GLOBAL JOURNAL OF GEOLOGICAL SCIENCES VOL. 2, NO. 2, 2004: 243 - 253
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USE OF ELECTROMAGNETIC PROFILING AND RESISTIVITY SOUNDING FOR GROUNDWATER EXPLORATION IN THE CRYSTALLINE BASEMENT AREA OF IGBETI, SOUTHWESTERN NIGERIA.

A. I. OLAYINKA, S. A. AMIDU and M. A. OLADUNJOYE

(Received 25 March, 2003; Revision Accepted 22 December, 2003)

ABSTRACT

A combination of electromagnetic (EM) profiling and vertical electrical sounding (VES) has been employed to investigate the prospect for groundwater development in the basement complex area of Igbeti and its environs, Southwestern Nigeria. The study area is northwest of Ilorin and north of Ogbomoso. The bedrock geology comprises a suite of metasediments, gneisses and intrusive granites.

The field survey was conducted at nine locations. In each case, an EM profile 150 m in length was measured with the Geonics EM-34-3 equipment; the coil spacing was 20 m and data collected for both the horizontal and vertical dipole modes. A Schlumberger VES with a maximum half-current electrode spacing (AB/2) of 133 m was subsequently conducted at the location of the anomaly identified on the EM profile.

The results indicate that there are three main targets for groundwater in this area. These include the weathered zone, the fractured zone and the vertical dykes. In four of the VES locations the resistivity of the prebasement layer is less than 50 ohm-m and this has been interpreted as a clayey lithology. On the other hand, the resistivity of this layer is higher than 85 ohm-m in four other VES locations, indicative of a sandier lithology. Moreover, the VES indicated a fairly shallow overburden thickness at less than 20 m. The fractured gneiss sequence could be inferred from the VES data as relatively low model resistivity (less than 1500 ohm-m) for the geoelectric basement. The vertical dykes were inferred from the large separation between the horizontal and vertical dipoles on the EM conductivity profiles, coupled with negative readings on the vertical dipole curves. The boreholes drilled in the area, based on results of the geophysical surveys, penetrated a sequence of topsoil/laterite, moderately weathered granite, fractured gneisses and fresh bedrock. The approach described in this paper is shown to be rapid and cost-effective in terms of location and assessment of groundwater resources in crystalline rock terrains.

KEYWORDS: Electromagnetic profiling, resistivity sounding, groundwater exploration, Igbeti area, southwestern Nigeria.

INTRODUCTION

Groundwater is a very important resource for human sustenance. Despite the common appearance of surface water all over the world, groundwater has been reported to occur more widely than surface water (March, 1966). In areas underlain by crystalline basement rocks, groundwater occurs either within (i) the weathered zone which is characterised by high porosity, a significant amount of water and low permeability on account of its relatively high clay content or (ii) fractures within the bedrock itself typified by high permeability. Perrenial yields can often only be obtained where a borehole penetrates a large thickness of the weathered zone (which acts as a reservoir) while at the same time intersects fractures in the underlying bedrock, with the fractures providing transport mechanism from the reservoir and hence the high yield (Barker, 2001).

Location of joints and associated narrow zones of deep weathering in crystalline terrain is best achieved using geophysical techniques, with electromagnetic profiling and vertical electrical sounding being two of the most widely used geophysical methods (Beeson and Jones, 1988; Hazel et al, 1988; Amadi and Nurudeen, 1990; Olayinka, 1990; Goldman et al, 1994). Electromagnetic profiling using Geonics EM 34-3 is a quick, simple and effective method of selecting water well drilling sites in fractures and highly weathered crystalline rock terrain (Dirks et al., 1983; Payne, 1988). It is used to measure the electrical conductivity of earth materials. Aquiferous zones typically have high conductivity and they often show anomalies, which may be high or low depending on the quantity/quality of water in the aquifer (Olorunfemi et al., 2000).

On the other hand, vertical electrical sounding (VES) provides information on the vertical variation in electrical resistivity with depth. Most commonly, it is used to assess the suitability of the features observed from EM survey because a variety of subsurface conditions can give rise to similar EM 34-3 data; it is also used to predict the depth to fresh rock which is important in assessing cost effectiveness and perenial yield of a well. This pre-drilling investigation is necessary for careful site selection if the drilling of unproductive holes is to be avoided. In fact, previous studies show that using this integrated approach would improve the

A. I. OLAYINKA, Department of Geology, University of Ibadan, Ibadan, Nigeria
S. A. AMIDU, Department of Geology, University of Ibadan, Ibadan, Nigeria
M. A. OLADUNJOYE, Department of Geology, University of Ibadan, Ibadan, Nigeria

