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TABLE OF CONTENTS

SECTION A: *Edited by Ebun Oni*

(i) Geodesy Research in Africa
(ii) Geomagnetic and Electromagnetic Induction Research in Africa
(iii) Seismology Research in Africa

SECTION B *edited by J.O. Ayoade and E.U. Utah*

(i) Meteorology Research in Africa
(ii) Atmospheric Physics Research in Africa

APPLICATION OF RESISTIVITY SOUNDINGS FOR BOREHOLE SITING IN CRYSTALLINE BASEMENT AREAS OF SOUTHWESTERN NIGERIA

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ABSTRACT

This paper establishes the reasons why the resistivity sounding technique is the preferred geophysical tool in borehole siting in crystalline basement areas of southwestern Nigeria. It also identifies ways in which its use could be optimized.

Factors for the widespread use of the technique include its relative cheapness, accuracy of depth determination, suitability in differentiating between the overburden and the fresh bedrock, speed of survey, popularity (and acceptability), and availability of equipment.

Due to the superposition of lateral variations in resistivity on sounding data, some 62% of the sounding curves from the study area are characterized by a terminal branch rising at an angle exceeding 45°. In all the sounding data presented the terminal branch of the curve starts rising at Wenner electrode spacing of less than or equal to 32 m. It is recommended that the maximum electrode spacing (AB/2 or a) should not be more than 150 m. Moreover, due to the irregular nature of the bedrock topography the separation between adjacent sounding centres should not exceed 100 m, thus permitting an adequate sampling of the subsurface. This approach might prove helpful in other basement areas.

INTRODUCTION

Several parts of Africa are underlain by Precambrian igneous and metamorphic basement rocks (Figure 1). These rocks have very low porosity and negligible permeability. As a result, the development of aquifers is limited to the overburden resulting from the in situ chemical weathering of the bedrock and the fissure/fracture systems in the bedrock. Geophysical surveying is recognized as an invaluable tool in the selection of sites for the drilling of water supply boreholes in these areas (Ako et al, 1986; Hazell et al,1992; Beeson and Jones,1988; Van Kuijk et al,1987; Barker et al,1992). The objectives of such surveys include :

(i) determination of depth to the hard, competent bedrock. In order to attain an adequate perennial yield, a minimum regolith thickness of 15 m is desirable.
(ii) indications of depth to water, extent of saturation and porosity of the regolith
(iii) location of steeply-dipping structures such as faults and dykes
(iv) mapping variations in overburden composition and bedrock lithology.

The present work seeks to establish to what extent surface geophysical measurements are incorporated into the choice of borehole sites in southwestern Nigeria (Figure 2). The dominant rock types in the study area include granites, gneisses, schist and quartzites. We have addresed the reasons why the drilling practitioners believe that geophysical methods could be of assistance in their operations; the techniques employed in geophysical surveying; and why in some cases geophysics is not employed. Suggestions are also proferred towards an improvement upon the current practises in the use of geophysics.

DATA COLLECTION AND ANALYSIS

An establishment-to-establishment enquiry was carried out among the various water drillers in the study area. The questionnaire draft was composed of series of issues directed to the accomplishment of the objectives of the research. It seeks to collate data on the techniques used in selecting the most favourable sites for borehole drilling. Specific

