The application of geoelectrical surveys in delineating groundwater in semiarid terrainCase history from central Arabian Shield

By Abdullah M.S. AL-AMRI *Department of Geology and Geophysics, King Saud University, P.O. Sox 2455, Riyadh 11451, Saudi Arabia*

ABSTRACT.   A resistivity survey was conducted, in Shaib Al Ziba, central Arabian Shield as part of groundwater exploration program in Ranyah area. The survey consisted of 30 vertical electrical soundings (VES) and IS horizontal electrical profiling (HEP) using Schlumberger and Wenner arrangements, respectively.

Two aquifer systems were delineated in the study area. The shallow aquifer system comprises the coarse alluvial deposits overlying fractured bedrock. The second aquifer system is that associated with fractures in the underlying diorite and granodiorite. The water in these deep fractures is recharged through the Wadi alluvium.

The analysis of VES curves and HEP contour map in conjunction with the results of groundwater parameters indicates that the SW section (VES 2-16) contains groundwater in clay-rich formation that yields poor water discharge opportunities. The middle part (VES 16-24) acquires relatively better groundwater potentiality, since the water-bearing layers have less clay content. The groundwater potentiality in the NE section (VES 24-30) is almost negligible since the basement depth is very shallow. The thin alluvium cover in this section does not contain significant groundwater for practical uses.   .

The results obtained from this study suggest that the groundwater potentiality occurs mainly at the intersection of Shaib Al Ziba and Wadi Ranyah. The most promising sites for borehole drilling which demonstrate relatively better groundwater potential-are VES 22, 21, 19, and 18 respectively. Further geophysical investigations are strongly recommended in the downstream of Wadi Ranyah because of its higher sedimentary thicknesses, less clay content, more fractured basement rocks and less saline water quality.

INTRODUCTION

In early 1990, SADM conducted a hydrological survey of the Ranyah area to evaluate the water resource potential of the Wadi channel. The findings of the study recommended that geological and geophysical studies should be performed to investigate the structural geology and evaluate the potential existence of groundwater. The proposed area of investigation (Shaib A1 Ziba) lies in the central part of the Arabian Shield on the southwestern margin of the regionally extensive sinistral NW-trending Najd fault system between latitudes 21.03°21.25° N and longitudes 42.78°-42.92° E. The area cuts Wadi Ranyah and is defined in a rectangular form with 3000 m length and 600 m width (Fig. 1).

Information on the Precambrian rocks was obtained from the 1:100,000-scale maps (Ramsay 1982). Much of the information on the Cenozoic volcanic rocks was obtained from Green (1985) and Al-Muallem & Smith (1987).

The following three points summarize the importance of conducting this study:

1) Water resources in fracture system have not yet been fully exploited in this region, although it is recognized that many old wells are located on fault lines.

2) There is not a great deal known about the groundwater exploration using resistivity techniques.

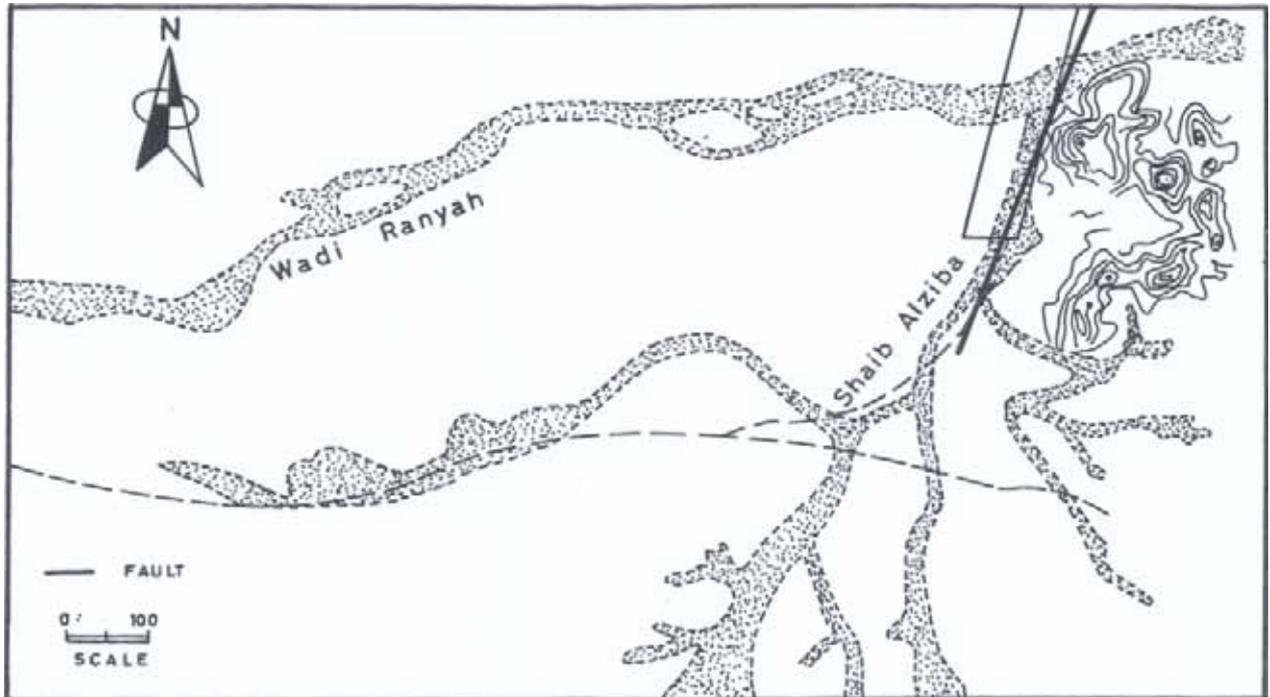3) Previous geologic and hydrologic surveying strongly recommend a