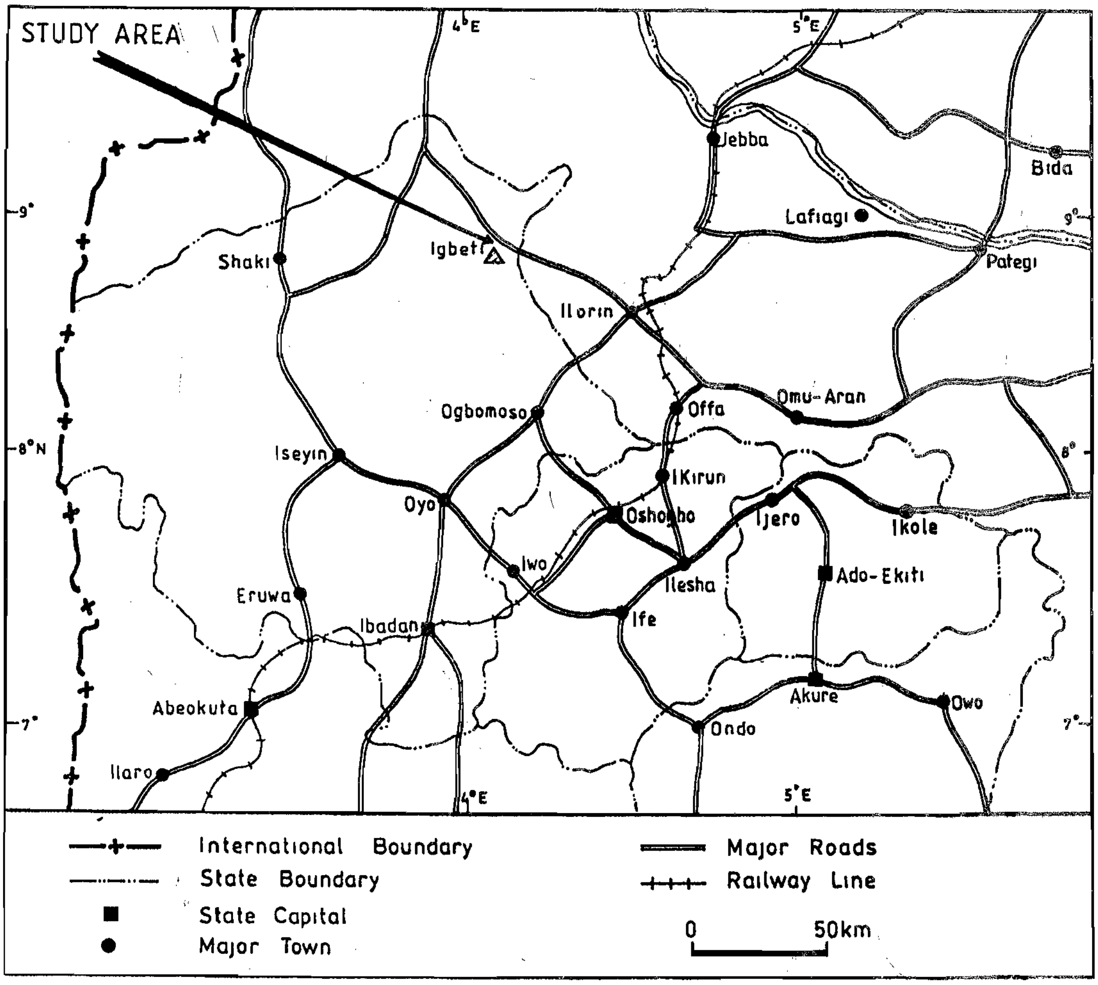

Fig. 1: Location Map of the Study Area showing the major Uban Centres

Table 1: Classification of the results from the Igbeti field survey on criterion of geophysical signatures

Location	Geophysical Target	Frequency
Oke-General area, Igbeti palace, Oriade area and Ogundiran village	Weathered basement	4
Aiyetoro, Oke-Ibukun and Asunmode areas	Fractured basement	3
Iyalode area and Olopa village.	Conductive dyke	2

success rate of borehole drilling. (Beeson and Jones, 1988; Palacky et al, 1981; Olayinka, 1990). The present work is aimed at assessing and locating suitable sites for borehole drilling to meet the water supply of the Igbeti area, southwestern Nigeria. As far as the authors are aware, this is the first published work on the use of geophysics for borehole siting in this area.

The Study Area

The study area is in the South Western part of Nigeria and lies between latitude $8^0\ 4^1$N and $8^0\ 53^1$N and longitude 4^0 05'E and 4^0 15'E. It is about 84 km North of Ogbomoso and 70 km North-West of Ilorin (Figure 1). According to the 1991 census, the population of Igbeti town was 26 867. Although there is limited industrialization in the town, the exploitation of marble has led to the establishment of the Nigerian Marble Mining Company. Save for those employed as semi-skilled workers in the company, most inhabitants of the community are engaged in subsistence agriculture. Igbeti area is underlain by metasediments, the gneisses and intrusive granites (Fig. 2). The younger metasediments consist of pelitic mica-schist with massive amphibolite boulders, quartz-schist, schistose quartzite, massive quartzite and marble with associated chalcedonic rock (Aina & Emofurieta, 1991). They characteristically form narrow NNE-SSW trending ridges and valley patterns. The crests of the ridges are dominated by massive quartzite, which grade into the

