Methods of 3D visual representation of interpreted geophysical data in regions of hydrogeological interest

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ABSTRACT

The geophysical methods of electrical sounding and seismic reflection are widely used in areas with hydrogeological interest because they are inexpensive and quick. Also, they give reliable information regarding the geological background of the surveyed area.

This work aims to stress the necessity of geophysical surveying, combined with sophisticated methods of 3D visual representation in regions of hydrogeological interest in Crete, in order to minimize the expensive and time-consuming boreholes.

1. INTRODUCTION

The target of this research is the 3D visual representation of water bearing geological formations at four different regions of Crete using interpreted geophysical data deduced from electrical sounding and seismic reflection.

Electrical sounding and seismic reflection data were processed using RESIX and PRO-MAX V6.0 software packages, respectively. Geological and drilling information as well as bibliographic and *in situ* measurements of rock resistivities were used for the interpretation of geophysical data. 3D visual representation and/ or vertical and horizontal profiles of the aquifer were created using Surfer, Rockworks, ArcView GIS and SURPAC 2000 software packages.

2. GEOLOGICAL OUTLINE OF SURVEYED AREAS, DATA ACQUISITION, PROCESSING AND REPRESENTATION

Four different regions of Crete with hydrogeological interest were studied in this work (Fig. 1).

2.1 Surveyed areas

a) Kissamos (Chania): Geological maps, data from twenty-eight (28) electrical soundings and one (1) borehole were used for the interpretation of the geological background and structures (Fig. 1).
b) Almiros Potamos (Herakleion): Geological maps, twenty-three (23) boreholes and twenty-six (26) electrical soundings were used (Fig. 1).
c) Mesi (Rethymnon): Geological maps, seven (7) boreholes, and fifty-four (54) electrical soundings were used (Fig. 1).
d) Epano Vatheia (Herakleion): One (1) seismic line, fourteen (14) boreholes and nine (9) electrical soundings were used (Fig. 1).

2.2 Geological outline

The geological formations of interest, which are exposed in the different study areas, are: Quaternary deposits, which consist of pebbles, sand and other loose soil deposits. Neogene sediments, which mainly consist of marls, marly limestone, sandstone, and conglomerate. The

Figure 1: Surveyed areas. a) Kissamos, b) Almiros Potamos, c) Mesi and d) Epano Vatheia.

Neogene deposits are overlain discontinuously on the rocks of the lower nappe of Crete. The latter consists of carbonaceous rocks and flysch sediments of the Olonos-Pindos and Tripolis zones, phyllites, quartzites and schists of the Phyllite nappe (Dornsiepen and Manutsoglu, 1994), marbles of the Trypali Unit. The Neogene sediment can also be directly deposited on the metamorphic sequences of the Plattenkalk group.

2.3 Data acquisition

For the determination of the geological structure of each area, the electrical resistivity method was employed. This geophysical method is widely used because of the convenience of application and the quality of results (Robinson and Coruh, 1988). This method can determine the electrical resistivity distribution with depth, namely the geoelectric structure. This can be achieved by applying electrical current and measuring the potential of the ground. The electric field is distorted by the geological structure and thus, by measuring the electrical potential the geolelectric structure can be indirectly determined. For the acquisition of electrical resistivity data, the Schlumberger array sounding was used. With this array, the apparent electrical resistivity is measured at the center of the array for different depths. This is accomplished by keeping the two potential probes fixed and by forcing the current to penetrate at greater depths by symmetrically increasing the distance of the two current probes from the center of the array.

Furthermore, the seismic reflection method was employed at the Epano Vatheia area. Seismic waves propagate with different velocities in soil layers with different lithological characteristics and/or different age. These waves are reflected and diffracted on the discontinuities of the soil layers. Thus, an artificial seismic excitation is performed on the ground and the amplitude of the reflected seismic waves as well as their arrival times are recorded on the surface. The seismic records are processed for the determination of the geological structure, which caused the reflection of seismic waves.

2.4 Processing

Following data acquisition, the next step is data processing. Processing of electrical sounding data is performed in order to estimate the electrical resistivity distributed with depth from the measured apparent resistivity. Figure 2 shows a typical outcome of processing, performed on electrical sounding at the Kissamos area using the software package Resix v3. Three layers were detected, attributed to:

1) an overburden layer of clayey marls of Neogene up to 75 m depth,
2) a second layer of schist of phyllitic nappe with a thickness of about 275 m and
3) compact carbonaceous formations of unknown thickness (union of Tripali and/or Platencalks) corresponding to the third identified layer.

