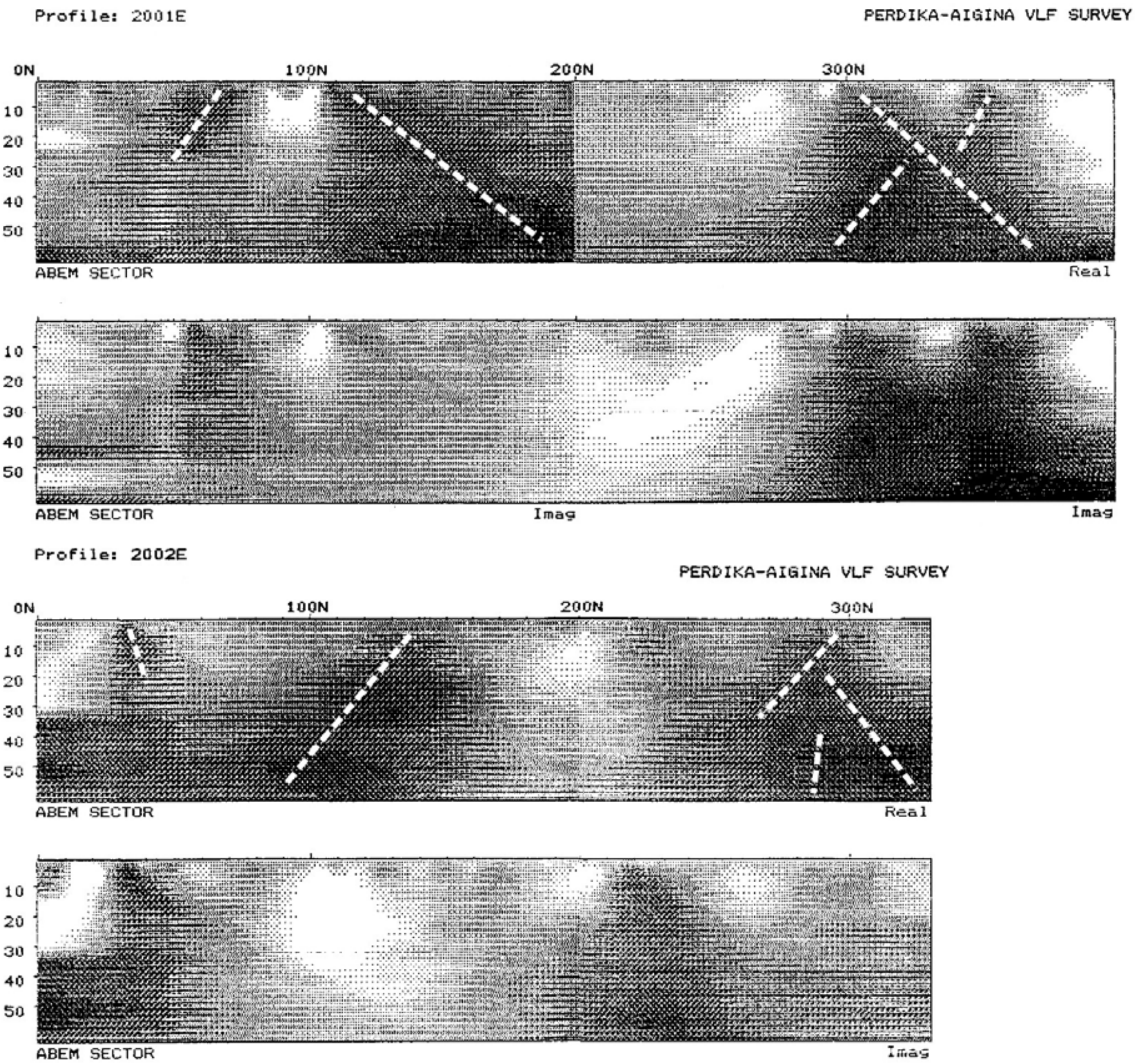


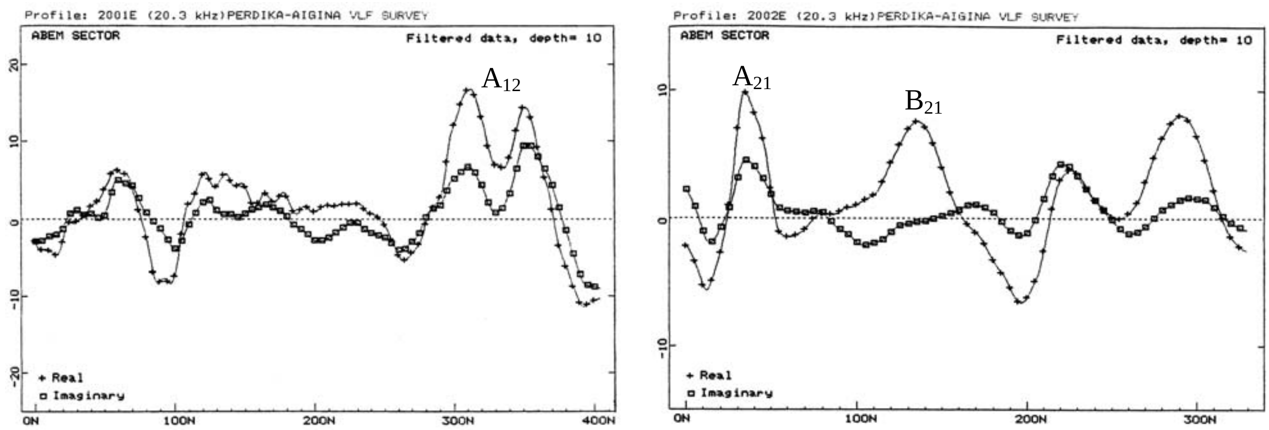
FIG. 6. A zoom in map of a small area of Figure 1, showing the main tectonic features and the locations of VLF traverses in this area.