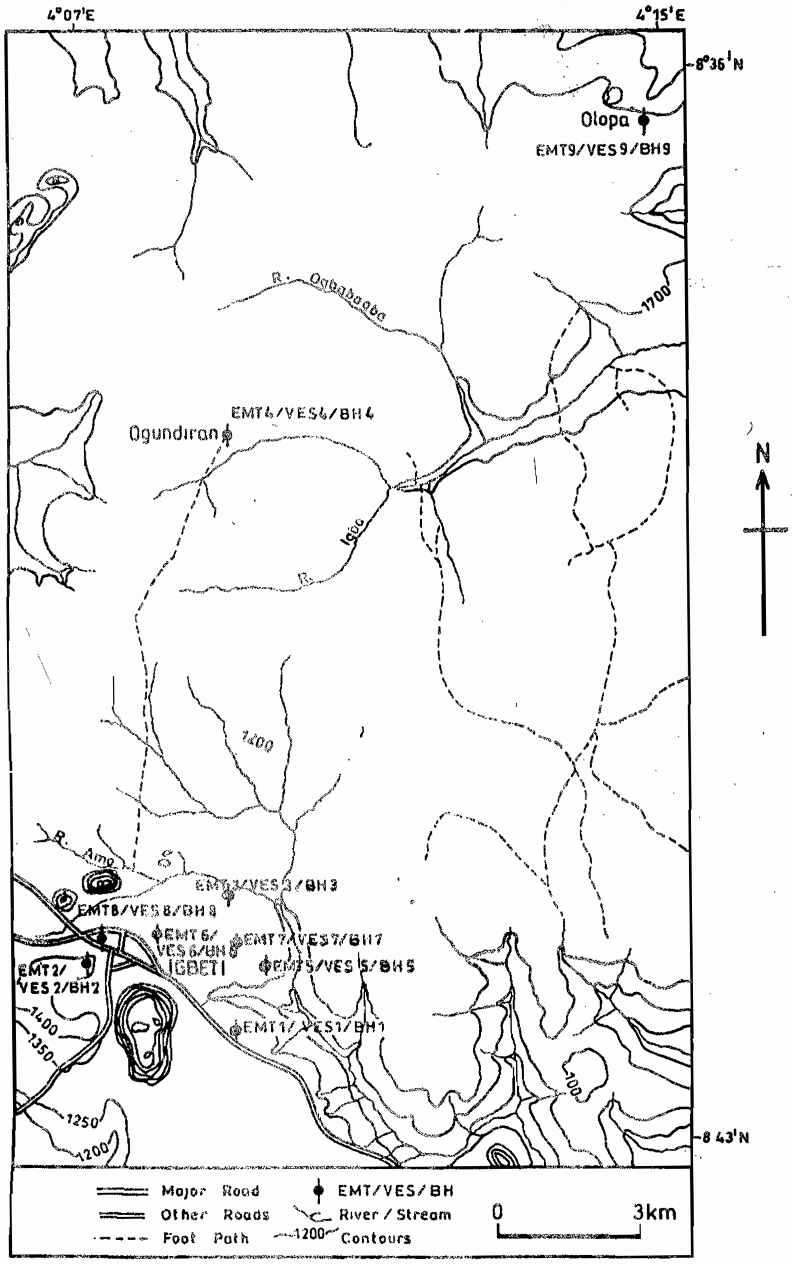

Fig. 2: Location Map showing the Sites Surveyed

schistose variety at the break of slopes and quartz-schist and mica-schist in the valleys. The younger metasediments are underlain by much older gneisses of Eburnean age (Rahaman et al, 1983). The metamorphic suite of rocks is intruded by N-S elongated granites of various textures and composition. The granites occur mainly as inselbergs (Aina and Emofurieta, 1991). Foliation planes are developed and marked by preferred alignment of feldspar phenocrysts while the granites have been affected by series of tensional faults.

It was obvious that jointing has occurred in all directions but the major trend is approximately normal to the grain of the host rocks thus representing cross joints that is well exemplified in the quartzites and gneisses. The NW-SE joint sets have been shown to constitute conduits for groundwater transmission. A preliminary hydrogeological assessment shows that the main sources of water in the survey area are streams and hand-dug wells, which are often affected by seasonal changes. The average total depth of the hand-dug wells is about 5 m.

Data acquisition and Analysis

The Geonic EM 34-3 used in measuring the EM response is a portable instrument that measures the electrical properties of the subsurface using EM induction as described in detail by McNeil (1980a), Dirks et al (1983) and Stewart (1982). The theory of operation of this equipment has also been given by McNeil (1980b). In the examples presented in this work, nine EM 34-3 profiles were made (Figure 3) using a 20 m coil spacing with an expected maximum depth of investigation of about 15 m for the horizontal dipole (HD) mode and about 30 m for the vertical dipole (VD) mode (McNeil, 1983). Using a station interval of 10 m, the HD and VD conductivity values were plotted into EM

Table 2. Summary of layer model interpretation for the sounding data from Igbeti area

(a). VES 1

Layer	Thickness (m)	Resistivity (ohm-m)	Probable lithology	Hydrogeological significance
1	0.6	774	Topsoil	-
2	2.4	181	Sandy clay	Negligible
3	4.1	24	Clay	Poor aquifer
4		1730	Weathered/fractured biotite granite	Good aquifer potential

(b). VES 2

Layer	Thickness (m)	Resistivity (ohm-m)	Probable lithology	Hydrogeological significance
1	0.9	201	Topsoil	-
2	2.1	154	Sandy clay	Limited aquifer potential
3	3.7	37	Clay	Limited aquifer potential
4		1302	Weathered/fractured biotite gneiss	Good aquifer potential

(c). VES 3

Layer	Thickness (m)	Resistivity (ohm-m)	Probable lithology	Hydrogeological significance
1	0.6	85	Topsoil	-
2	1.9	12	Saturated clay	Poor aquifer
3	2.0	34	Clay	Poor aquifer
4		6076	Fresh granite bedrock	Poor aquifer

(d). VES 4

Layer	Thickness (m)	Resistivity (ohm-m)	Probable lithology	Hydrogeological significance
1	0.5	323	Topsoil	-
2	3.0	89	Clayey sand	Poor aquifer
3		4297	Fresh granite bedrock	Poor aquifer

(e). VES 5

Layer	Thickness (m)	Resistivity (ohm-m)	Probable lithology	Hydrogeological significance
1	0.9	103	Topsoil	-
2	3.8	700	Compacted lateritic soil	Poor aquifer
3	13.1	144	Sandy clay	Good aquifer
4		1052	Weathered/fractured gniess	Good aquifer potential