Figure 1. Location of the study area.

Considering the aforementioned points and in order to fully understand the subsurface hydrogeologic picture, the main objective of the proposed study is to investigate the subsurface structural features obtained from the resistivity data and locate any potential water-bearing fractures in the bedrock, thus pinpointing the most suitable sites for borehole drilling.

GEOLOGIC AND HYDROLOGIC SETTING

The geology and tectonic history of the study area is complex. It contains Precambrian metasediments and metavolcanic rocks intruded by a wide range of ultramafic to felsic plutonic rocks. Two lithologic units dominate the study area: The granite and granodiorite/diorite rock units (Fig. 2). The granites of the northern area of Wadi Ranyah have been subjected to a different tectonic regime than those to the south. The northern granites have been imbricated by low angle thrust faults and the geological conditions north of the Wadi are not favorable to the development of a fracture based water resource.

The area is believed to represent two distinct orogenic belts, The Hijaz is the oldest (600-1000 Ma) and the more recent Najd orogeny (520-540 Ma). The N-NE striking fractures run parallel to the Red Sea rifting and in accord with major transform faults in the Gulf of Aqabah.

Previous geologic work indicates that faults in Ranyah area vary in persistence and width. Narrow faults and shear zones measuring tens of meters are common whereas the larger faults associated with shear zones are persistent in length over several kilometers and have width in the range 200-500 m. The degree of shearing and fracturing at the surface may indicate that the permeability of fault zones is sufficient to produce the required abstraction, should water be present (SADM 1991).
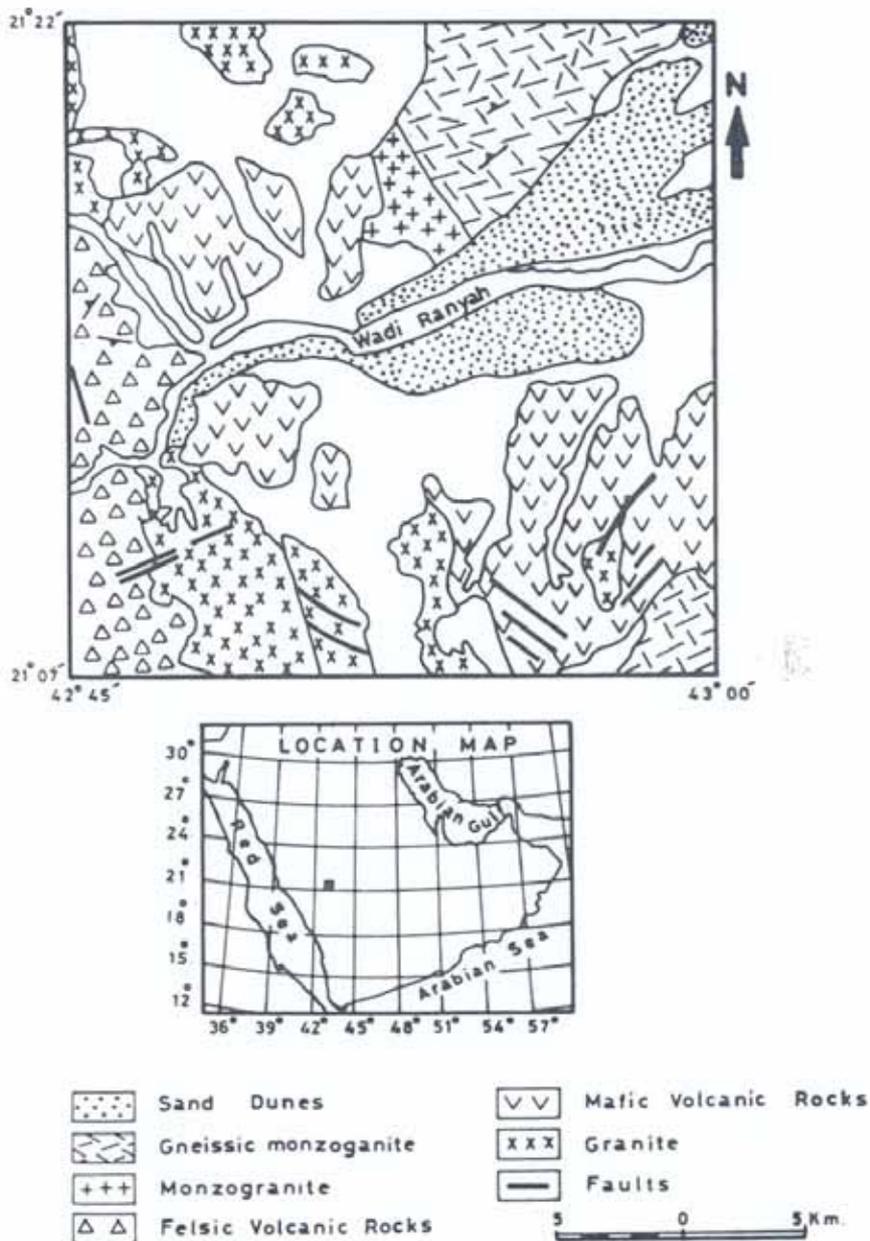
Figure 2. Modified geological map showing major lithologic units of Ranyah area (Al-Muallem & Smith 1987).

