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Delineation of fractured zones in crystalline basement rocks by direct current electrical resistivity method in Oke-Ila area, southwestern Nigeria

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Abstract

A dc-electrical resistivity investigation of Oke-Ila area was carried out with a view to delineating fractured zones within the crystalline basement rocks. The electrical resistivity survey involved vertical electrical soundings at twenty five locations using ABEM SAS 1000 terrameter. The results of the investigation revealed three distinct geoelectric layers: top soil, weathered layer and fractured/fresh crystalline basement rocks. Fractured zones with high aquifer potential were delineated as resistivity lows against the background resistivity highs of the fresh basement rocks. The study revealed that the fractured zones which constitute the productive water bearing zones are discontinuous (localized) and they occur at an average depth of 37.5m.

Keywords: Aquifer, Fractured bedrock, Basement depression, Regolith, Superficial deposits.

Introduction

Groundwater is ubiquitous and immensely important for human uses but there is inadequate supply especially in the basement complex terrain as most boreholes are either abortive or cannot yield sustainable water to wells. Oke-Ila lies within the Precambrian basement terrain where there are several difficulties confronting groundwater development. One of such difficulties includes the spatial variation of vital parameters such as fractures and joints that characterize the groundwater regime. A major reason for the failure of the boreholes sunk in this terrain is the lack of pre-drilling investigation. Ten (10) percent of the world's population is already affected by chronic water scarcity and this is likely to rise to thirty-three (33) percent by about 2025 (WHO, 1996). The need for development of groundwater resource to meet up domestic demand of the growing population has called up for detailed preliminary geophysical investigations to delineate productive zones.

Field observations have shown that aquifers in crystalline basement terrains are highly localized and are mainly controlled by weathered regoliths and secondary porosities developed from fractures and joints (Adelusi *et al*., 2000; Bala & Ike, 2001; Abdullahi, 2005; Olasehinde & Raji, 2007). The capacity of the fractured crystalline rocks to store, transmit and yield appreciable quantity of water depends on the thickness and continuity of the fractures (Bayode, 2000). Because of the discontinuous (localized) nature of basement aquifer, successful exploitation of groundwater in basement terrains requires proper understanding of geo-hydrological characteristics. Hence, detailed geophysical investigations precede drilling programmes for groundwater development in these terrains.

The aquifers within the weathered unconsolidated materials overlying the basement rocks often occur at shallow depths, and the people living in these areas abstract water through hand dug wells from these shallow aquifers with obvious lack of concern for aquifer vulnerability to near-surface contaminants and groundwater water quality. Delineation of fractured zones in crystalline bedrock is of prime importance in groundwater investigations in this terrain due to the fact that the groundwater within the fractured bedrock occurs at greater depths and is protected from near surface contaminants. These zones are often characterized by relatively low resistivity values (basement depressions) against the background high resistivity values of fresh basement rocks.

The electrical resistivity method is the most widely used geophysical method for exploration of groundwater in the crystalline basement rock terrains because it constitutes a useful tool for defining the significant