(f). VES 6

Layer	Thickness (m)	Resistivity (ohm-m)	Probable lithology	Hydrogeological significance
1	0.7	828	Topsoil	-
2	6.3	126	Sandy clay	Limited aquifer
3		3037	Fresh granite bedrock	Poor aquifer potential

(g). VES 7

Layer	Thickness (m)	Resistivity (ohm-m)	Probable lithology	Hydrogeological significance
1	0.9	172	Topsoil	-
2	1.3	340	Lateritic soil	Poor aquifer
3	6.4	45	Clay	Poor aquifer
4		3882	Fresh granite bedrock	Poor aquifer

(h). VES 8

Layer	Thickness (m)	Resistivity (ohm-m)	Probable lithology	Hydrogeological significance
1	2.0	94	Topsoil	-
2	10.8	127	Sandy clay	Good aquifer
3		1402	Weathered/fractured gneiss	Good aquifer potential

(i). VES 9

Layer	Thickness (m)	Resistivity (ohm-m)	Probable lithology	Hydrogeological significance
1	1.1	773	Topsoil	-
2	4.8	125	Sandy clay	Limited aquifer potential
3		4311	Fresh granite bedrock	Poor aquifer

profiles. The EM profiles were interpreted qualitatively by matching with geophysical models for high yield aquifers developed by McNeil (1980a) and Palacky et al (1981).

Vertical electrical sounding (VES) was carried out using the Schlumberger electrode configuration (Parasnis, 1979; Zohdy et al 1974). An ABEM SAS 300B Terrameter was used for resistance measurements. A collinear expanding array of current electrodes together with fixed potential electrodes indicate the variation of apparent resistivity with depth. In all, nine sounding points were located and occupied