The main source of water for this area is accumulation of rainfalls, which occurs rarely. Average annual rainfall varies between 125-150 mm. Sometimes, heavy rainfalls of short duration cause floods that fill wadis and their tributaries with water. The eastern area of Ranyah contains parts of some of the largest

drainage systems in the central part of the Arabian Shield. Wadi Ranyah and Wadi Bishah, drain E-NE into Wadi Rayyaniyah.

There are two aquifer systems in the study area. The shallow aquifer system comprises the coarse alluvial deposits overlying fractured bedrock. This aquifer is unconfined and receives recharge from sporadic flows in Wadi Ranyah. The second aquifer system is that associated with fractures in the underlying diorite and granodiorite. The granite is considered to be tight and unlikely to yield significant quantities. The water in these deep fractures is recharged through the Wadi alluvium.

METHODOLOGY AND DATA TREATMENT

All geophysical and geologic methods provide only indirect indications of groundwater, as underground hydrologic data must be inferred from surface information. In order to delineate the hydrostratigraphy and to enable assessment of groundwater, the resistivity method was carried out applying two different electrode spacing arrangements, namely, Schlumberger and Wenner to create vertical electrical soundings (VES) and horizontal electrical profiling (HEP), respectively.

The object of VES is to deduce the variation of resistivity with depth and correlate it with the geological information in order to infer the depths and resistivities of the layers present. The Wenner Arrangement were used in HEP to detect lateral variations in the resistivity and to mark the structures with near-vertical boundaries, such as faults, dikes and fractures. The ground geophysical field work carried out in a Wadi alluvium plain, consisted of 30 VES and 15 HEP perpendicular and parallel to the fault lines, covering an area of 600 m width and 3000 m length and cutting across the plain in a northeasterly direction (Fig. 3). The VES and HEP are spaced at 100 and 200 m intervals, respectively.
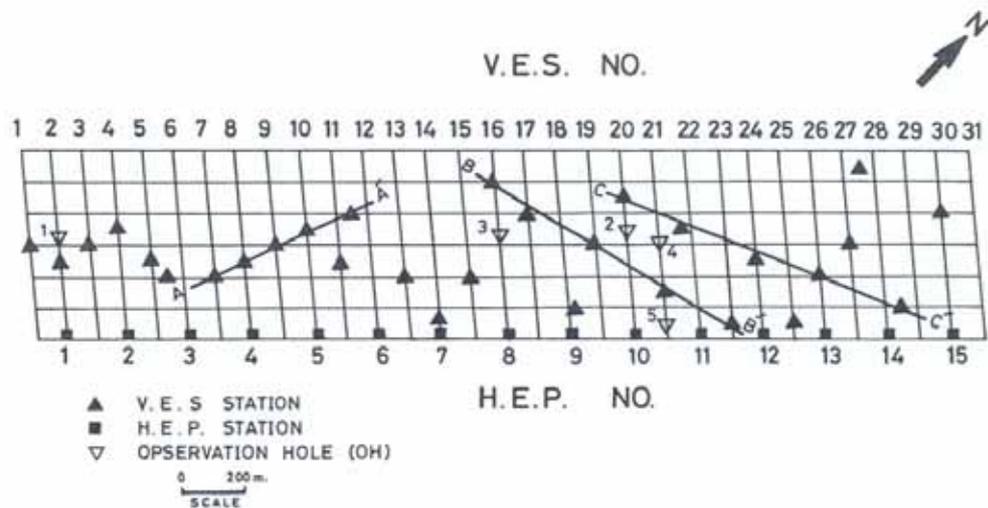