(a)

(b)

FIG. 7. Pseudosections of equivalent current density across large scale tectonic features indicated in Figure 6, a) Traverse 2001E and b) Traverse 2002E. Darker zones indicate higher current density. White dashed lines denote potential fracture zones.



(a) (b)

FIG. 8. VLF filtered data for a depth d=10 meters, showing the presence of anomalies related to subsurface conductive (A_{12}, A_{21}) or semi-conductive bodies (B_{21}), a) Traverse 2001E and b) Traverse 2002E.

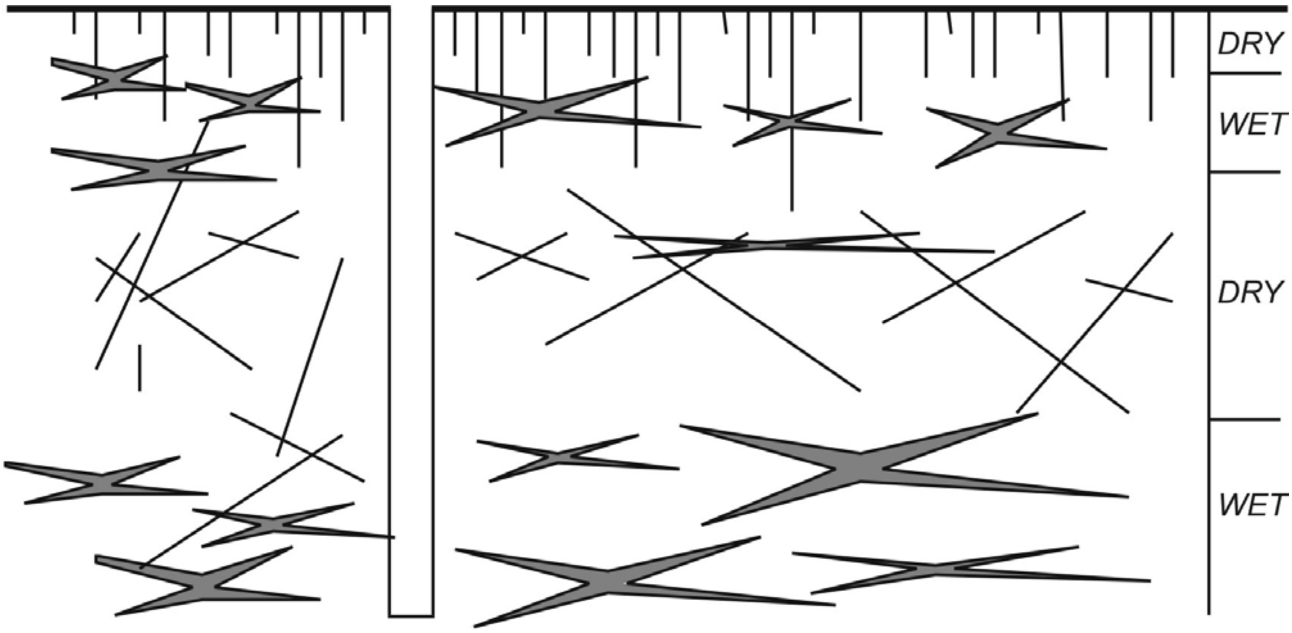


FIG. 9. A schematic model showing the enrichment mechanism of the deep seated aquifer, as deduced from this study.

WATER ENRICHMENT MECHANISM OF DEEP AQUIFERS

The recharging mechanism of the deep seated aquifers in volcanic terrain is the main scope of this research. A comprehensive way to approach such a problem is to examine the geological and tectonic regime of the area under investigation and extrapolate the surface outcrop conditions at depth by using the appropriate geophysical methods.

For the area of Perdika the surface geology and borehole data showed a) two potential aquifers, one phreatic near the surface and one deeper horizon close to the sea level and b) joints and fractures on different volcanic rockmasses (pyroclastic and dacitic lavas).

A model for the recharging mechanism of both aquifers was proposed based on hydrogeological criteria (Stournaras, 1995). The proposed model was further verified here by carrying out geoelectrical and VLF measurements. The improved model of the recharging mechanism (Fig. 9) shows dry and wet zones which correspond to low and high conductivity layers, respectively. The deep seated aquifer is water supplied through large fractures and/or faulted zones revealed from the aerial photographs and the interpreted VLF results.

CONCLUSIONS

The detection of deep seated aquifers in volcanic rockmasses could be realised by using geophysical methods. An integrated study which incorporates geological and tectonic evidence, minimum borehole data and a good coverage of geophysical investigations, provides a useful and reliable tool for further water exploitation purposes, even in the rugged and inaccessible volcanic terrains.

In this paper, an emphasis was given to the recharging mechanism of the deep seated aquifer of the area of Perdika. The presence of two discrete lithologically layers based on the borehole and geological evidence and four geoelectrical layers with alternating high and low resistivity values, at the same location, supports the model proposed in Figure 9. The water enrichment of the deep aquifer is attained through the large fractures and/or faulted zones as it was revealed from the VLF results.

It should be emphasised that the solution of hydrogeological problems in complex areas as the volcanic ones, needs a multidisciplinary approach comprising geological and geophysical methods successfully handled, as in the case of Perdika in Aegina island.

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