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出版情報：九州大学工学紀要. 68 (1), pp.83-92, 2008-03-21. 九州大学大学院工学研究院

Memoirs of the Faculty of Engineering, Kyushu University, Vol.68, No.1, March 2008

Geophysical Study of the Sedimentary Cover in Darb El-Arbeen, South Western Desert, Egypt

by

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(Received February 7, 2008)

Abstract

A Bouguer gravity anomaly map and eight Vertical Electrical Sounding profiles in an area 23° 30’ – 23° 50’ latitude and 30° 00’ – 30° 40’ E longitude in the southern Western Desert of Egypt were used to determine the thickness of sedimentary cover containing the main water rich sandstone formation. The predominant structures affecting the basement rock and sedimentary cover were also studied. Resistivity surveys are routinely employed in groundwater exploration to locate zones of relatively high conductivity corresponding to water-saturated strata at depths to about 400 m, as well as provide structural and lithological information. Measurements of electric resistivity were carried out on a selected profile that was surveyed previously by a gravity method. The geoelectric cross-section and gravity profiles showed the thickness of the sedimentary rocks increases towards the east and the basement surface is characterized by the presence of two highs and lows. The major uplift of the basement surface recorded in the west of the section bounded by a normal fault results in the ground water aquifer being near the surface. The Darb El-Arbeen area is characterized by the presence of a huge amount of groundwater. Accordingly, this area must take priority in programs for the sustainable development of groundwater in southern Egypt.

Keywords: Darb El-Arbeen, Bouguer gravity anomaly map, VES, Water-saturated strata, Gravity profile, Groundwater aquifer

1. Introduction

The geophysical study area for this work is accessed by an asphalt road in the western part of the study area, and the road runs in a southwest direction along the famous old Darb El-Arbeen track connecting the main towns of Assiut and Kharga and then continues further south to the Egypt-Sudan border and passes Gebel Abu Bayan to the northwest. The study area is 23° 30’ to 23° 40’N in latitude and 30° 00’ to 30° 40’E in longitude (**Fig. 1**).

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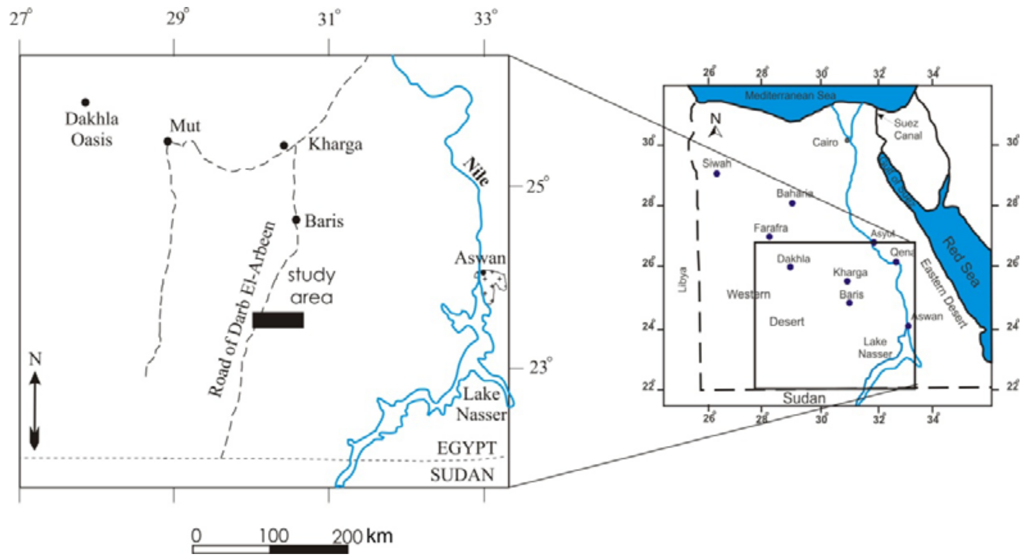

Fig. 1 Location map of the study area.

