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Geophysical Characterization of Basement Rocks and Groundwater Potentials Using Electrical Sounding Data from Odeda Quarry Site, South-western, Nigeria

[1]B.S. Badmus and [2]O.B. Olatinsu
[1]Department of Physics, Federal University of Agriculture, Abeokuta, Nigeria
[2]Department of Physics, University of Lagos, Akoka, Lagos, Nigeria

Corresponding Author: O.B. Olatinsu, Department of Physics, University of Lagos, Akoka, Lagos, Nigeria

ABSTRACT

This study was carried to characterize the basement rocks and groundwater potentials by delineating the resistivity and overburden thickness of subsurface lithology of Odeda quarry, south-western, Nigeria. Vertical electrical soundings were carried out at fifteen locations using Schlumberger electrode arrangement. The maximum current electrode spread and potential electrode separation were 200 and 5 m, respectively. Data acquired were interpreted using the manual partial curve matching method and a fast computer iteration technique to generate the geoelectric layer of various resistivity values and thicknesses. The geoelectric sections revealed the lithological sequence as: topsoil, weathered layer and fresh bedrock. The overburden coefficient of anisotropy also revealed that, the underlying basement rock is suspected be granite gneiss/granite-schist. The overburden coefficient of anisotropy was calculated for each sounding location and this ranges from 1.00 to 2.30. This was used in delineating the study area into region underlain by granite gneiss (λ between 1.00 and 1.03) and those regions with granite-schist (λ between 1.30 and 2.30) as the underlying basement rocks. At locations where current terminated at the fresh bedrock region, the thicknesses were undetermined. Groundwater potential is presumed to be very low within the study area as outcrops of gneissic rocks dominate the area. Locations where the regolith is of appreciable thickness, the resistivity of the layer suggests a material medium likely composed of clay/sandy clay or clayey sand which are not good aquiferous media from which groundwater could be extracted.

Key words: Electrical sounding, resistivity values, basement rock, groundwater, geoelectric layers

INTRODUCTION

Electrical resistivity technique has been widely employed in groundwater exploration, depth to bedrock determination and basement rock characterization (Zohdy *et al.*, 1974; Beck, 1981; Olorunfemi and Okhue, 1992). Geoelectric investigation of Odeda quarry site was carried out with a view of understanding the subsurface lithology and hydrogeological setting to characterize the groundwater potentials. Geophysical survey of basement rock is useful because such surveys are more time and cost efficient than collecting data through borehole drilling and coring technique. Geophysical surveys provide non-invasive spatial images of the subsurface, while borehole data only provides information of the subsurface close to a well. Beacon and Jones (1988) and

Caruther and Smith (1992) have all shown the significance of the use of electrical resistivity techniques for sitting wells and boreholes in crystalline basement aquifers in sub Sahara Africa. However, interpretation of the geophysical data can be ambiguous if clear correlations are not established between the geophysical attributes and the geologic properties coupled with the stratigraphic properties of the subsurface (Koster and Harry, 2005). Given the usual sparsity of core and geophysical logs, establishing such a correlation is often problematic. As good alternative, geophysical studies of outcrops strata in basement complex terrain are often used (Wolfe and Richard, 1996; Hubbard and Rubin, 2000). Water content affects a variety of geophysical attributes, such as electrical resistivity, seismic, radar velocity and reflectivity (Heigold *et al.*, 1979; Kelly and Frohlich, 1985; Mazac *et al.*, 1988; Metwaly *et al.*, 2010; Smith and Jol, 1995; Doser *et al.*, 2004). Outcrop studies provide a robust qualitative tool for identifying major stratigraphic features on the basis of their resistivity character (Koster and Harry, 2005).

Weathering is not a uniform phenomenon in any environment and results in heterogeneous and hydrological characteristics of the rock formations. The conceptual structure of hard rocks is that of a fresh basement overlain by materials which have undergone different stages of weathering. Groundwater availability is therefore attributed to weathering in the overburden and basement surface. Basement weathering presents themselves as zones of disintegration (K'Orowe *et al.*, 2008). These zones appear as low electrical resistivity anomalies compared to the massive basement rocks that surround them. Consequently, basement troughs with deep weathering are points of disintegration which are hydro-geologically viable as far as groundwater aquifers are concerned (Ahmed *et al.*, 1988; K'Orowe *et al.*, 2008).