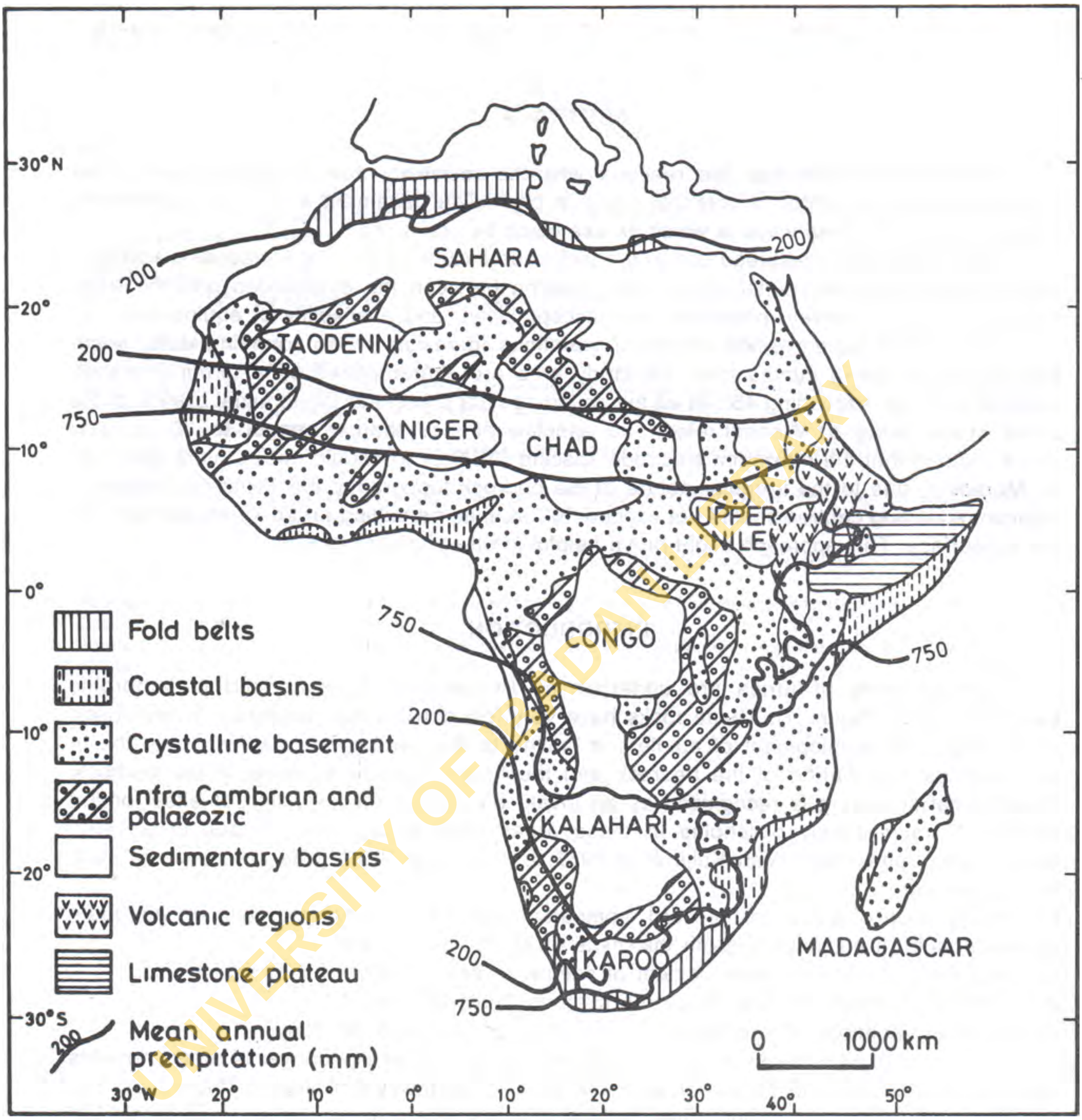

Fig.1: Groundwater regions of Africa
(adapted From Farquharson and Bullock, 1992)

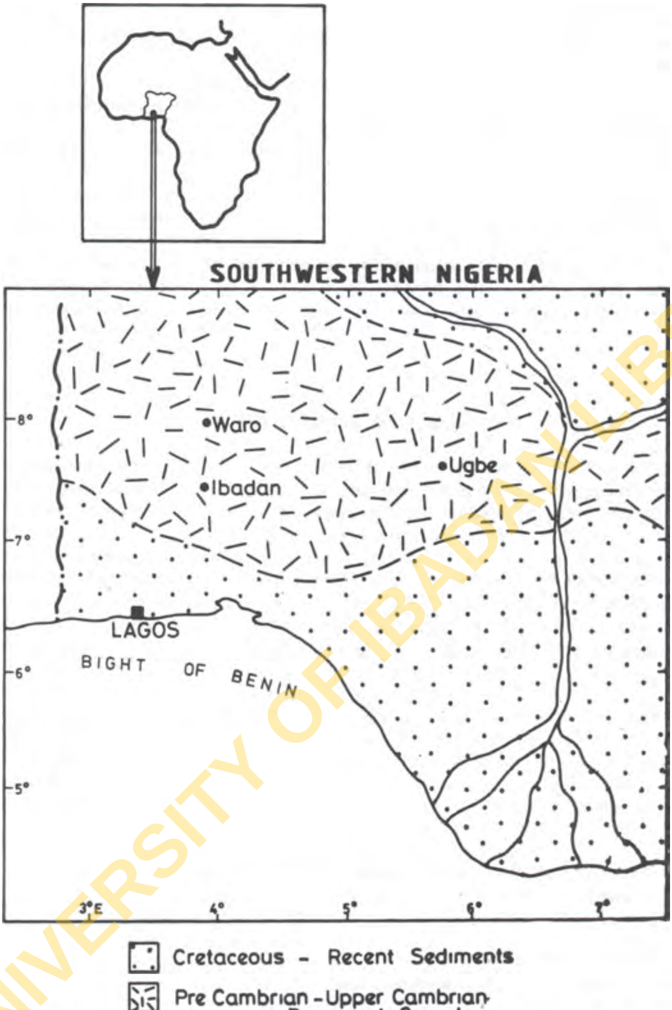

Fig. 2: Generalized geological map of Southwestern Nigeria

questions raised include :

(i) techniques considered in the preliminary assessment of the probable occurrence of groundwater

(ii) whether surface geophysical surveying is routinely employed

(iii) if the answer to (ii) is YES, which specific geophysical methods are preferred and why

(iv) if the answer to (ii) is NO, why

(v) what other factors, if any, apart from the above-mentioned are taken into consideration. Give reasons.