Figure 3. Location and distribution of VES, HEP, and observation well sites.

The maximum half current electrode spacing (AB/2) in Schlumberger arrangements reached about 200 m, while the intensity of measurements was about 6 readings per decade at AB/2 values of 1.5, 3, 4, 5, 7, 9, 10, 12, 15, 30, 45, 60, 90, 120, 150, and 200 m. Wenner configuration was applied using AB/3 = 20 m and station spacing of 30 m.

The first step in treatment of VES data was to plot individual sounding and introduce the necessary correction. Most of the soundings indicated noise interference, particularly at larger AB/2. Distinguishable fluctuations due to noise interference were easily observed and introduced serious distortions to the sounding curves at greater depths. The main causes of such noise could be due to the low power of the instrument used in this survey, which cannot provide sufficient signal strength to exceed the required signal to noise ratio. Such effect was observed at larger AB/2 distances where current penetration increases at greater depths.

On the other hand, the noise also increases when the current passes through good conductors (e.g., clays) and noise also increases at relatively shallow depths.

The field data were re-examined as individual sounding and a tremendous effort was paid to recover the unacceptable errors in the apparent resistivity curves. The following procedures were applied to introduce the possible correction to the resistivity curves:

1. Re-calculation of the resistivity measurements taken at AB/2, MN/2 values which do not satisfy Schlumberger configuration. The recovery of such measurements was achieved by the re-calculation of the proper geometrical factor.

2. Rejection of the distinct noise measurements when caused by extremely large AB/2 values and corresponding extremely small MN/2 values (e.g., 15, 0.5; 90, 3, etc.).

3. Careful interpolation between widely spaced points on the bilog plot especially at the lower AB/2 values of each decade.

4. Rejection of the improper overlapping measurement curves at the same AB/2 values when increasing the MN/2 values.

A special computer program was designed to introduce the previous corrections to the field data. The computer program allows either automatic correction or user defined corrections. The final corrected resistivity curves were then re-digitized for subsequent data analysis and interpretation.

DATA ANALYSIS AND RESULTS

Sounding curve analysis aims to obtain the equivalent subsurface layering model for each of the apparent resistivity curves. This operation was automatically carried out using the advanced software of two modern techniques (Zohdy 1989, Koefoed 1979).