MATERIALS AND METHODS

Study area and the geology: This study area revealed outcrops in a heterogeneous, unconfined and unconsolidated rock exposed at the Odeda quarry site, south-western Nigeria. Odeda is in the north central region of Ogun State and has accessible and well-connected roads and foot paths. The quarry has two phases; the abandoned site and the new site. This study covered part of the new site to the extreme of the abandoned site. The quarry site lies within the southwest basement complex of Nigeria. In general, the surface is covered with granitic boulder of outcrops of different sizes with thick sage brush between the boulders. Topographically, the site consists of steep natural slopes with several intervening drainage courses. Structural blocks and intervening valleys characterize this physiographic region. The area is underlain directly by crystalline formations (Precambrian to upper Cambrian) of the basement complex of south-western Nigeria. The prolonged weathering of the crystalline rocks has led to the development of regoliths of varying thicknesses which in effect reduced the conductivity of the parent rocks. The degree of weathering also depends on the depth of the rock beneath the earth surface. When the rock is very close to the surface, weathering is faster because it can be easily affected by rainwater and other weathering agents. But when the rock is buried far deep within the earth, weathering rate is reduced. The physical changes in rock material as a result of weathering are referred to as litho-facie changes.

The basement complex area of Nigeria (Fig. 1) is composed predominantly of migmatitic and granitic gneisses, quartzite, slightly migmatised to unmigmatised meta-sedimentary schist and meta-igneous rocks, charnockitic, gabbroic and diorite rocks and the members of the older granite

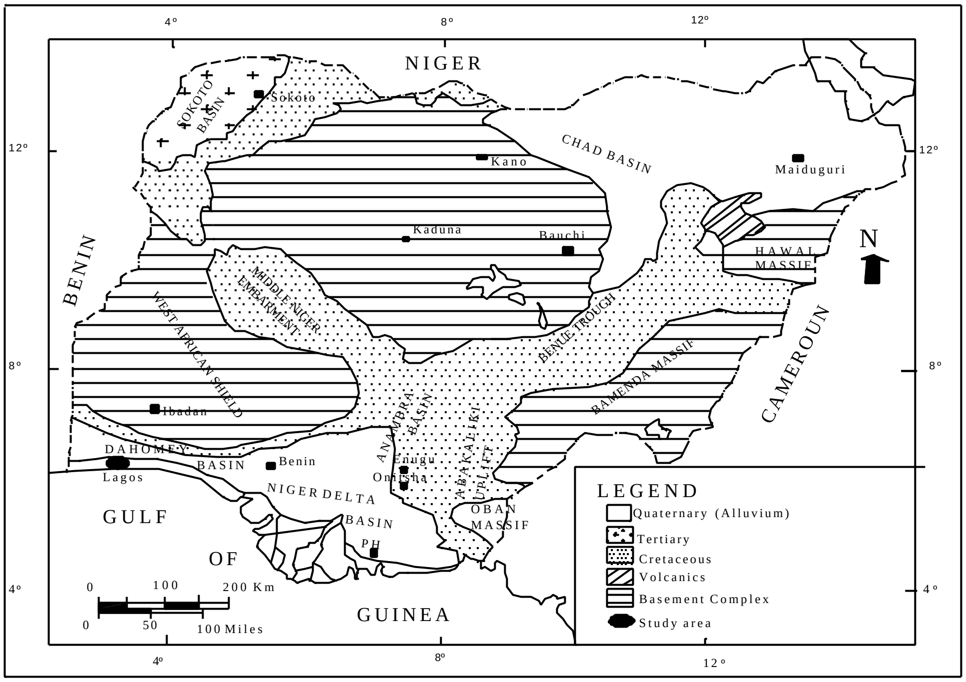


Fig. 1: General geological map of Nigeria

suite mainly granites, granodiorites and syenites. The migmatite (gneissic quartzite) is mostly widespread in the basement complex of south-western Nigeria (Fig. 2) which comprises of gneisses, quartzite, cal-silicate rocks, biotic (hornblende schist) and amphibolites. The slightly migmatised to unmigmatised paraschist and meta-igneous rock are described as younger or newer metasediments. Charnockites occur west of Ibadan as dyke-like bodies scattered over a wide area. Jones and Hockey (1964) recognised three main groups of granites: an early phase comprising granodiorites and quartz diorites; a main phase, comprising coarse porphyrite, hornblende granite, syenite and coarse porphytic biotite granite; and a late phase comprising homogeneous granites, dykes, pegmatites and aplite.