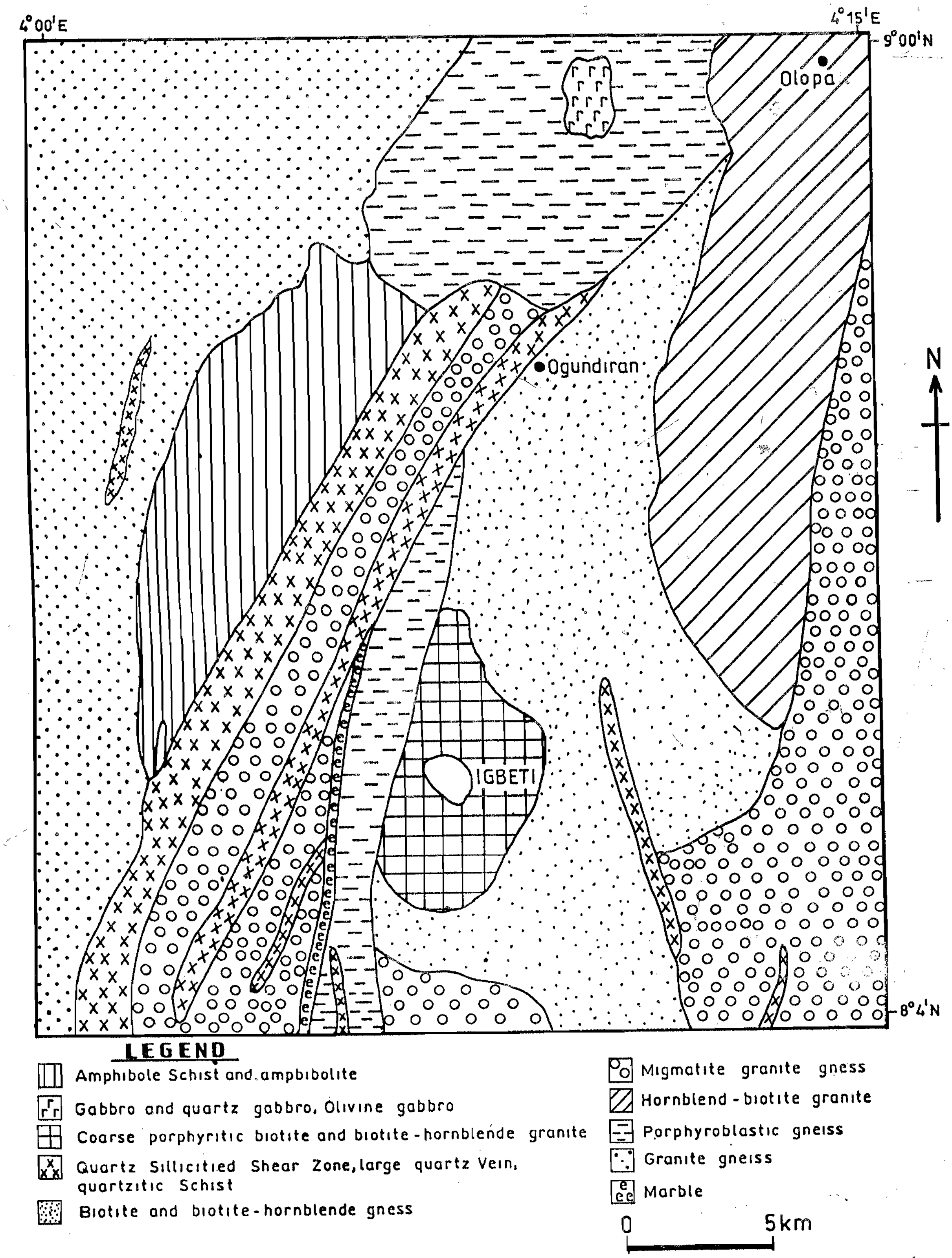

Fig. 3: Geological Map of the Study Area

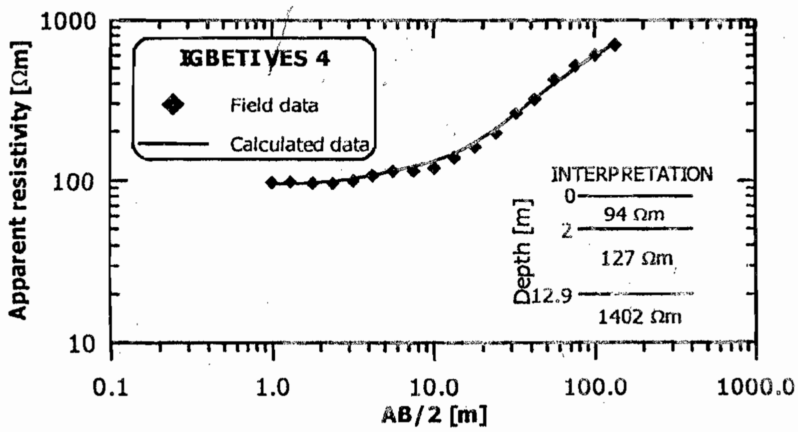

Fig. 4: Computer interpretation of a representative VES curve from Igbeti area

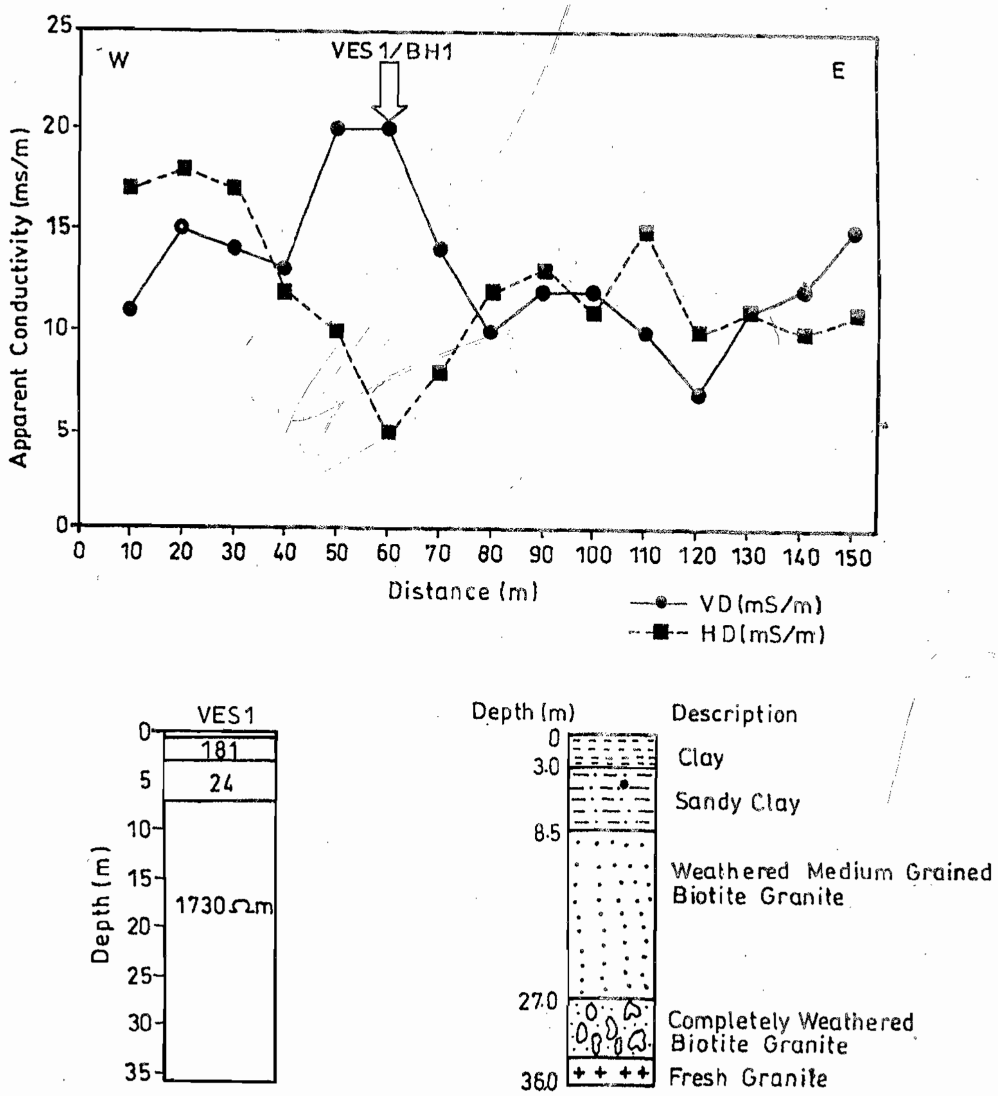

Fig. 5: The EM Profile, Geoelectric section derived from sounding Curve interpretation and the borehole litholog at Oke-General Area