Fig.1. Map of the study area

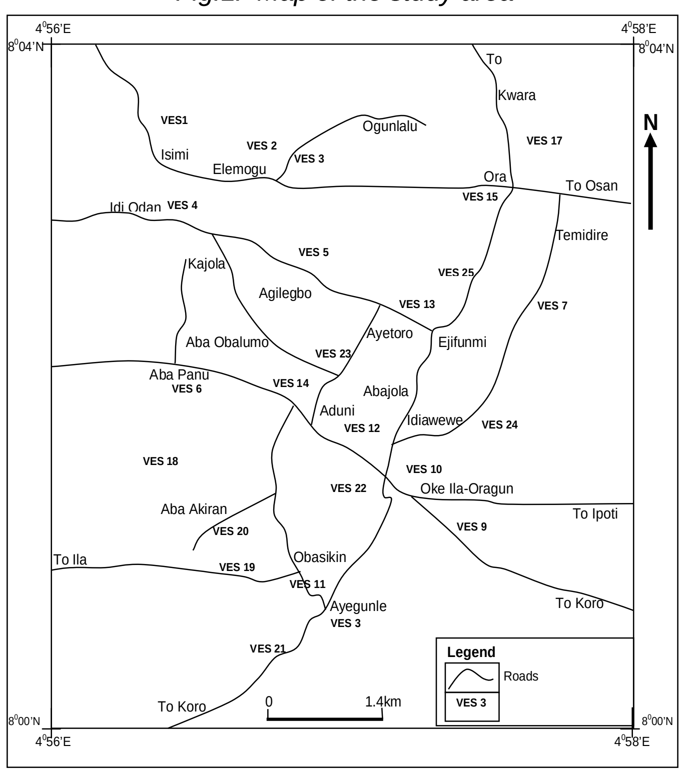
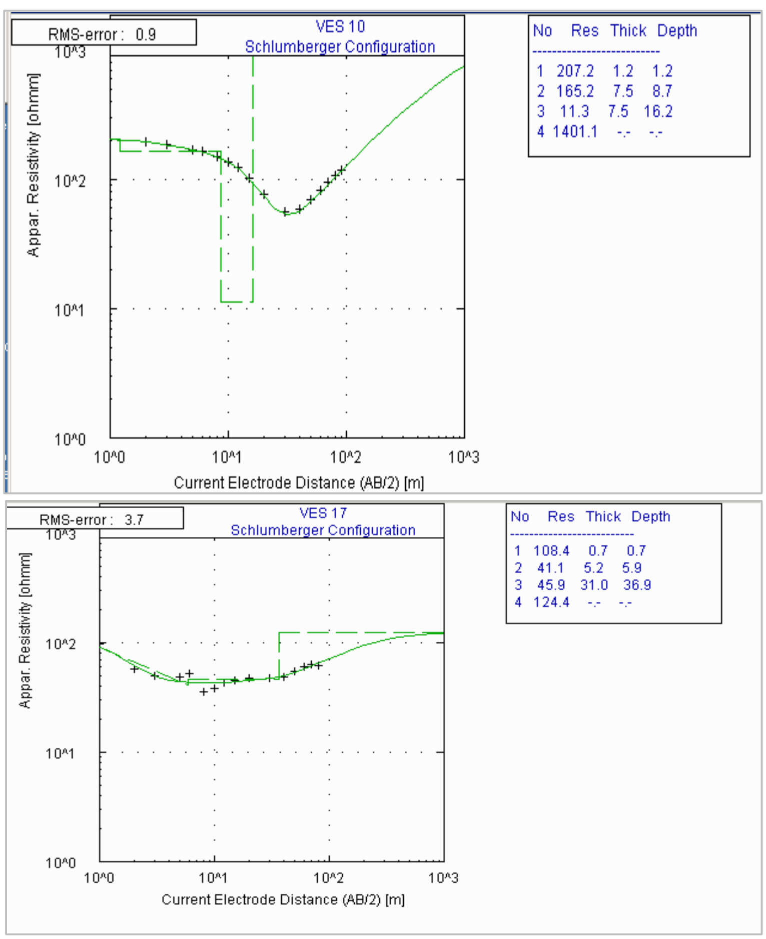