The study area constitutes a portion of the great arid belt covering Egypt. The land surface is slightly undulating and generally slopes towards the north and east, with several low-lying hills and longitudinal depressions breaking the monotony of the plain. The area exhibits three geomorphic units: a sandy plain, sand dunes and isolated hills, as shown in **Fig. 2**. Regionally, the ground surface of eastern El-Oweinat slopes gently from west to east and from south to north. It is characterized by a low relief of 1m / km (Geological Survey of Egypt, internal report, 1988)[1]. Ground elevation ranges between 200 m in the west and 100 m at the eastern limit. Sand dune drifts, barchans and sand ripples are the outstanding features in the area, with dunes ranging between about 3 m and 10 m above the surrounding surface (Issawi, 1971)[2].

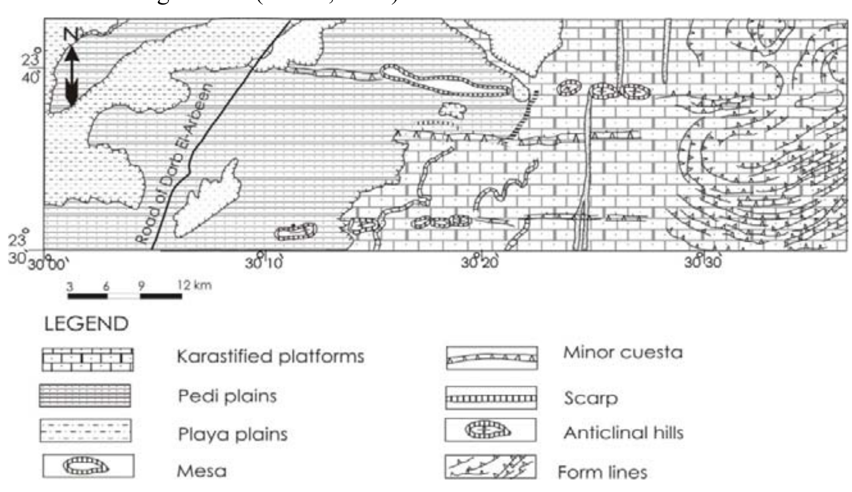

Fig. 2 Geomorphological map of the study area.[3]

The study area is considered as part of the region's uplift zone, where the sedimentary cover is relatively thin. The exposed rocks in the study area were mapped on the basis of lithostratigraphical divisions by the Egyptian Geological Survey and Mining Authority (1988)[1] as shown in **Fig. 3**.

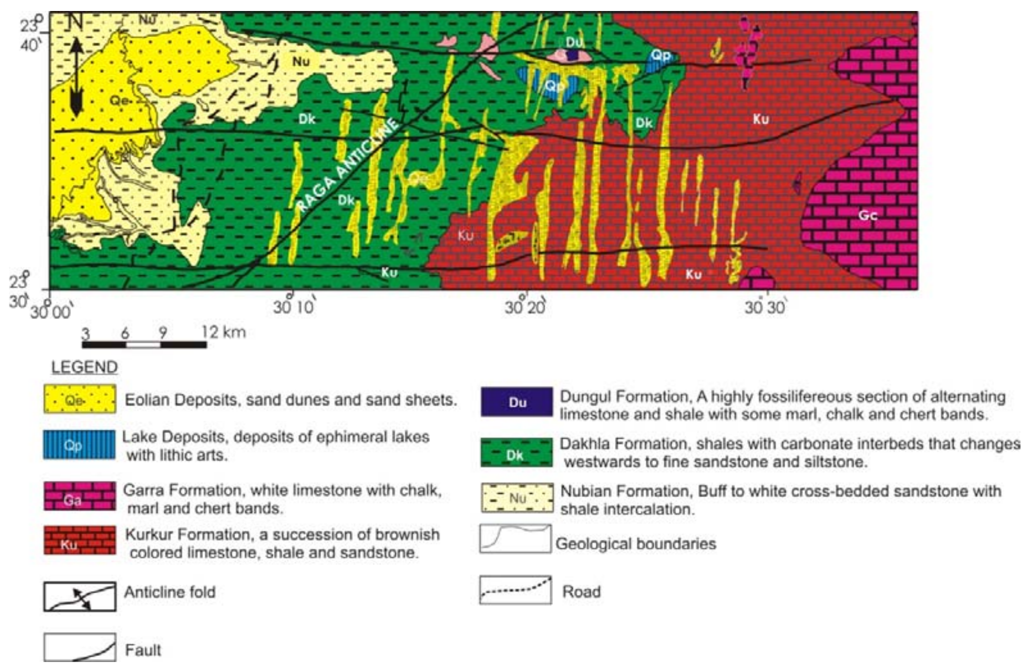

Fig. 3 Geological map of the study area.