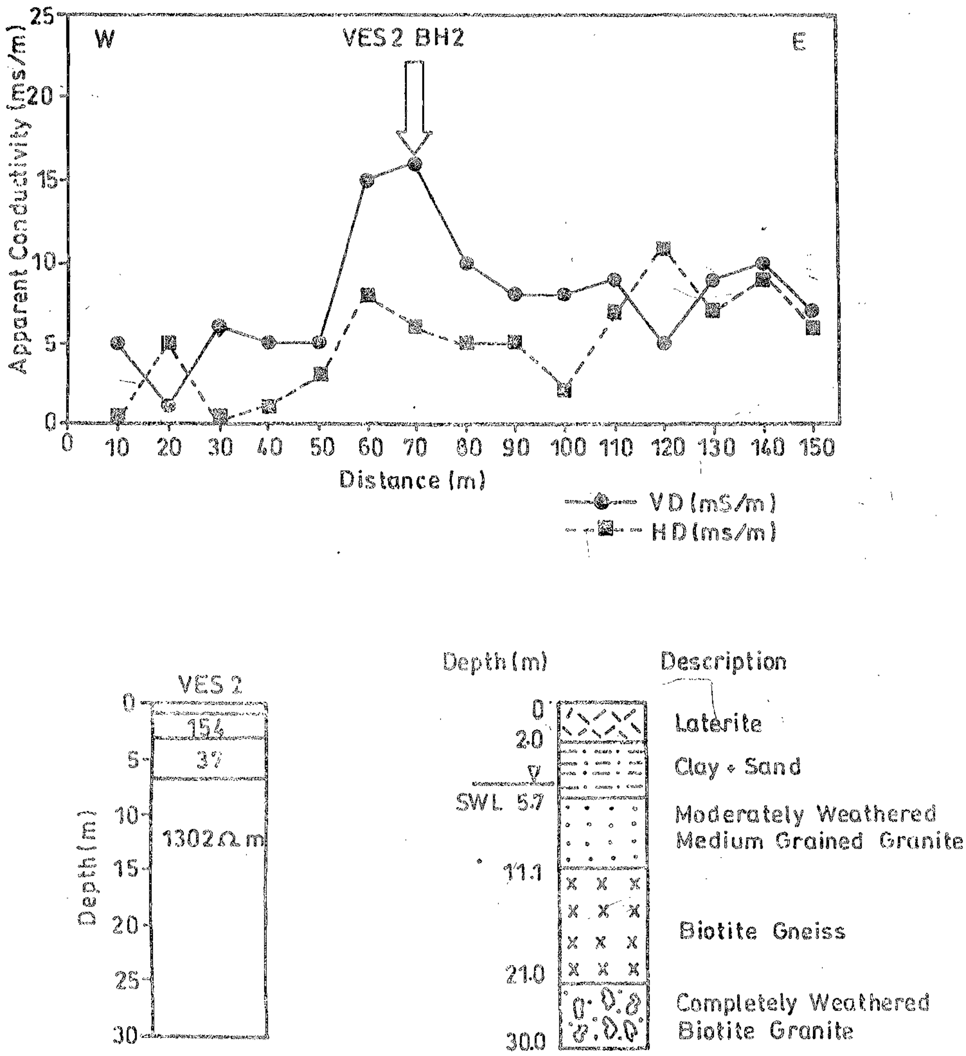

Fig. 6: The EM Profile, Geoelectric section derived from sounding Curve interpretation and the borehole litholog at Igbeti palace

with a maximum half-current electrode separation (AB/2) of 133 m. Analysis of the resulting graph of apparent resistivity versus current AB/2 yields a layered earth model composed of individual layers of specified thickness and resistivity. An infinitely thick bottom layer of high resistivity exceeding about 1500 ohm-m (geo-electrical basement) often indicates fresh rock (Olorunfemi and Fasuyi, 1993; Olayinka, 1996). The quantitative analysis and interpretation of the VES data was carried out by partial curve matching and computer-assisted iteration (Ghosh, 1971; Zohdy et al, 1974).

RESULTS

The EM profilies, the geoelectrical succession as interpreted from the VES data and the lithological logs of the boreholes drilled under the rural water supply scheme are presented in this section. A representative VES curve from the study area and its computer interpretation is presented in Fig. 4. For the sake of brevity, the study area has been grouped into three geophysical targets (Table 1) namely weathered basement, fractured basement and conductive dykes, respectively. The layer-model interpretation of all the VES curves is given in Table 2.

Target 1 – Weathered basement

The results from four locations within the study area have been classified as indicative of a weathered basement aquifer. The EM profiles show similar signatures, with a wide separation between the vertical and horizontal dipoles at points which were subsequently further investigated using VES. Two representative EM profiles from Oke-General area and Igbeti Palace are shown in figures 5 & 6, respectively. Interpretation of VES data indicates a depth to geo-electric basement ranging between about 4 and 7 m while the borehole lithologs indicate a depth to the basement of between about 5 and 11 m.

The boreholes drilled into a weathered basement aquifer target in the study area were terminated in weathered granite, with a maximum total depth of 45 m at Ogundiran village. The wells gave a moderate to high yield and were completed as production wells.

Target 2: Fractured basement

The EM anomalies on the profiles at Aiyetoro, Oke-Ibukun and Asunmode area indicate a probable fractured basement sequence. A representative EM profile at Aiyetoro area is shown in figure 7. The VES carried out at the anomalous points on the EM profiles gave a depth to the basement ranging between about 7 and 18 m while the lithologs show an overburden thickness ranging between about 6 and 18 m. The wells at Oke-Ibukun and Asunmole were terminated in a fractured basement with a total drilling depth of 39 and 30m, respectively. The wells gave a moderate to high yield and was completed as productiion wells.