Table 1. VES interpreted results

VES station	Resistivity (Ωm) $\rho_1/\rho_2/\rho_3/-/\rho_n$	Thickness (m) $h_1/h_2/h_3/-/h_n$	Types curves
1	224.8/88.6/109.1/1224.7	1.1/9.2/11.3	HA
2	603.5/51.3/114.6/1008.2	1.2/5.1/9.7	HA
3	388.3/32.8/84.2/123.3	0.6/1.4/18.5	HA
4	192.4/41.7/303.8/1586.4	0.8/11.6/28.3	HA
5	184.2/31.6/73.5/1837.3	1.5/6.6/3.6	HA
6	806.9/580.6/326.2/81.4/3116.4	1.212.8/3.0/9.3	QHA
7	184.8/621.6/48.1/3014.7	0.9/10.4/8.6/	KH
8	336.2/553.9/214.8/1735.1	1.4/5.1/13.1	KH
9	308.6/67.2/215/616.9	0.9/15.1/32.5	HA
10	207.2/165.2/11.3/1401.1	1.2/7.5/7.5	QH
11	123.6/19.8/224.2/42.9/1220.7	0.8/1.1/4.8/29.3	HKH
12	741.6/17/746/238.6/1359.1	0.6/1.0/7.0/25.0	HKH
13	810.2/158.4/127.8/581.8	0.6/3.3/20.8	HA
14	186.4/15.3/96.7/1635.6	1.2/6.3/14.5	HA
15	851.9/234.1/41.6/349.2	1.3/6.8/49.0	QH
16	89.1/21.1/37.3/3538.1	1.3/3.7/8.7	HA
17	108.4/41.1/45.9/124.4	0.7/5.2/31.0	HA
18	511.3/137.5/156.4/1008.1	1.3/10.8/20.6	HA
19	426.7/168.1/83.3/1462.4	1.0/8.5/30.5	QH
20	131.4/375.2/63.8/1608.1	0.9/14.4/8.8	KH
21	239.7/15.3/375.6/1279.4	1.0/4.4/28.1	HA
22	184.1/27.3/413.7/1362.8	1.6/7.5/21.4	HA
23	209.8/762.3/286.2/1663.2	0.5/15.2/5.8	KH
24	121.8/61.5/172.3/3307.1	1.2/8.9/17.6	HA
25	117.2/521.3/3267.1	4.5/13.8	A

Fig. 2. Typical resistivity curves obtained from the area



contrast in the geoelectric parameters of the superficial deposits, in-situ weathered material, fractured and fresh crystalline rocks and has been successfully used to study hidden subsurface structures like fractures and joints (McDowell, 1979; Koefoed, 1979; Ako & Olorunfemi, 1989; Olasehinde, 1989; Olayinka, 1996).

The objective of this study is to locate these fractured zones that might yield quantities of water at greater depths and free from near surface contaminants.

Location and geology

The study area, Oke-Ila is located in Osun State, Southwestern Nigeria (Fig.1). It is bordered by longitudes 4°56'E and 4°58'E and latitude 8°00'N and 8°04'N. The area lies within the Precambrian basement complex terrain of Southwestern Nigeria and have been affected by the Pan African orogeny. The major lithologic units include the migmatite-gneiss complex which is made up of three main lithologies: the early gneiss; the amphibolites, biotite-gneiss and Pan African granites (Rahaman & Ocan, 1978). The main rock types of the study area are the meta-sedimentary units consisting of succession of N-S trending schists. There are also minor pegmatite vein and quartz vein intrusions and noticeable geologic structures include faults, folds, and joints. Rahaman (1976) recognized that the migmatite-gneiss complex might have resulted from a complex association of deformative, shearing, folding, granitization and migmatization process.

The barrovian type of metamorphism has affected the area and metamorphic grade is from green schist to amphibolite facies (Rahaman, 1989).

Materials and methods

In this study, the vertical electrical sounding using Schlumberger configuration was employed. This array is the most widely used of all other configuration in depth sounding techniques because of its high probing capabilities in groundwater investigation (Zohdy *et al.,* 1974; Ako, 1996). The current electrode separation was varied between 2 and 90m. The data were collected at twenty five locations using the ABEM SAS 1000 terrameter. The apparent resistivity values obtained from the field were plotted against half current electrode spacing on log - log graph paper. The initial interpretation of the VES data was accomplished using conventional partial curves matching technique utilizing master curves (Koefoed, 1979) and the corresponding auxiliary curves (Orellana and Mooney, 1966) from which resistivity values and thicknesses of the layers were obtained. The software winResist version 1.0 was used for refining the partial curves matching interpretative results (Vander Velpen, 2004) which successfully reduced the interpretation errors to acceptable levels (Barker,