The processing of seismic reflection data is focused on the distribution of seismic velocities with depth. The interpretation of seismic results, using borehole and geological information, consists of the correspondence of seismic velocity to geological layers. Figure 3 shows a stacked seismic section at the Epano Vatheia area after processing with PROMAX V6.0. Nine (9) different geological layers were identified according to their velocities. The discontinuity of layers at CDP 221 is attributed to the existence of a fault.

2.5 3D visual representation of the results

After the interpretation of geophysical data, the next step was to reduce the number of geological formations in order to produce clearer and more comprehensive 3D images of the interpreted geological formations.

This was performed by grouping the

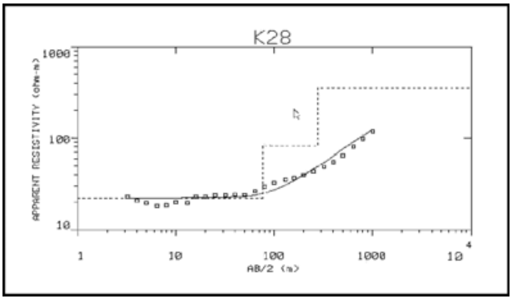

Figure 2: Typical diagram of electrical sounding results, deduced from Resix v3. Squares represent measurements and solid line is the response of geoelectrical model, presented with dashed line.

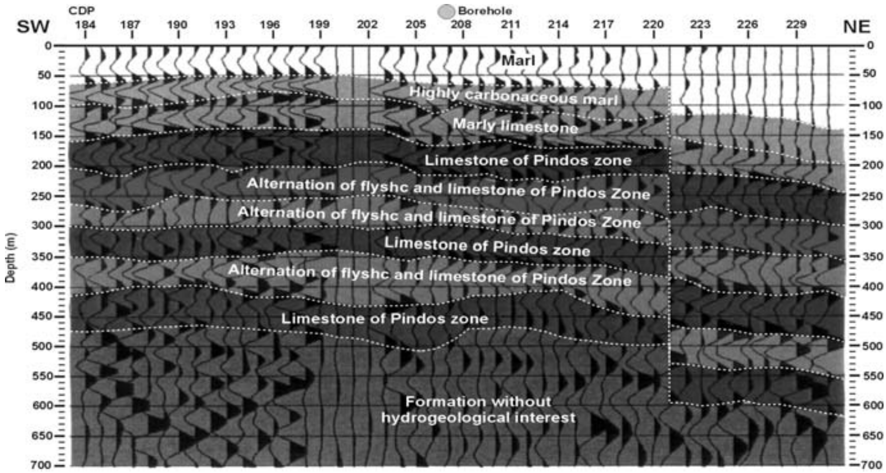

Figure 3: Stacked seismic section at Epano Vatheia area.

individual geological formations into two (2) to four (4) geological formations (depending on the area), namely:

a) the loose Quaternary sediments,
b) the loose Neogene deposits,
c) the marly limestone of Neogene and the carbonaceous formations with hydrogeological interest, and/or
d) phyllites-quartzites and schists.

Coordinates and elevation data concerning the top of each grouped geological formation, derived from boreholes, soundings, seismics and other surface data from geological maps, were interpolated using either Kriging, or triangulation methods. Layers' interfaces were used for 3D visual representations of the above-mentioned grouped geological formations in order to present the stratigraphic succession of hydrogeological interest.

Four different software packages were used for the production of 3D visual representation of the surveyed areas. Rockworks was used for Kissamos area, ArcView GIS and Surfer, for the areas of Epano Vatheia and Almyros Potamos and SURPAC 2000 and Surfer, for the area of Mesi.

3. RESULTS

3.1 Kissamos area (Chania)

For the optimum representation of the geological structure at the large area of Kissamos, the entire region was divided into three parts: the east, the center and the west part. A 3D visual subsurface model for the entire area (Fig. 4a), as well as cross-sections at different directions were created (Fig. 4b and 4c).

The thickness of Neogene sediments at the center of the area (Fig. 4c) exceeds the survey depth and thus there is no information about schists and carbonaceous formations under these sediments (Hamdan *et al.*, 2002). In this area, not only the carbonaceous formations are of hydrogeological interest, but also the Neogene sediments because of the underlying impermeable schist.

3.2 Almiros Potamos area (Herakleion)

The survey area at Almiros Potamos was divided into two (2) separate parts, Tylissos and Krousonas because of sparse geological and geophysical data present in the area between them. The digital dynamic 3D representation of the subsurface is supported with the use of ArcView GIS (Fig. 5). The digital terrain model (DTM) of the studied area was also created. Cross-sections of the 3D model at N-S and E-W directions, as well as maps of the interpreted formations at different elevations were produced using Surfer, supported by proprietary algorithms, and inserted to the database via hotlink (Kritikakis *et al.*, 2002).