However, no appreciable quamtity of water was encountered in the well at Aiyetoro area, in spite of drilling to a total depth of 60 m. A depth to the basement of about 18m was indicated with a prebasement model resistivity of 144 Ohm-m which suggests absence or low quantity of water (Olorunfemi et al, 1999). Although the bedrock model resistivity suggested the presence of bedrock fractures, it is probable that the highly resistive weathered zone could not provide significant amount of water (Barker, 2001). The well was abandoned as an unproductive well.

Target 3 – Conductive dyke

The EM signature of profiles at Iyalode area and Olopa village are typical of a highly conductive vertical dyke. The EM profile at Iyalode area shows that vertical dipole values were generally lower than the horizontal dipole values with minimum negative value of –8 mS/m at a distance of 90 m on the profile (Fig. 8). The EM profile measured at Olopa village shows a similar signature. Negative readings are typical of highly conductive dykes and could be accompanied by high borehole yield (Hazel et al, 1988; Payne, 1988).

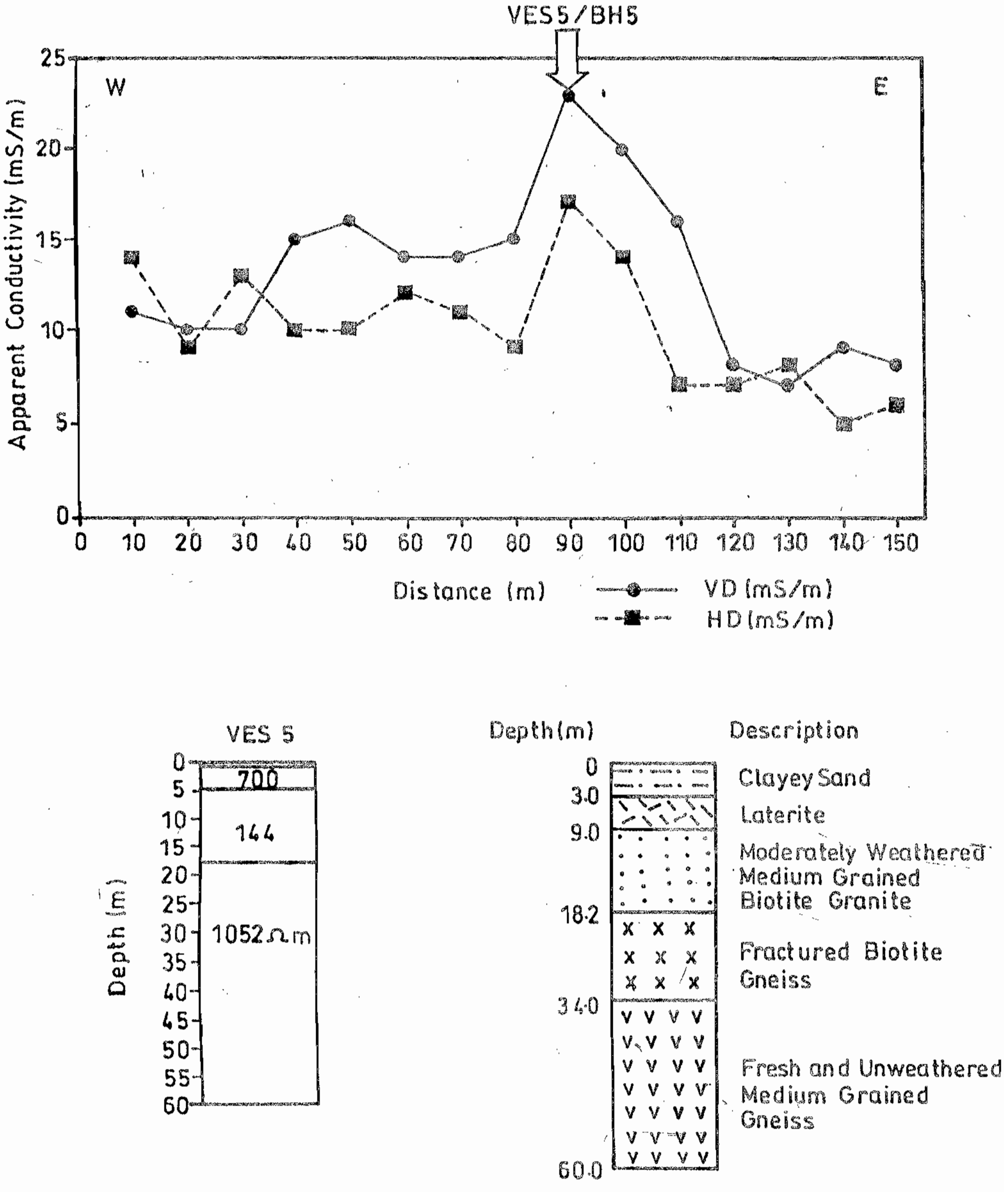

Fig. 7: The EM Profile, Geoelectric section derived from sounding Curve interpretation and the borehole litholog at Aiyetoro Area