The first technique is adopted by Zohdy (1989) to obtain the so-called n-layers model equivalent to corrected apparent resistivity sounding curves. The resistivity values and the sampling intervals on the curve are used automatically to create the first approximation of the corresponding multilayer model. Hence, this model is modified in layer thicknesses and resistivities through a number of iterations until the best-fit between the calculated curve and the apparent resistivity curves is reached.
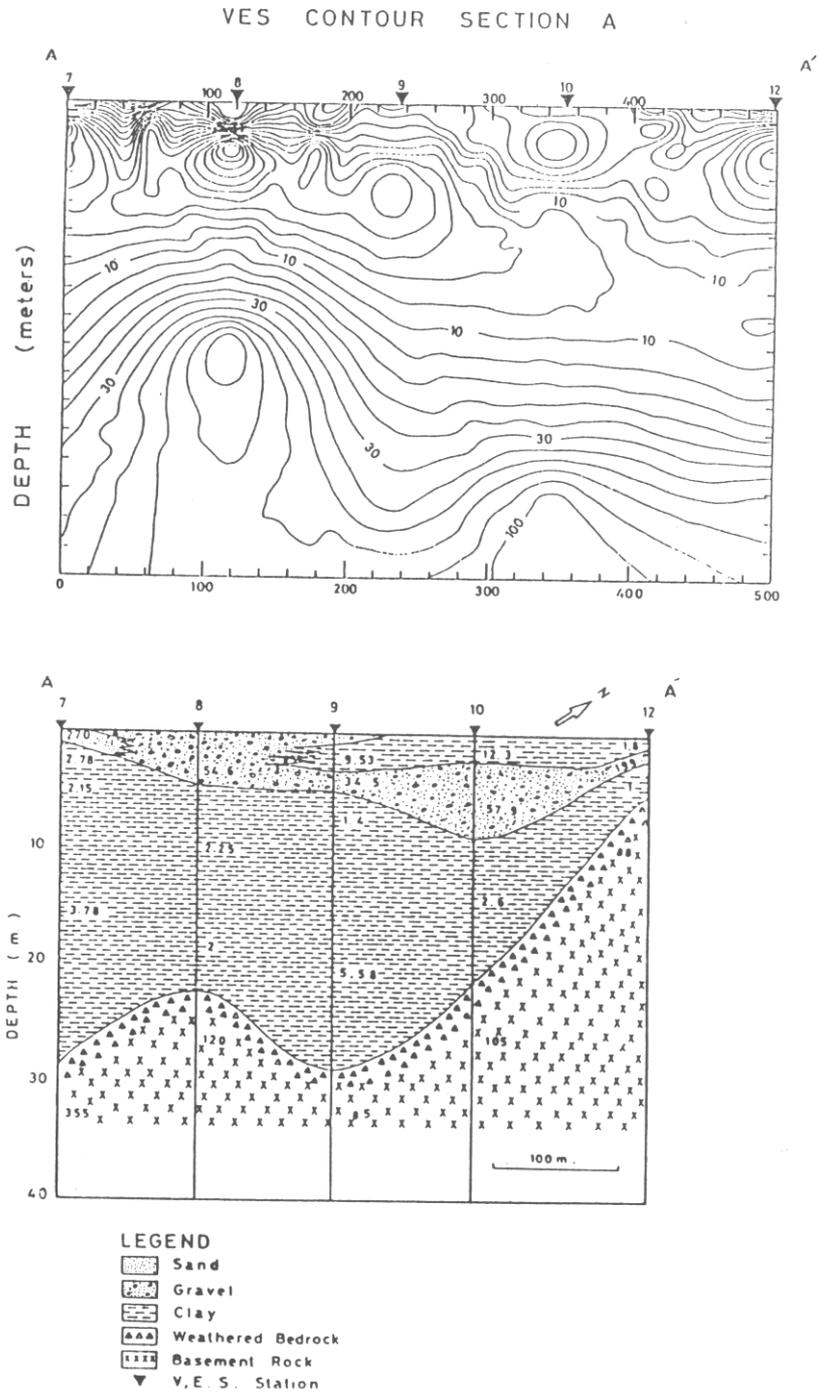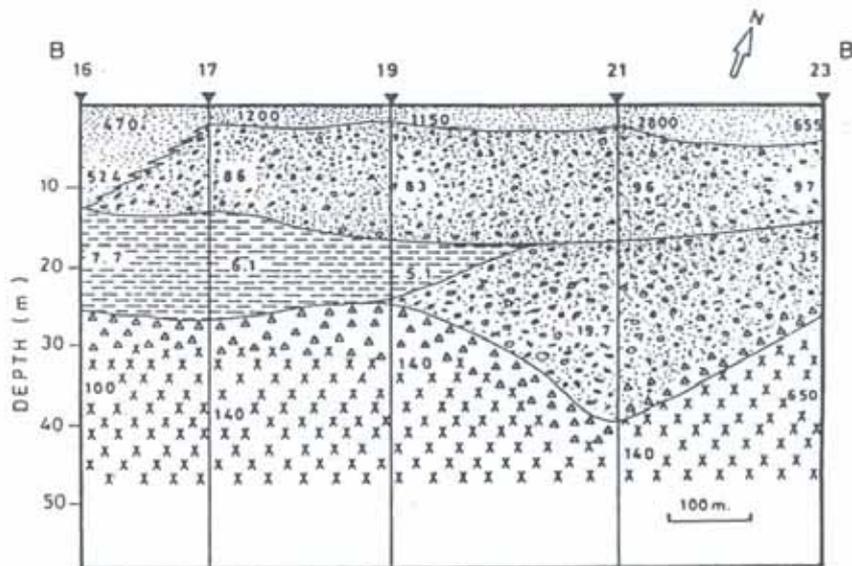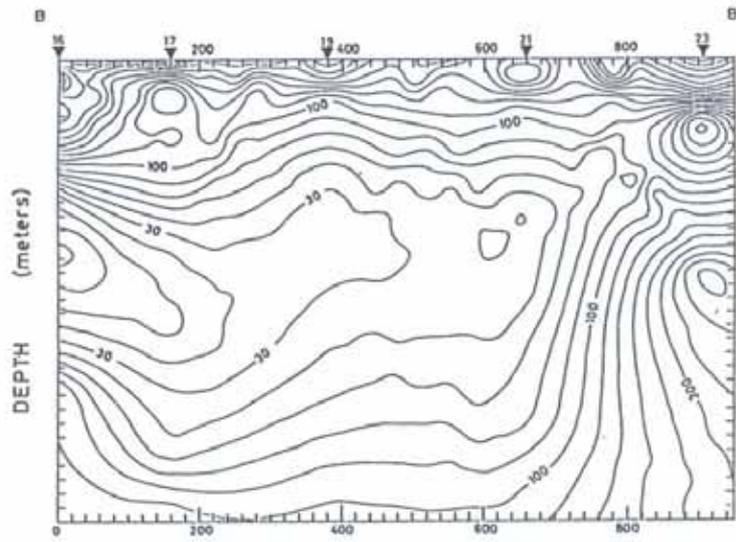
VES   CONTOUR   SECTION   A