3.3 Mesi area (Rethymnon)

The elevation contours of a local topographic

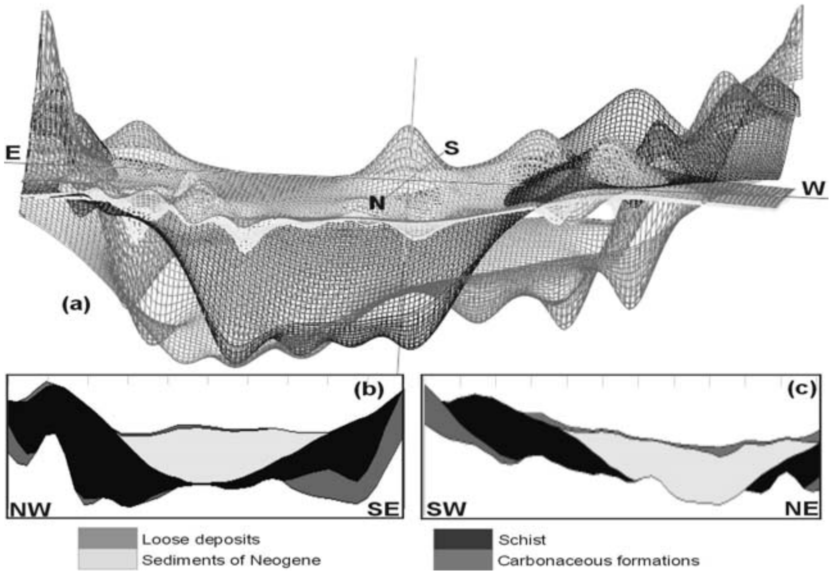

Figure 4: 3D visual representation of layers' interfaces (a) and cross-section towards NW-SE (b) and SW-NE (c) for the area of Kissamos.

map have been digitized and the DTM of Mesi area was created using the software package Surpac 2000. Borehole, sounding and map data were imported in Surfer for each layer interface and 3D images of each layer were produced. Figure 6 presents the upper surface of dolomitic

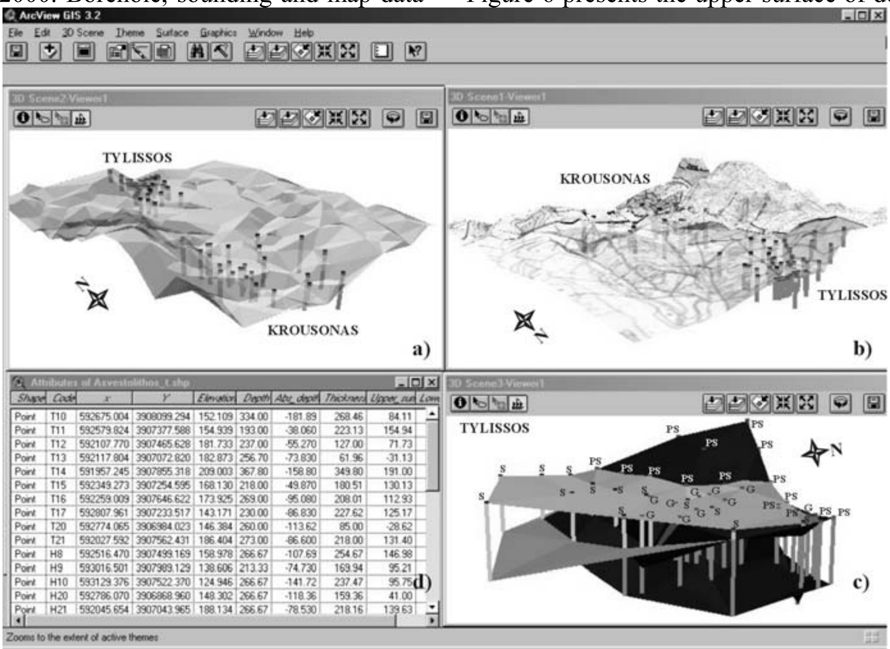

Figure 5: Semitransparent 3D representation of Almiros Potamos DTM (a) where geological and topographic maps are superimposed on the surface (b). Soundings and boreholes are located below the surface. The digital 3D visual representation of subsurface layers' interfaces (c) is supported by database (d).