Faults are the main structural features in eastern El-Oweinate and are frequently marked by long, straight and trough-like landforms. Furthermore, shearing and cleavage parallel to the faults have been extensively developed in the adjacent rocks. Most of the detected faults are normal type (El-Etr et al., 1982)[4]. It is known the different geological structures, such as faults and joints, directly contribute to the distribution and movement of groundwater. Therefore, the determination of the number and direction of the faults and features exposed on the surface are very useful for groundwater studies in the area.

2. Geoelectric Technique

Electric exploration is a major branch of exploration geophysics. It uses the principles of geoelectricity that involve the detection of subsurface effects produced by electric current flow in the ground. The resistivity techniques measure earth resistivity by driving a direct current (DC) signal or very low frequency alternating current into the ground and measuring the resulting potentials (voltages) created in the earth. From such data the electrical properties of the earth (the geoelectric section) are derived and thereby the geologic properties are inferred. **Figure 4** is a schematic diagram showing the basic principles of resistivity measurement. Two electrodes are driven into the earth to apply the current to the ground. Two additional electrodes are used to measure the earth voltage (or electrical potential) generated by the current. Depth of investigation is a function of the electrode spacing and

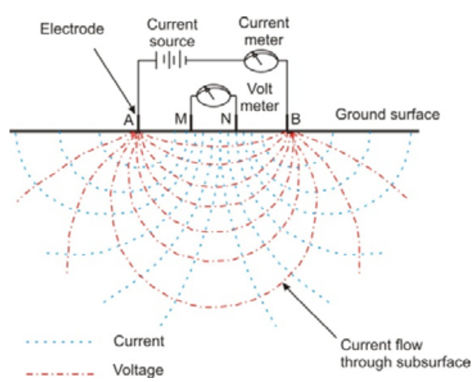

Fig. 4 Schematic diagram showing the basic principles of resistivity measurements.

the greater the spacing between the outer current electrodes, the deeper the electrical currents will flow in the earth. The resistivity data are then used to create a hypothetical model of resistivity structures (geoelectric sections). Resistivity models are generally not unique; i.e., a large number of earth models can produce the same observed data or sounding curve (Parasniss, 1997)[5)]. In general, resistivity methods determine the "conductance" of a given stratigraphic layer or unit. The conductance is the product of the resistivity and the thickness of a unit. Hence the layer could be thinner and more conductive or thicker and less conductive, and produce essentially the same results. Because of this constraint on the model, borehole data or assumed unit resistivity can greatly enhance the interpretation. The end product from the resistivity survey is generally a "geoelectric" cross section (model) showing thicknesses and resistivities of all the geoelectric units or layers. If borehole data or a conceptual geologic model is available, then a geologic identity can be assigned to the geoelectric unit.

3. Field Work and Instruments of Resistivity

Measurements of electric resistivity were carried out on a selected profile, which was surveyed previously by the gravity method. These measurements were executed applying the vertical electrical sounding (VES) technique using a SYSCAL R2. The VES station sites were chosen to be on the aligned profiles at accessible places. The spacing between neighboring VES stations ranged between 5 and 7 km as shown in **Fig. 5**.

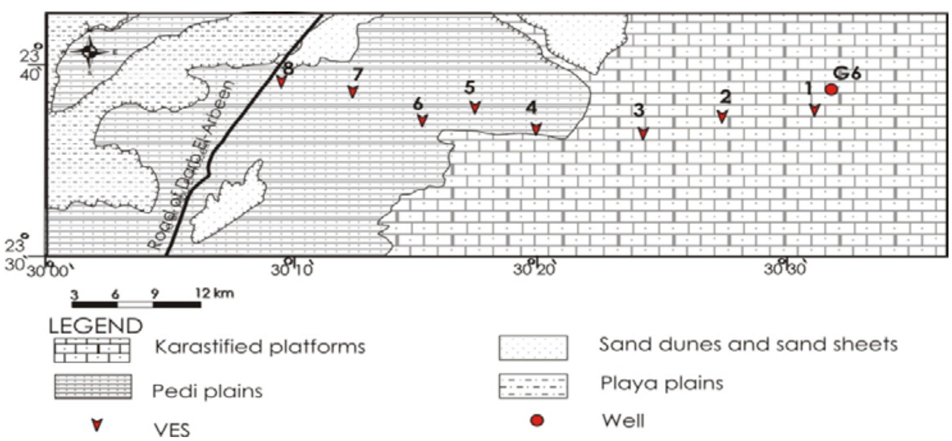

Fig. 5 Location of VES's.