Data acquisition and interpretation: In this study, a total of fifteen VES (Vertical Electrical Sounding) stations were carried out (Fig. 3). ABEM Terrameter SAS 300B and its accessories were used. Consecutive readings of resistance were taken automatically by the Terrameter and the result stacked and ranged continuously thereby increasing the signal-to-noise ratio of measured values. The apparent resistivity values were obtained using the product of apparent resistance and geometric factor.

For the manual data interpretation, apparent resistivity values were plotted against half current electrode separation (AB/2) on a log-log graph. Partial curve-matching was performed using the Schlumberger array master curve and auxiliary curves to determine the layer resistivity values and thicknesses. The results obtained from the manual curve-matching procedure served as initial model for the fast computer iteration technique using software "RESIST" (Velpen, 1988) for further

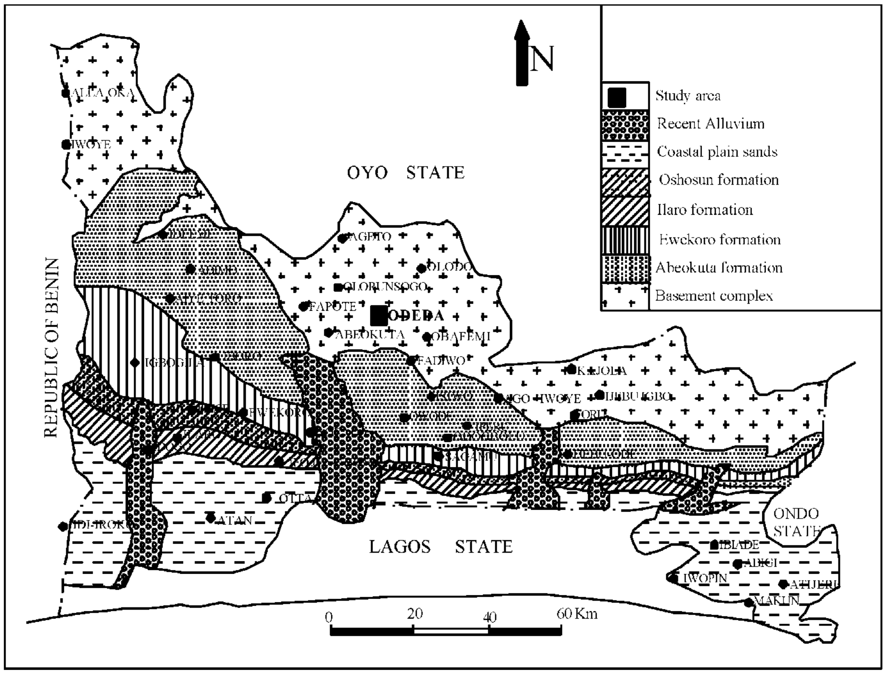


Fig. 2: Ogun State geology map showing the study location

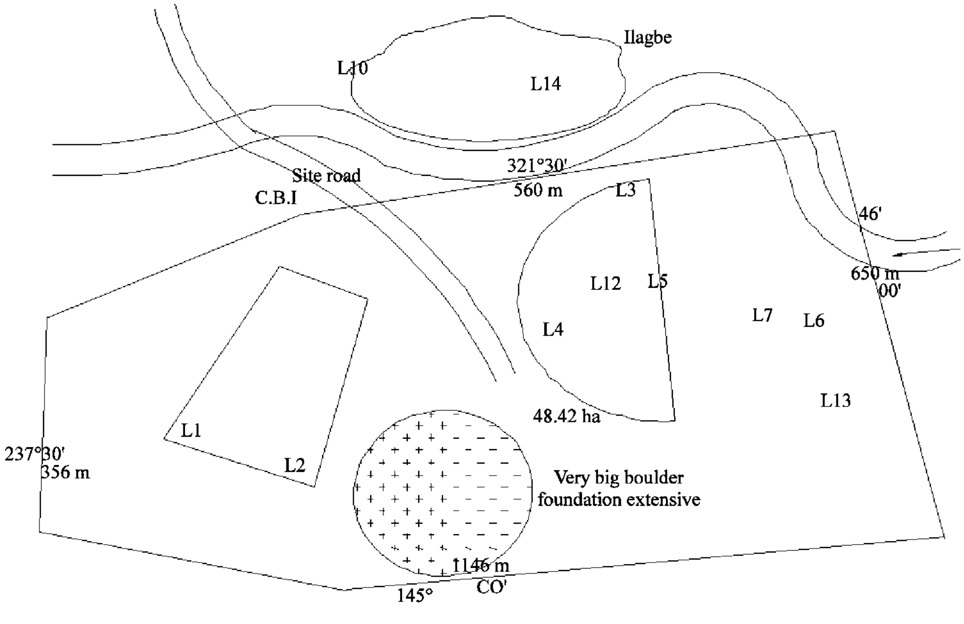
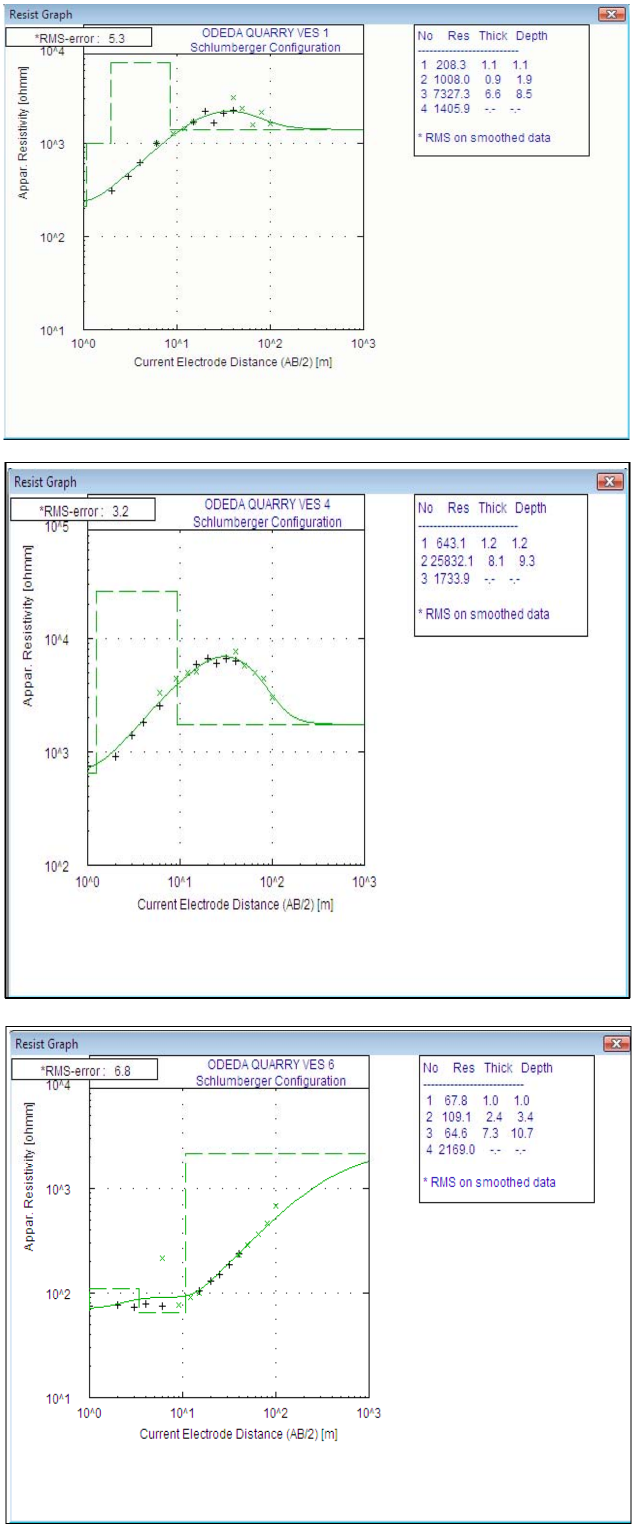


Fig. 3: Data acquisition map of the study area

refinement of the results. Samples of the curves obtained after a number of iterations until the model generated for all VES curves are totally resolved with minimum RMS error, are presented in Fig. 4a-c.