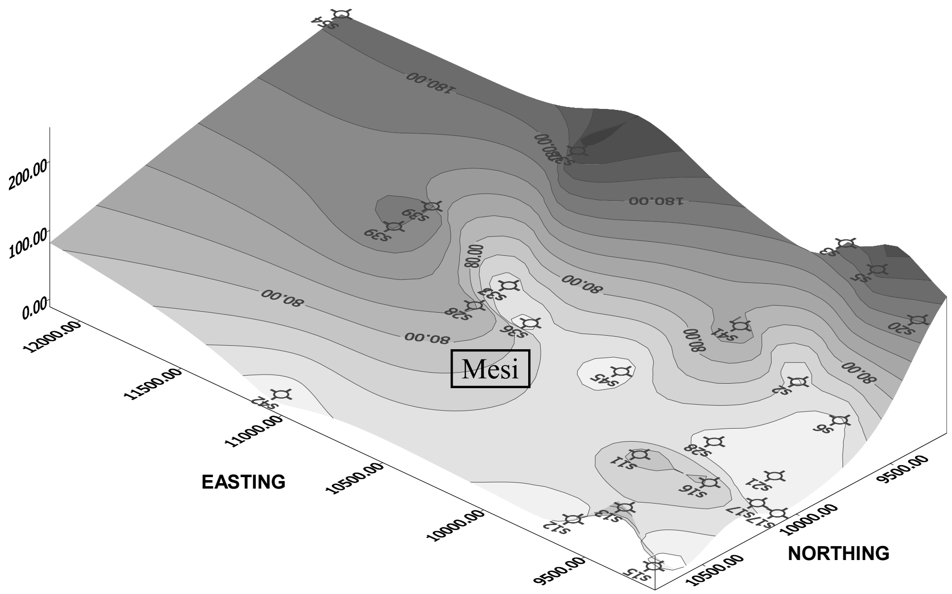

Figure 6: Interpreted 3D visual representation of the upper surface of Tripolis dolomitic limestone at the area of Mesi. The positions of soundings, which encounter that layer, are also shown.

limestone of Tripolis at the area of Mesi. The location of soundings, which encounter this layer, are also shown. This formation of hydrogeological interest appears at shallower depths towards the S – SW, whereas some soundings at NE meet the limestone below zero elevation (Spanoudakis *et al.,* 2002).

3.4 Epano Vatheia area (Herakleion)

Apart from geological and geophysical data, the DTM was also imported to the ArcView GIS

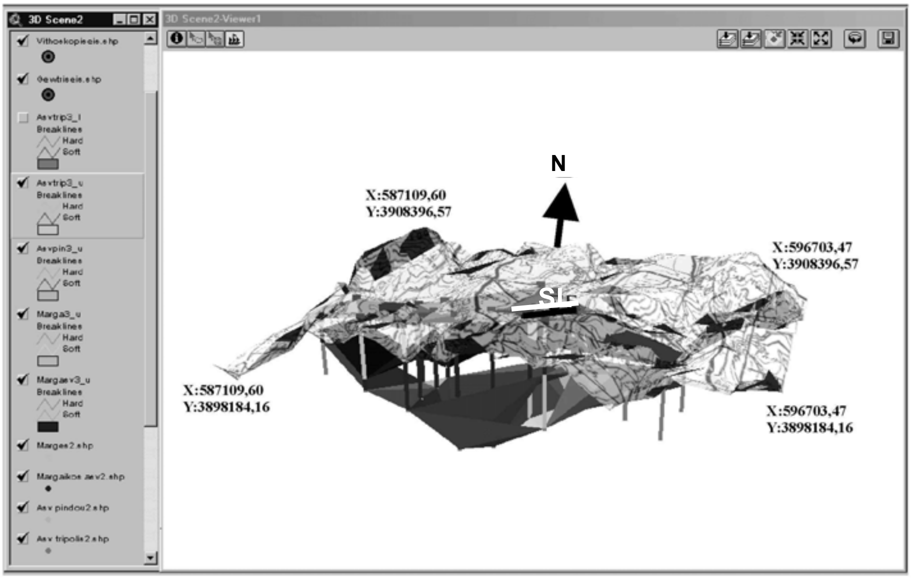

Figure 7: Superimposing of topographic and geologic maps on the DTM of Epano Vatheia area. Boreholes and layers' interfaces of the grouped geological formations are also presented.

database (Fig. 7). The 3D representation of the limestone of the Tripolis zone, which is the aquifer, showed that the shallowest occurrence of that formation is 600 m. At such great depths of interest, both the database and the visual representation through ArcView GIS proved to be very useful for developing Decision Support Systems (DSS) (Andronikidis *et al.*, 2002).

4. CONCLUSIONS

This work highlights two very important issues for the management of water resources. First, the ability of geophysical methods to provide useful interpretable information about the shape and the dimensions of geological formations with hydrogeological interest and second, the necessity of visual subsurface representation using state of the art techniques in order to lead those who study hydrogeological problems to sufficient decisions.

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