The investigated area east of El-Oweinat is characterized by a flat surface covered by drift sand and sand dunes trending nearly north-south. This made it difficult to construct a geoelectrical sounding station for two reasons: first, measurement points are inaccessible in that they lie within the sandstones and sand drifts, and second, some locations are covered by relatively thick loose sands, which have bad contact with the electrodes due to their extremely high electrical resistivity and hence prevent the current from penetrating to the subsurface. To overcome the bad contact of a single current electrode with the loose sand soil, three electrodes arranged in a circle on each side were used instead of one. During the measurements, caves or holes to a depth of 1 meter were made and filled with wet clay to establish good contact between the electrodes and the surface layer.

The maximum electrode spacing (AB) was chosen to be 2000 m, with the aim to obtain sufficient information on the thickness (h) and electric resistivity (ρ) of the different layers to a depth of 400 m. The resistivity measurements were recorded a second time after changing the supplied voltage. The well known Schlumberger configuration of electrode separation ranging from AB/2 = 1.5 m to 1000 m was applied for a VESs 1 to 7 and AB/2 = 1.5 to 400 m was used for VES 8. Accordingly, eight vertical electrical soundings were measured in the area. It is fortunate a hydrogeological borehole exists near the study area, and is referred to as borehole G6 as shown in **Fig. 6**.[6)]

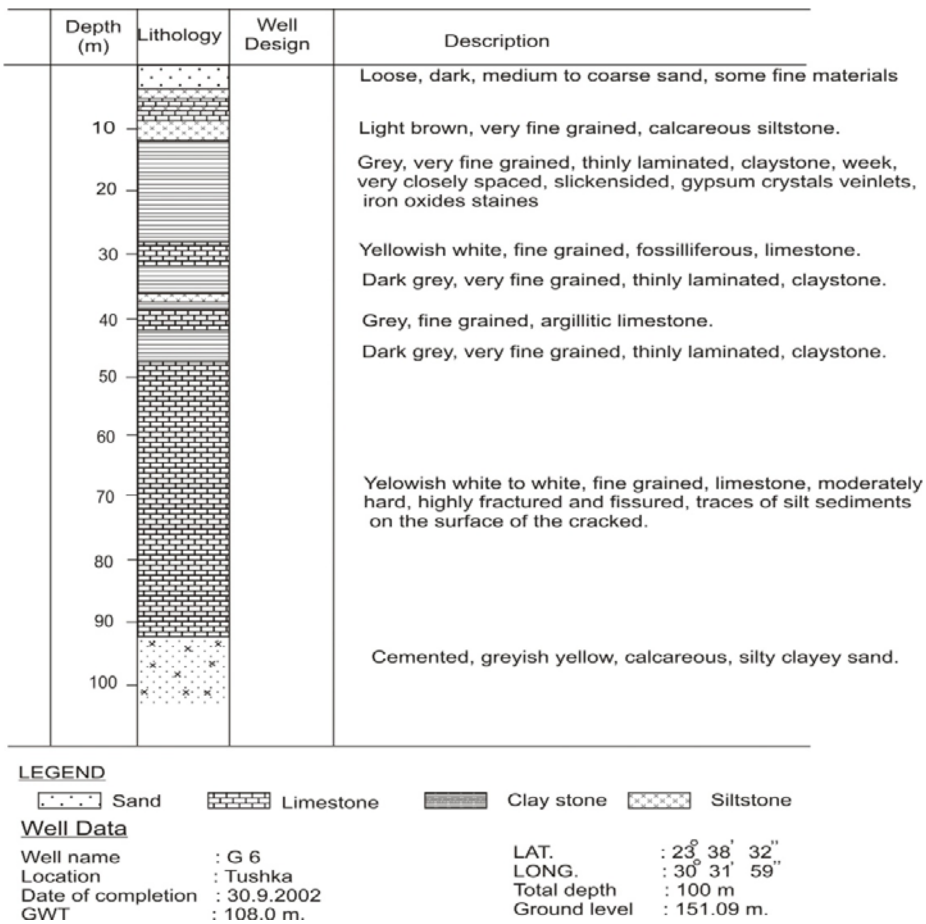

Fig. 6 Geological cross section of borehole G6.[6)]