Figure 4. Interpreted subsurface true resistivity and equivalent geological sections along profile A-A'.

VES CONTOUR SECTION B

Figure 5. Interpreted subsurface true resistivity and equivalent geological sections along profile B-B'.

The second technique is based on the Marquardt algorithm (Koefoed 19T and is widely used by the B.R.G.M, France. This method is used to fit same layE thicknesses and/or resistivities to the apparent resistivity curves through number of layers which describes the lithology variation beneath the soundin,~ site. The number of layers is mainly related to the geological layers that migh occur beneath the sounding and not to the number of resistivity measurement: in the sounding as considered in the Zohdy method. The advantage of thi'. method is that it can directly express the lithological layering model in a straighi forward interpretation and does not require as high a skill in interpretation as does the Zohdy method.

VES curves were subjected to both techniques of sounding analysis. A multilayer model and an absolute layering model corresponding to each sounding were then obtained using an advanced software.

The n-layer models of some selected soundings that are located at proper spacing on a profile were used to produce a subsurface true resistivity contour section beneath this profile. This procedure was used to prepare three sections namely, A-A', B-B' and C-C' (Fig. 4, 5 and 6, respectively).

Section A-A' of Figure 4 consists of the results of VES 7, 8, 9, 10, and 12. The high resistivity values (>100 ohm.m) beneath VES 7, 8 and 9 are associated with the basement rocks at depths greater than 20 m. The contour section reveals also the extent of thick clay layer which is associated with the lowest resistivity values (< 10 ohm.m) and indicates that the water-bearing layer is rich in clays. The clay content decreases beneath VES 12.

Section B-B' of Figure 5 lies approximately in the central part of the study area and indicates that the upper surface layer is dry alluvium which is associated with high resistivity values. Water-bearing layer varies in thickness and resistivity values and becomes thicker beneath VES 21 where clay content and salinity diminish.   .

The northeast portion, where section C-C' in Figure 6 cuts VES 20, 22, 24, 26 and 29 indicates that the sharp increase in the resistivity values beneath VES 24, 26, and 29 is probably due to the existence of the basement rocks at shallow depths.

DISCUSSION AND INTERPRETATION

In Shaib A1 Ziba area, significant and detectable contrasts in physical properties of the lithological units enabled the application of VES and HEP for groundwater exploration.