*RMS-error : 5.3

ODEDA QUARRY VES 1
Schlumberger Configuration

```
No   Res  Thick  Depth
---------------------------
 1  208.3   1.1   1.1
 2 1008.0   0.9   1.9
 3 7327.3   6.6   8.5
 4 1405.9   -.-   -.-

* RMS on smoothed data
```

*RMS-error : 3.2

ODEDA QUARRY VES 4
Schlumberger Configuration

```
No   Res  Thick  Depth
---------------------------
 1  643.1   1.2   1.2
 2 25832.1  8.1   9.3
 3 1733.9   -.-   -.-

* RMS on smoothed data
```

*RMS-error : 6.8

ODEDA QUARRY VES 6
Schlumberger Configuration

```
No   Res  Thick  Depth
---------------------------
 1   67.8   1.0   1.0
 2  109.1   2.4   3.4
 3   64.6   7.3  10.7
 4 2169.0   -.-   -.-

* RMS on smoothed data
```

Fig. 4(a-c): VES (a) 1, (b) 4 and (c) 6 computer iterated results

RESULTS AND DISCUSSION

The results of the electrical soundings carried out in this study area are presented in tables (Table 1) and geoelectric sections (Fig. 5a-c). The fifteen locations sounded at the quarry site were used to characterize the subsurface lithology to a depth of about 200 m. Based on the interpretation of the VES resistivity data, the inferred geoelectric sections (Fig. 5a-c) revealed the thickness of the