4. Interpretation of the Field Data

4.1 Bouguer gravity anomaly map

The Bouguer anomaly map of the study area was derived from the Bouguer anomaly map of the South Western Desert of Egypt compiled by the Egyptian General Petroleum Cooperation (EGPC) in 1980[7)] as shown in **Fig. 7**. The gravity values range from a maximum of -10 mgal in the west to less than -32 mgal in the east according to the variation in the thickness of the sedimentary cover. The steep variation in the contour lines in the west suggests the presence of a fault, which may be a cause of the eastern uplift of the basement rocks. The steep gradient from low to high gravity values in the west and from high to low in the east are the most significant features. These steep gradients can be interpreted as being associated with normal faults with low density rock against high density rock. The gravity values of the sedimentary cover were determined and then removed from the Bouguer gravity anomaly map using an equation described by Nedelkon and Burnev (1962)[8] and Skells (1965)[9],

$$\Delta g = 2\pi G\rho h \tag{1}$$

where Δg is the gravity effect in gal, G is the international gravitational constant, which is equal to 6.67x10-8 c.g.s. units, ρ is the contrast between each layer density and the basement density in gm/cc as determined by Senosy (2002)[10] and h is the unit thickness in cm. The gravity values at the top of the basement rocks are shown in **Fig. 8**. The stripped gravity map shows the same features as does the Bouguer anomaly map except for some displacement of the anomalies.

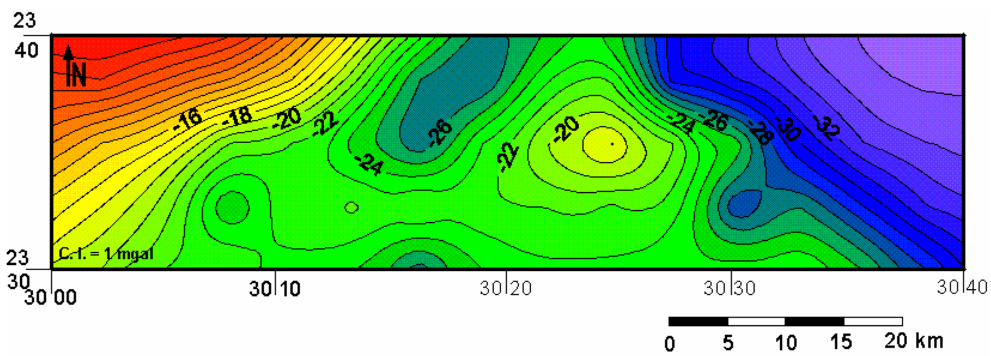

Fig. 7 Bouguer gravity anomaly map of the study area.

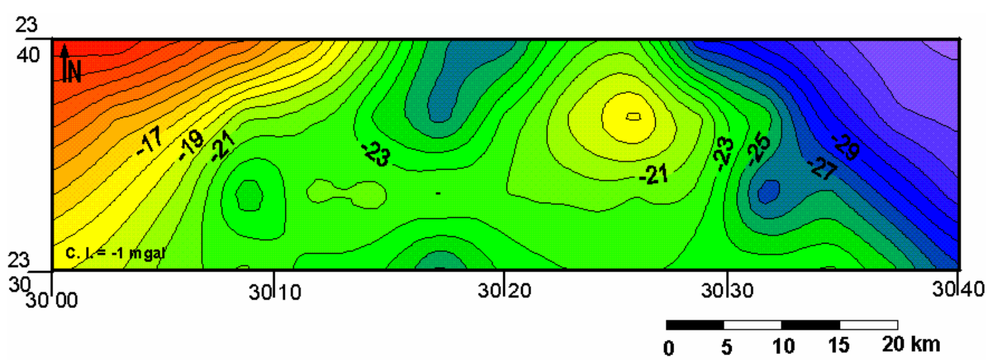

Fig. 8 Bouguer gravity anomaly map at the top of the basement.