Most, if not all, the geoelectric sections exhibit nearly the same general profile, namely a section consisting of three major layers. The uppermost layer would generally be classed as a moderately resistive layer. This layer is interpreted as being composed of gravel and unconsolidated dry sediments. The middle layer has low resistivity values, particularly, below section A-A' of Figure 4. It is proposed that this layer is composed of clay and within it, sediments and sand are intermixed with water. Evidence from these measurements indicates that watertable varies in depth between 7-10 m. The lower layer has high resistivity values and may represent the upper part of the basement. Depths to the basement rocks range from 4-24 m.
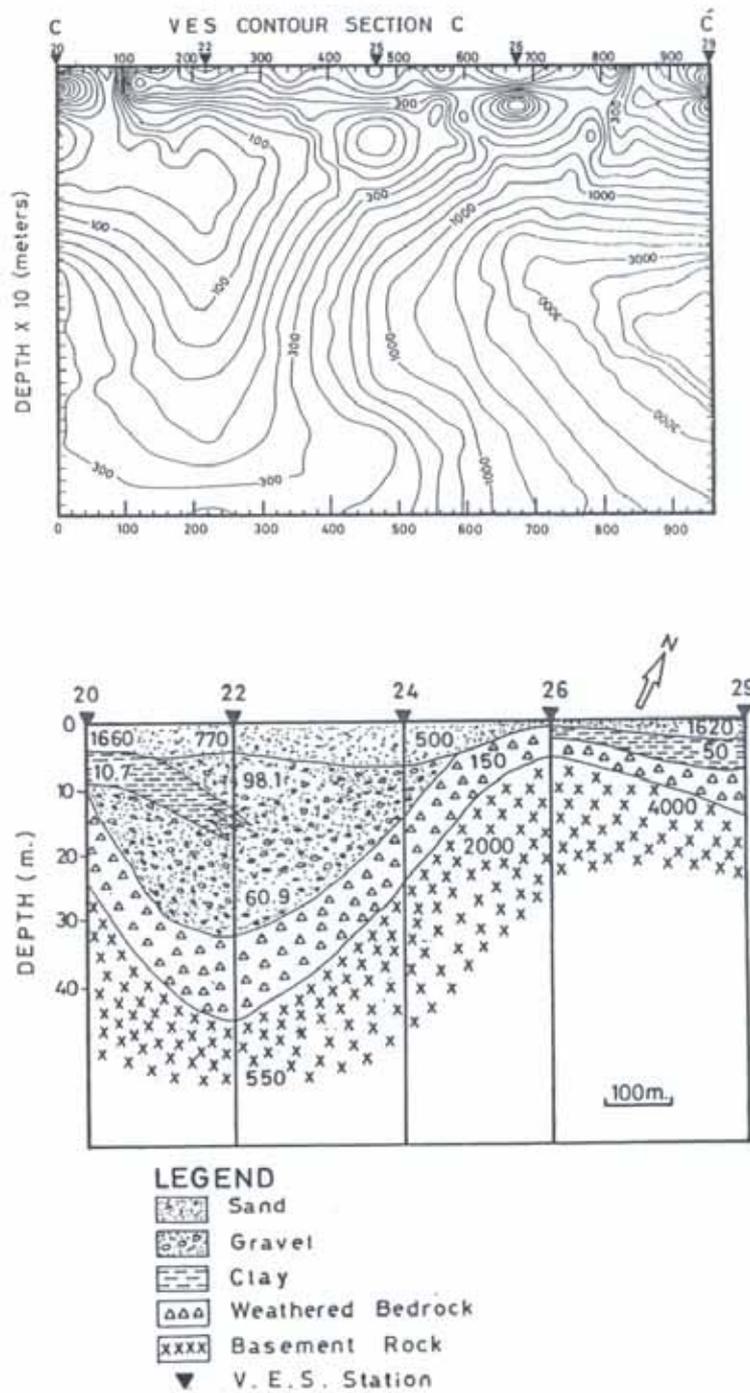
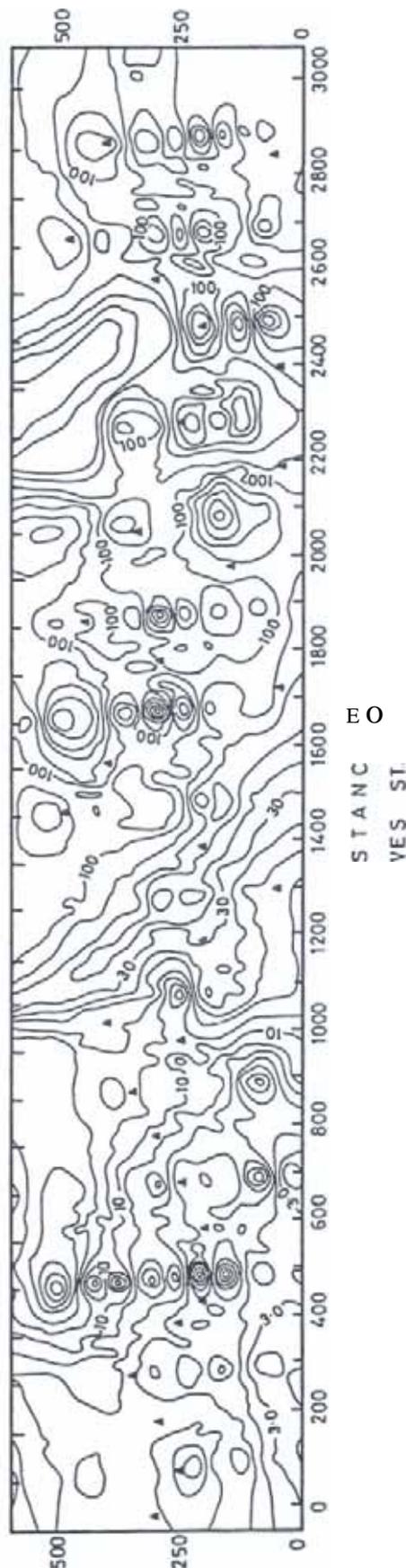Figure 6. Interpreted subsurface true resistivity and equivalent geological sections along profile C-C'.