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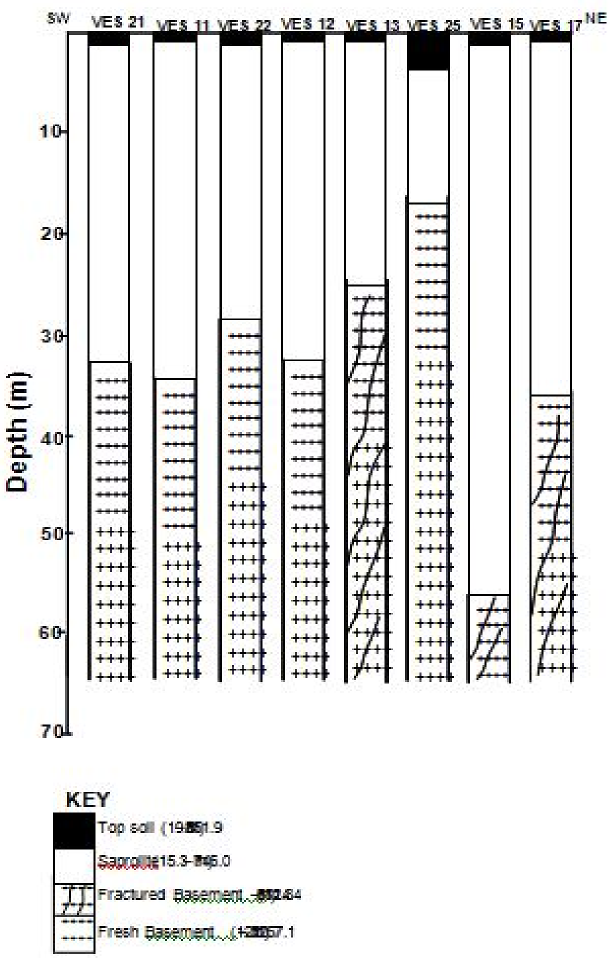
Fig.3. Geoelectric section of the study area along a line section in Fig.1



1989).

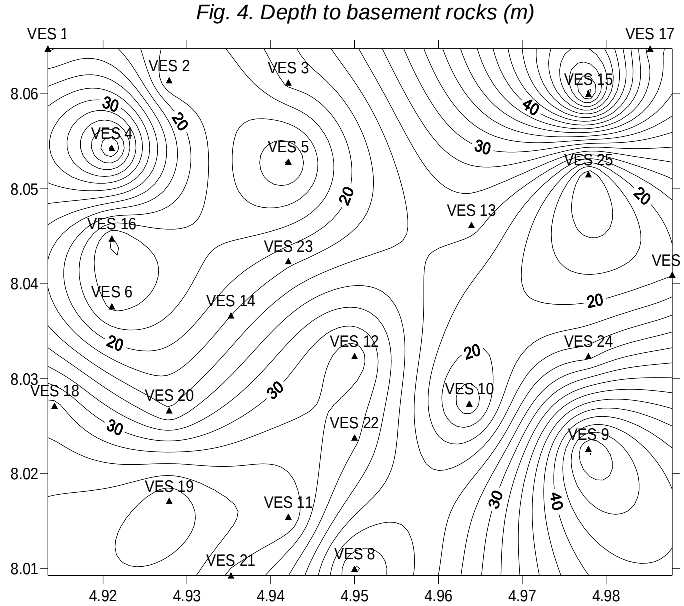
The resulting curves and their final model parameters after quantitative interpretation are presented in Fig. 2 and Table 1. The final model geoelectric parameters were used for the preparation of the geoelectric section (Fig. 3).

Results and Interpretation

The depth sounding curves were classified into different type curves: HA (56%), KH (16%), QH (12%), KHK (8%), QHA (4%) and A (4%). The geoelectric section (Fig. 3) which was drawn from the interpreted results show three subsurface layers namely: top soil, weathered basement rocks (saprolite) and fractured/fresh basement rocks.