4.2 Vertical Electrical Sounding Curves (VES)

A quick look at the shape of the resistivity curves was taken to form a preliminary idea of the number of geoelectric layers encountered, the variation in thickness of these layers along a certain direction, their resistivity interrelationship and the continuity of these layers along a certain direction or in the whole area, which indicate the degree of homogeneity in the study area. It has to be mentioned that the field curves of resistivity for small AB/2 values reflect surface or near surface variations, and in many cases the very shallow information may confuse the main interpretation objectives. Therefore, the resistivity behavior at large AB/2 values of the field curves is of prime importance in judging the homogeneity of the subsurface layers.

The apparent resistivity curve map reveals a dominant curve type HKH over the entire area in which $\rho1>\rho2<\rho3>\rho4>\rho5$ except in VESs 7 & 8. The prevalence of the curve type indicates a homogeneous subsurface succession and in most sounding curves the same number of layers was found. Nevertheless, the thickness of any layer may differ from one locality to another as observed from the correlation of the AB/2 values for different curves in which the minimum or maximum resistivity corresponds to that layer. Slight variation in the curve type can be recognized for VES 4, where the above mentioned curve type HKH is modified to AK in which $\rho1< \rho2<\rho3>\rho4>\rho5$.

The variation is due to the presence of a low resistivity surface layer at this VES station. It is relevant to mention the last segment on most of the field curves is characterized by H-type in which the resistivity of the deepest layer increases with depth. This behavior may reflect the detection of the basement rock for most of the field curves. For VES 7 the above mentioned curve types changed to QKH in which $\rho1>\rho2>\rho3<\rho4>\rho5$. This variation reflects the deepest layer, which has high resistivity, became thicker and shallower than for other VESs. A slight variation in curve type for VES 7 can be observed and it changes to KH type, where $\rho1<\rho2>\rho3>\rho4$ suggests the surface less resistive layer disappears as shown in **Fig. 9**.

The geoelectric cross-section is constructed by drawing the true resistivity with true thickness of different layers along the aforementioned profile. It clearly reflects the actual geoelectric subsurface condition prevailing in the area. Correlation of the geoelectric cross-section with the available geological information gives a geological interpretation of the study area. Lithological information from borehole G6, in conjunction with the geological information from the area, was used in constructing the geoelectric cross section. The geoelectric cross section in **Fig. 10** comprises five geoelectric units: the first geoelectric unit, that exhibited in VESs 1-6 is characterized by relatively high electric resistivity values ranging between 145 ohm·m at VES 3 and 2900 ohm·m at VES 6. The thickness of this unit is about 2 m, which corresponds to the surface layer. The second geoelectric unit is characterized by very high resistivity values more than 1.1E+5 for VES 6 and the thickness ranges between 5 and 45 m, which corresponds to the dolomitic limestone of the Kurkur Formation. The third geoelectric unit is characterized by resistivity values ranging between 200 ohm·m and more than 600 ohm·m. The maximum thickness of this unit is about 47 m, observed at VES 4, and this unit corresponds to shale of the Dakhla Formation. The fourth geoelectric unit is characterized by low electric resistivity values ranging between 3 ohm·m at VES 3 and 72 ohm·m at VES 6. This unit has a thickness reaching 427 m for VES 4, which corresponds to saturated sandstone. This unit is considered as the aquifer of the area containing groundwater. The unit appears in VESs 7 & 8 near the surface. The fifth geoelectric unit is the last penetrated unit of the section and is characterized by high electric resistivity values. This layer may correspond to the basement rock. The geoelectric cross-section shows the thickness of sedimentary rocks increases towards the east and the basement surface is characterized by the presence of two highs and lows. The major uplift of the basement surface recorded in the west of the section bounded by the normal fault brings the groundwater aquifer near the surface.

Profiles along the Bouguer anomaly map and gravity map on the top of the basement rock are constructed on the geoelectric cross-section. These profiles show the gravity lows are consistent with the thicker sedimentary cover. In contrast, the gravity highs are consistent with a thinner sedimentary cover. Consequently, the maximum gravity value (-12 mgal) was recorded in the uplifted area in the west of the geoelectric cross-section and the minimum value (-31 mgal) was recognized in the subsidence area in the east. In the west, a steep change from a low gravity value to a high gravity value reflects the presence of a normal fault that results in dense basement rock within less dense sedimentary rocks.