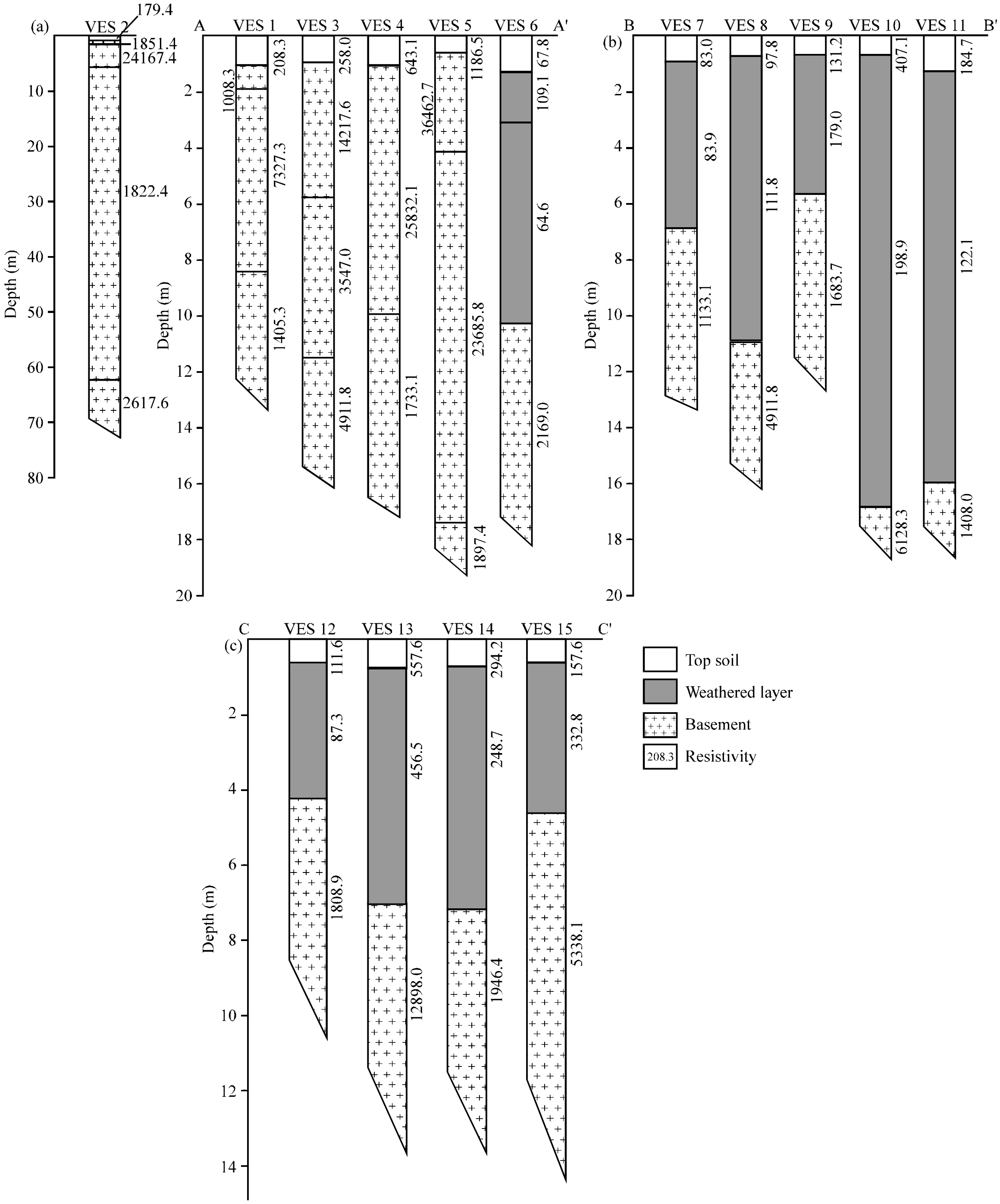


Fig. 5(a-c): Geoelectrical section beneath profile (a) A-A' (VES 1-6), (b) B-B' (VES 7-11) and (c) C-C' (VES 12-15)

Table 1: Apparent resistivity using the fabricated resistivity equipment

Current electrode separation (m)	Potential electrode separation (m)	Resistance values (Ω)	Geometric factor (K)	Apparent resistivity (Ωm)
1	0.25	92.30	5.89	543.647
2	0.25	48.68	24.74	1204.343
3	0.25	29.30	56.16	1645.488
4	0.25	23.56	100.15	2359.534
6	0.25	8.60	225.83	1942.138
6	0.50	5.40	112.33	606.582

regolith in the range 2.2 to 16.3 m. The resistivity of the weathered layer varies from a minimum of 63.9 Ωm to a maximum of 456.5 Ωm. The basement rock is suspected to be granite of different litho-facie changes. The lateral resistivity changes in Odeda granite can be attributed to the nature of the rock, degrees of compaction, depth of burial and other geological features.

The qualitative interpretation of the data revealed a minimum of three geoelectric layers and a maximum of five geoelectric layers. The curve types obtained in soundings over a horizontally stratified earth is indicative of the number of layers as well as the electrode configuration adopted (Zohdy *et al*., 1974). The curve type A occurred mostly in this study and it reveals a steady increase in resistivity with depth as the current electrode spread is increased. The steeply rising segment of the curves at a large electrode distance indicates the characteristic high resistivity of basement rocks (Olayinka, 1990; Olayinka and Sogbetun, 2002). The weathered layer (materials above the basement) is very thin in most locations, a manifestation that the site is clustered with outcrops.

Granite gneiss/schist which underlain the quarry site can be classified into three litho-facie changes:

Facie I : Basement rocks with resistivity values greater than 25,000 Ωm. These are highly compacted, dense and fine grain

Facie II : Basement rocks with resistivity values in the range 10,000 to 25,000 Ωm. These are compacted, mixed with sandstone and less dense

Facie III : Basement rocks with resistivity below 10,000 Ωm; very porous as well as having cracks

The resistivity values of granite-gneiss/schist range between 2136.5 and 36462.7 Ωm and thicknesses between 1.8 and 11.0 m. The overburden coefficient of anisotropy (Christensen, 2000; Olatinsu, 2003) was calculated for each sounding location and this ranges from 1.00 to 2.30. This was used in delineating the study area into region underlain by granitic gneiss (λ between 1.00 and 1.03) and those regions with granite-schist (λ between 1.30 and 2.30) as the underlying basement rocks.

CONCLUSION

Possible locations where granite rock are close to the surface for exploration and possible excavation can be found mainly along traverse A-A' with VES 1-6. The depth to bedrock is significantly high at VES 8, 10 and 11 and as a result, could be less cost effective because of the extra cost in reaching these depths. However at VES 13, 14 and 15 where there is a possible existence of fracture units of moderate resistivity (above 250 Ωm), groundwater exploitation may be difficult, as the results of this study revealed most areas of appreciable overburden thickness to compose of sandy clay, clay or clayey sand. These media are not suitable aquiferous media for groundwater extraction.

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