The first layer constitutes the top soil with resistivity values that ranged from 89.1 to 810.2Ωm. The layer thickness varied from 0.5 to 45m. The second layer which has resistivity values that ranged from 11.3 to 746 Ωm constitutes the weathered basement rocks (saprolite) and is characteristic of clay/silt/sand, the thickness of this layer varied from 10.2 to 55.8m. According to Lenkey *et al.* (2005), the thick weathered layer (containing less

Fig. 4. Depth to basement rocks (m)



percentage of clay) above the basement rock constitutes a water-bearing layer.

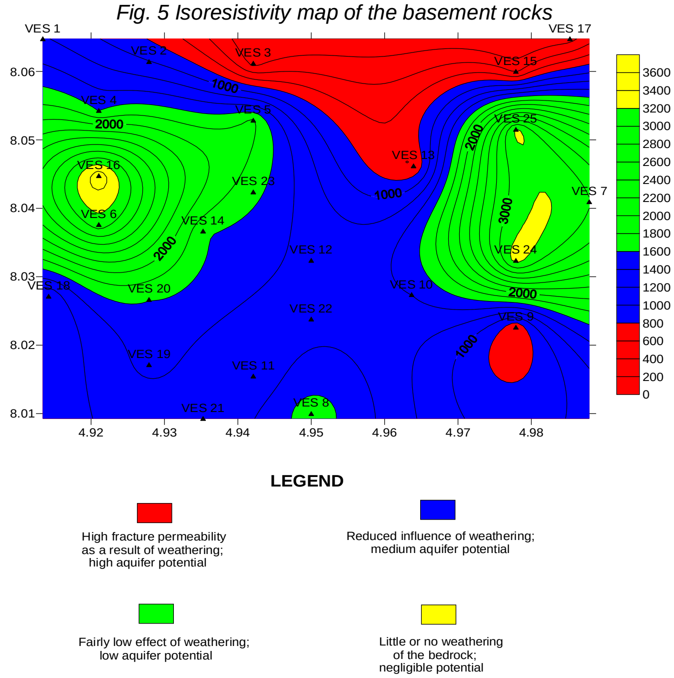
The aquiferous unit (second layer) may be prone to contamination from near surface sources due to its shallow nature (average depth is 8.6m) and high vulnerability to contamination. (Aweto, 2011). Optimum aquifer potential are attained in the mid-range of saprolite resistivity (20 to 100Ωm) while resistivity values less than 20Ωm indicate clays (Wright, 1992). The third layer constitutes the fractured and fresh basement rocks with layer resistivity that ranged from 123.3 to 3538.1Ωm. The depth to the basement rocks (Fig.4) varied between 11.7m (VES 5) and 57.1m (VES 15). When the bedrock has relatively low resistivity (<750Ωm), this could indicate fracturing and high aquifer potentials (Olayinka *et al.,* 1997).

Recognizable structural features in the geoelectric section are the basement depressions (<750Ωm) within the basement highs which indicated fracturing in the basement rocks beneath VES 3, 9, 13, 15 and 17 occurred at depths of 20.1m, 48.9m, 24.7m, 57.1 and 36.9m respectively. The basement depressions (low resistivity values within the basement rocks) depicted by red colour in the isoresistivity map (Fig. 5) indicates fracturing which are relevant for groundwater development are priority zones for possible location of boreholes.

Conclusion

The geoelectric investigation of the study area has revealed three sub-surface geoelectric layers: top-soil, weathered basement and fractured/ fresh basement rocks. The second layer which is presumably clay/silt/sand constituted the aquifer units in the study area where they are thick and contain less percentage of clay, but may be vulnerable to pollution that may arise from indiscriminate disposal of wastes and surface runoff due to the shallow nature of this aquifer and poor

Fig. 5 Isoresistivity map of the basement rocks



protective capacity of the overburden materials above the saprolite (aquifer) in the study area. Hence, the basement depression in the northernmost and southwestern parts (at VES 3, 9, 13, 15 and 17) which indicates fracturing and high aquifer potentials are priority zones for possible groundwater development since they occur at greater depths and may be less vulnerable to contaminants/pollution from near surface sources.

The dc-resistivity method has proved very successful in identification and delineation of deep zones of fracturing within the crystalline basement rocks.

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