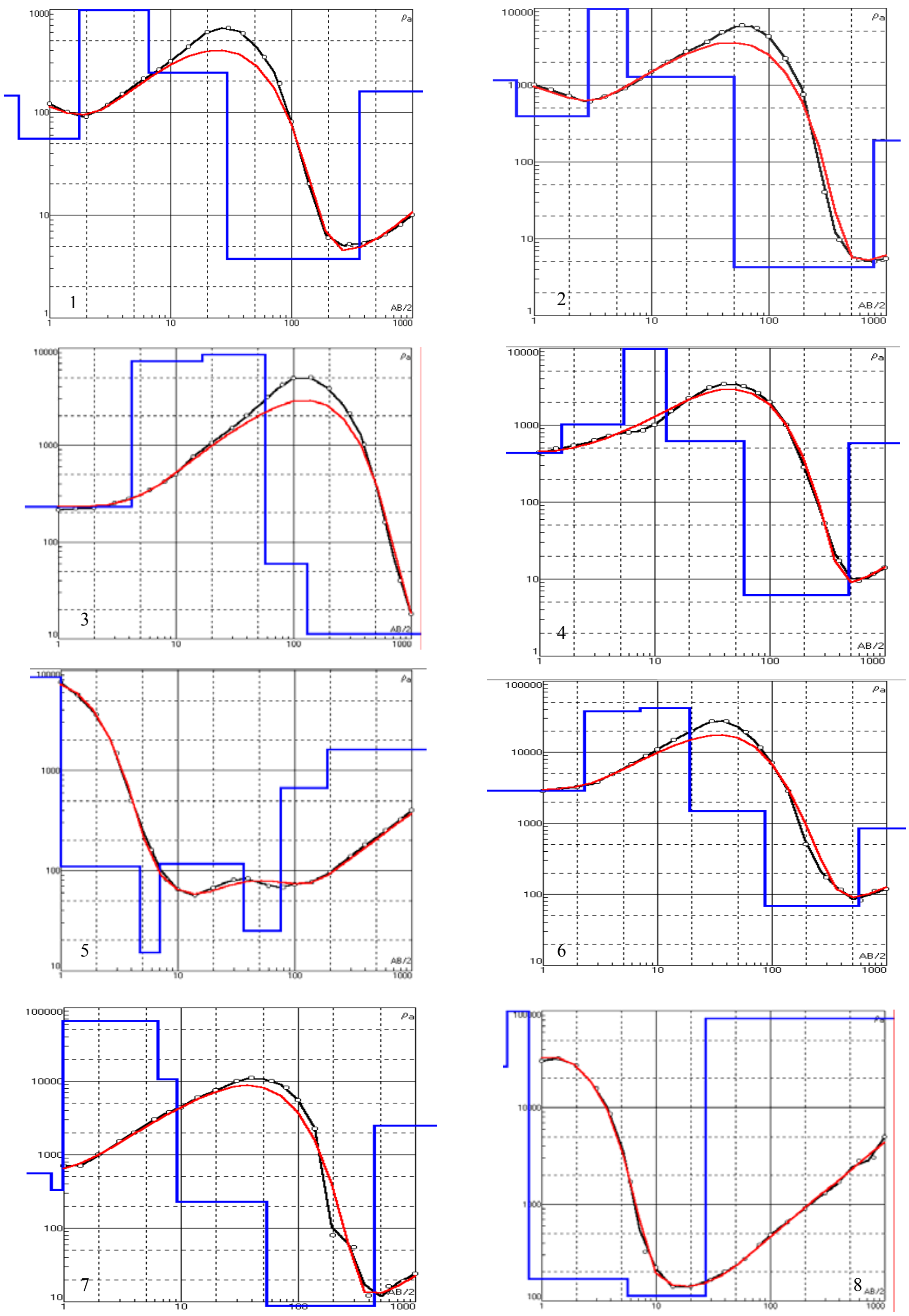

Fig. 9 Vertical Electrical Sounding curves 1-8.