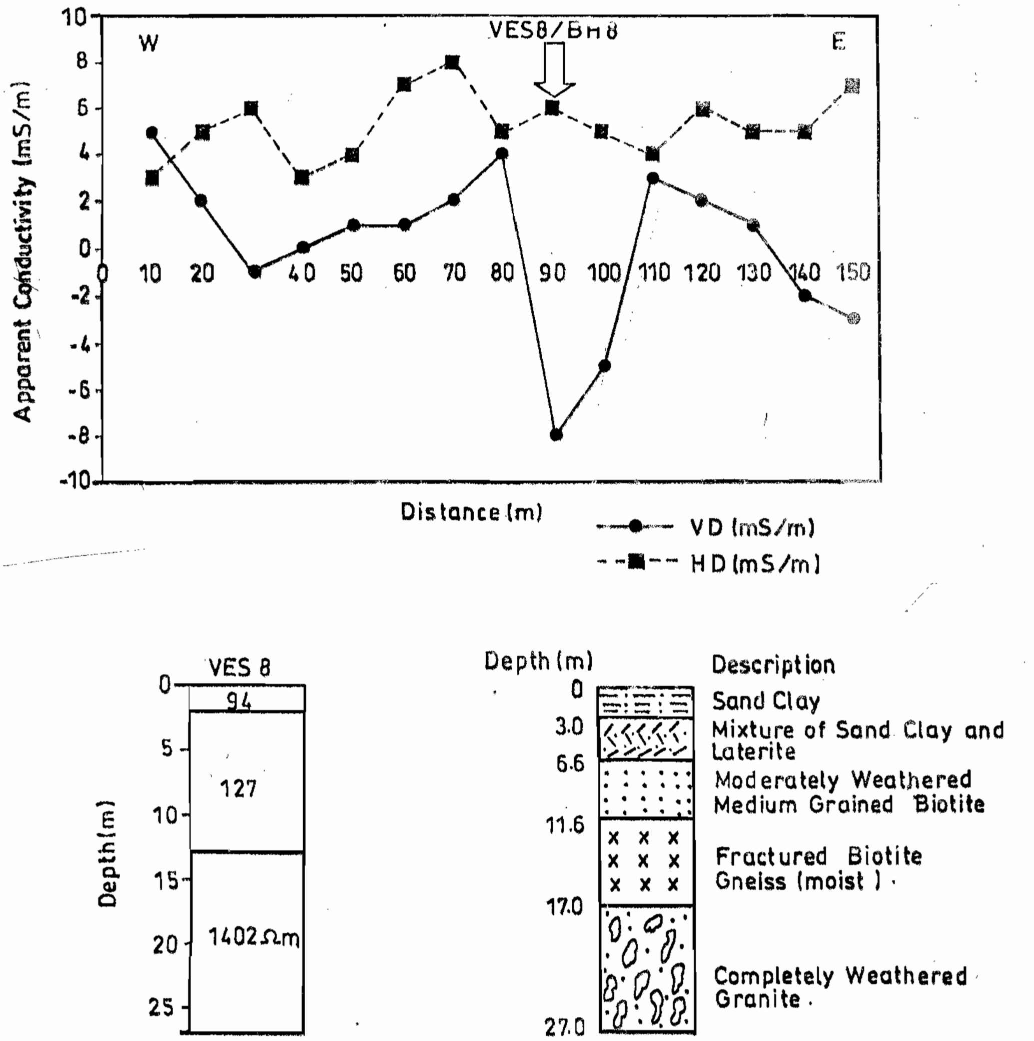

Fig. 8: The EM Profile, Geoelectric section derived from sounding Curve interpretation and the borehole litholog at Iyalode Area

A sounding conducted on the EM anomaly at Iyalode area indicates a depth to the basement of about 13 m while that at Olopa village was about 5 m. Information obtained from drilling report at Iyalode area indicates a depth to the basement of about 12 m and about 5 m at Olopa village. These are in good agreement with the VES interpretation.

Moreover, the litholog at Iyalode area shows that there is a fractured biotite gneiss sequence in the depth interval from 11.6 to 17 m; this is in agreement with the relatively low model resistivity of about 1402 ohm-m for the geo-electrical basement in the VES interpretation. The borehole at both locations gave a high yield and was completed as production wells.

DISCUSSION AND CONCLUSION

The electromagnetic profiling and resistivity sounding surveys in Igbeti area have contributed to a better understanding of resistivity and/or conductivity conditions in this part of the basement complex of Nigeria. A fractured basement sequence zone may not give an appreciable geoelectric signature unless the zone is relatively shallow, significantly thick or severely fractured (Olorunfemi and Fasuyi, 1993; Olayinka, 1997). Sites with high conductivity anomalies can be expected to be economic aquifers. However, high conductivity does not necessarily imply a groundwater resource apart from deep weathering, such high conductivities could result from a predominantly clayey regolith. Conversely, the EM curves over a vertical dyke structure is characterised by very low or negative readings on the vertical dipole mode and a relatively high reading on the horizontal dipole mode. This was observed in the examples in Figs 8 and 13. Vertical electrical sounding should therefore be conducted at locations selected from EM profiling to obtain a depth profile of electrical conductivity and to optimize the conductivity profiling results. Based on the results obtained from this study, it can be concluded that this approach is rapid and accurate in the location of the deeper and narrower zones, which are specially important for abstraction of groundwater in the basement. This was confirmed by a success rate of about 90% in the study area. However, a combination of resistivity sounding (essentially to help calibrate the electrical section) and traversing at carefully selected separations aided by computer modeling gives best promise for groundwater exploration. In this regard, a combined electromagnetic profiling and resistivity sounding should always be adopted for groundwater exploration in the crystalline basement complex. This would reduce the number of abortive boreholes being drilled due to sub-optimal site selection.

ACKNOWLEDGEMENTS

The authors are grateful to the Oyo State Rural Water and Sanitation Agency, Ibadan, for permission to publish the data. An anonymous reviewer of the Global Journal of Geological Sciences provided insightful comments which contributed greatly towards improving the clarity of the paper.

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