After distributing the questionnaires a follow-up visit was made with oral discussions held with the responding officer, who invariably is either the chief executive, geologist, drilling engineer, or operations manager.

A total of 20 establishments responded to our enquiries, of which 15 are wholly owned by Nigerians, 3 are joint ventures between local and foreign investors, 1 owned by the Federal Government of Nigeria while 1 is a United Nations outfit. Our findings are presented below.

TECHNIQUES OF BOREHOLE SITING

It has been revealed that the methods considered in the preliminary assessment of groundwater occurrence at a site in the study area include surface geological mapping (with a frequency of 70%; study of regional geologic maps (55%) and study of aerial photographs (25%). More than one method may be employed by a particular driller, hence the summation of the frequencies exceeds 100%. Ordinarily, geological mapping of a survey location should always be carried out but quite often there is a regolith covering the bedrock. Regional geologic maps can be a useful guide to ascertaining the rock type and deciphering structural trends. Unfortunately, most parts of Nigeria are yet to be mapped on such a scale as to permit a detailed examination of the local geology. Anomalies identified from aerial photographs should be confirmed by a ground survey.

Seventeen (or 85%) of the respondent establishments routinely use geophysical techniques. The reasons given for the application of geophysics are shown in Table 1. It may be noted that one company gave no reason. The budget for geophysical survey should ideally constitute about 10% of the total cost for the drilling and completion of a borehole penetrating crystalline basement rocks in the study area but most drilling contractors spend far less than this.

Table 1: Reasons for the use of geophysics for borehole siting (sample size, n=20)

Reason	Frequency (%)
Provides information on aquifer (depth;thickness)	50
Cost effectiveness	15
Availability of space (access)	10
Reduction in risk of wildcat drilling	5
Popularity	5
Increased success rate	5
Absence of cultural noise	5

Availability of space for geophysical traverses may be a critical factor in built-up or thickly vegetated areas; this is often responsible for incompleteness of field data. It is also essential to avoid a situation where boreholes will co-exist with potential sources of pollution such as septic tank, buried dump and underground reservoirs of petroleum products.

Among the geophysical techniques, it has been found that the electrical resistivity method (mainly vertical electrical sounding) is the most widely used (Table 2). It is followed by electromagnetic (Slingram, VLF), seismic refraction and ground magnetometer surveys. In some instances, more than one method is used (often VES +EM).

Table 2: Techniques involved in geophysical surveying (n=20)

Technique	Frequency (%)
Electrical resistivity (mainly VES)	75
Electromagnetic	25
Seismic refraction	15
Magnetic	15

Reasons given for the preference given to VES (Table 3) are technically sound and are in good agreement with experiences from other basement areas. White et al (1988) reported that depth to bedrock interpreted from sounding results in Victoria Province, Zimbabwe, was to within

Table 3 : Reasons for the preference for resistivity soundings (n= 20)

Reasons	Frequency (%)
Accuracy of depth determination	40
Cost effectiveness	25
Sensitivity to aquifer delineation	20
Speed of survey	15
Popularity	15
Availability of equipment	15

+25% of that indicated by subsequent drilling. The accuracy of depth determination is affected by equivalence and suppression (Barker et al, 1992; Olayinka and Oladipo, 1994).

The cost of conducting a resistivity sounding survey for borehole siting in the Ibadan area of southwestern Nigeria is about 20 000 Naira (as at December 1994, Nigerian Naira N22=US$1.00; although subject to exchange rate fluctuations). Quite commonly, only between 3 and 4 hours are devoted to the geophysical surveying of a site and during this period enough Wenner or Schlumberger soundings (typically between 3 and 5) can often be carried out, especially if there are no access problems.

There are cases when no pre-drilling geophysical survey is carried out (Table 4). Even if the consultant/contractor recommends the use of geophysics the client may be reluctant to accept this proposal on account of its cost implications. The driller is consequently prevailed upon to commence drilling without much scientific rationale for the choice of the location.

Table 4: Reasons why geophysical methods might not be used (n=5)

Reason	Frequency (%)
Availability of enough data from existing wells	100
Economic considerations	40
Lack of space	25
Presence of cultural noise	25
Too technical and time consuming	20
Presence of phreatophytes	20

Moreover, the client may not be easily convinced as to the need for geophysics, especially if there are existing productive wells nearby. Experience has shown, however, that there is a great danger in interpolating or extrapolating subsurface hydrogeological conditions in basement terrains due to the unpredictable behaviour of basement aquifers (Adegoke -Anthony and Ajayi, 1989). Boreholes that are spaced only 5 m apart may differ greatly in yield(Beeson and Jones, 1988).