The previous VES's were used for construction 2D geoelectric cross section, a borehole drilled near the surveyed area was used for correlation and interpretation purposes. Quantitative interpretation shows the study area consists mainly of five geoelectric units. The lithology of these layers is dolomitic limestone for the highly resistive surface layer, silty clayed sand for the considerable low resistivity second layer, shale for the low resistivity third layer, a low resistivity third layer of considerable thickness, water bearing Nubian sandstone for the fourth layer and a high resistivity final layer perhaps representing the basement rock. The geoelectric interpretation shows the probability for finding groundwater accumulation increases toward the east due to the increase in the thickness of the sedimentary cover.

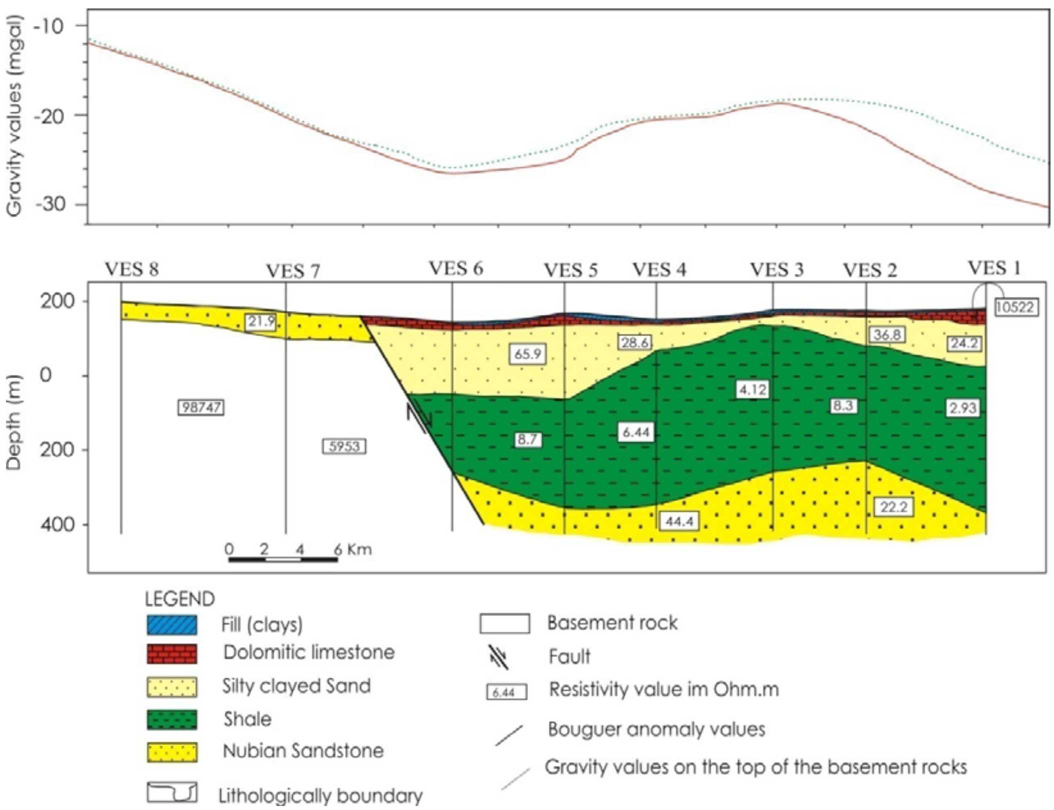

Fig. 10 Geoelectric cross section and gravity profiles.

5. Conclusion

Eight VESs were performed along a selected profile, which had been previously surveyed by a gravity technique. Additionally, data from one borehole drilled near the surveyed area were used for correlation and interpretation. Interpretation of the geoelectric data included analysis of the VES curves and drawings and geoelectric cross-sections, to give an outline of the subsurface geology and water-bearing parameters. The geoelectric and gravitational interpretation show the probability for finding groundwater accumulation increases toward the east due to the increase in the thickness of the sedimentary cover.

Acknowledgements

We would like to express our great appreciation of the staff of Geoelectric and Geothermic Laboratory (NRIAG), for their kind cooperation during the preparation of this work. Special thanks is given to the staff of the Laboratory of Geothermics, Faculty of Engineering, Kyushu University.

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