Figure 7. HEP contour map of Shaib Al Ziba.

Examination of HEP contour map (Fig. 7) reveals the lateral resistivity variations in a thin surficial zone (skin zone). The thickness of this zone is mainly dependent on the array spacing (AB/3). As previously mentioned, AB/3 is 20 m. Therefore, it is expected that the thickness of the surficial zone expressed in the HEP is relatively large. According to HEP contour map (Fig. 7), this area can be divided into three zones. Zone 1, from VES 1 to VES 16 (SW of the area), is characterized by extremely low resistivity values which may reflect the abundance of clay content and may also indicate high saline groundwater occurrences. The examination of VES curves in this zone supports the results given by HEP and hydrological characteristics. This confirms that the water potentiality here is not promising since the discharge will be very low. This interpretation is also substantiated by data from well 1 (Fig. 3) which is located at VES 2. Groundwater samples of this well contain TDS concentration of 38600 Mg/l.

Zone 2 extends from VES 16-24. This zone is characterized by relatively moderate resistivity values which are believed to be attributed to a remarkable decrease in the subsurface clay intercalations and/or a probable decrease in water salinity. This assumption could be supported by the fact that this zone represents the segment of intersection of Wadi Ranyah and Shaib A1 Ziba at VES 20, 21 and 22. Average TDS concentrations of wells 2, 3, 4 and 5 in this zone is 980 Mg/1.

Zone 3 extends from VES 24 to 30 and is characterized by relatively high resistivity values. The most probable cause for this high resistivity is that the basement rocks occur at shallow depths within the limited zone of penetration of the HEP array.

Generally speaking, the analysis of VES and HEP data in conjunction with the results of groundwater occurrences and hydrochemical parameters indicates relative heterogeneities in the subsurface geological conditions. The surficial zone of the alluvial formation varies from clayey in the SW part to alluvium with low clay content in the middle part to thin alluvial section in weathering products in the NE part. Zone 1 contains groundwater in clay-rich formation that yields poor water discharge opportunities. Zone 2 acquires relatively better groundwater potentiality, especially at VES 19, 21, 22 and 23 since the water-bearing layers have less clay content. The groundwater potentiality in Zone 3 is almost negligible since the basement depth is very shallow, the thin alluvial sections do not contain significant groundwater.

CONCLUSIONS AND RECOMMENDATIONS

It could be concluded from the integration of HEP maps, VES and true resistivity contour that the groundwater potentiality occurs mainly at the intersection of Shaib Al Ziba and Wadi Ranyah (zone 2) because of it is low clay content and highly fractured rocks underlying the Wadi alluvium. The VES in the order of preference for the sequence of drilling which demonstrate relatively better groundwater potential are VES 22, 21, 19, and 18, respectively. The maximum depth of penetration for dug wells, based on VES modeling, is in the range of 2535 m below the ground surface. It was possible to realize that this zone is a part of Wadi Ranyah which was recommended for further investigation.

The plains in Shaib Al Ziba in zone 1 are clay-rich and contain a relatively thicker alluvial section with water-bearing layer. This considerably decreases the groundwater potential, hence this zone should not be considered as a source of groundwater.

The alluvial section in zone 3 acquires a very limited thickness and comprises mainly weathered products of the surrounding basement. The basement rocks at the bottom are of crystalline nature and occur at shallow depths. The groundwater potential in this zone is almost negligible.

ACKNOWLEDGMENTS

REFERENCES

Al-Muallem, M.S. & Smith, J.W. (1987): Explanatory notes to the geologic map of Ar Rawdah quadrangle.- Saudi Arabian Deputy Ministry for Mineral Resources, GM-85 C, scale 1:250,000, p.

Green, R.C. (1985): Reconnaissance geologic map of the Harrat Nawasif quadrangle.- Saudi

Koefoed, O. (1979): Geosounding principles.- Elsevier, Amsterdam, 276 p.

Ramsay, C.R. (1982): Ranyah granite belt; exploration targets related to post tectonic plutons.- Saudi Arabian Deputy Ministry for Mineral Resources, Open-File Report DGMR-OF-02-19, 66 p.
Saudi Arabian Dames and Moore, SADM, (1991): Water resources assessment of Wadi Ranyah, Unpublished Report.
Zohdy, A. & Bisdorf, R. (1989): Programs for the automatic processing and interpretation of
    Schlumberger Sounding curves.- U.S. geol. Surv., Open-File Report 89-137, 64 p.