A related problem is that drilling of water boreholes is often carried out by non-professionals (or differently put, quacks) who are invariably only interested in monetary gains. This practise thrives as there is no enabling legislation as yet forbidding it.

Due to poor planning, most urban centres in southwestern Nigeria do not have adequate water supply from public sources. In an attempt to ameliorate this, it may be decided to drill a borehole. However, this scenario arises after the building construction might have been completed with all the infrastructures (e.g; underground cables, pipes, septic tanks, concrete surfaces) already in place. It then becomes very difficult to be able to conduct geophysical survey without extensive noise interference.

There have been attempts to correlate the presence of phreatophytes (e.g mango trees) with a probable occurrence of groundwater (Acworth, 1981). Such plants, with deeply penetrating roots that habitually reach the water table, are localized along streams and areas with relatively shallow water tables. They may also indicate the presence of buried stream channels. The efficacy of this is yet to be documented, moreso when the problem often encountered is not neccesarily the mere occurrence of groundwater; rather it consists of locating an aquifer which would give adequate and perennial yield.

It is generally assumed that well yields will increase from the crests of hills, to slopes, to flat upland areas, to valleys and broad ravines (Le Grand, 1952). However, recent studies in Nigeria (Olorunfemi, 1990) and Zimbabwe (Barker et al, 1992) suggest that this trend is not always observed; rather, the thickest development of weathering may be displaced towards the slopes. The lithology of the weathered profile in valleys may at the same time be clay-rich thus lowering well yield while the valley sides may be sandier and hence of higher permeability and greater well yield. It may be seen, therefore, that a great reliance on topographic variations as a guide to the selection of borehole sites may not always be very successful.

OPTIMUM USE OF RESISTIVITY SOUNDINGS

Typical resistivity sounding curves from the study area are shown in Figure 3. The curves display a minimum, as the relatively low resistivity regolith is bounded by highly resistive materials (soil on top and the bedrock below). The Waro sounding was conducted adjacent to a large-diameter well where the static water level is at 7.75 m below the ground surface. Computer interpretation of the sounding data indicated a depth to bedrock of 12 m. At the Ugbe site, there are two existing shallow wells with a static water level of 1.06 m below the ground surface. Computer modelling of Ugbe VES 3 gave a depth to bedrock of 14.6 m. A borehole that was subsequently drilled at the sounding location penetrated weathered materials down to a depth of 15 m, which is in very good agrement with the sounding results. Fractures were intersected within the migmatite gneiss bedrock and the borehole was productive, with an airlift yield of 5000 gallons/hr.

It should be emphasized out that apart from these simple H-type curves, other resisitivity combinations that are frequently encountered in this area include K-, A-, HA-, and QH-types (Olorunfemi and Olorunniwo, 1985; Olayinka and Olorunfemi, 1992).

It has been observed from the soundings analyzed that the Wenner electrode spacing at which the minimum apparent resistivity is measured does not exceed 32 m (Table 5). This is consistent with the findings by David (1988). Trial runs with several H-type models have shown that this electrode spacing is always less than the depth to bedrock (see also Zohdy, 1989). This can subsequently be used as a rule of thumb in establishing the minimum depth to bedrock. It can also guide in reducing the range of equivalent models in the computer interpretation of resistivity sounding data. However, there may be complications in the presence of thin layers whose effects may be suppressed on the sounding curve.

Table 5 : Wenner spacings at which minimum apparent resistivity was recorded and those at which slope of terminal branch exceeds +1

Spacing (m)	Number of sounding (Minimum apparent resistivity)	(Terminal branch with slope >+1)
2	19	0
4	66	1
8	92	9
16	70	14
32	19	66
64	0	48
Total	266	138

The maximum depth of borehole drilling in the study area is often less than 100 m (Adegoke-Anthony and Ajayi, 1989). It has been shown that the most productive bedrock fissures are intersected within 20 m of the regolith-bedrock interface. This has far reaching implications on the maximum electrode spacings in resistivity surveys. It would appear that this spacing for either the Wenner or Schlumberger (a or AB/2) should be of the order of 150 m. At very large spacings there is a greater likelihood of lateral effects being superposed on the sounding data.

The attendant saving in time compared to if larger maximum electrode separations had been used can be utilised in acquiring additional soundings, in which the distance between sounding centres is relatively small. This would permit a very dense sampling of the subsurface to give a more geologically realistic two-dimensional imaging of the subsurface. In this regard, it is recommended that the separation between soundings should not exceed 100 m.

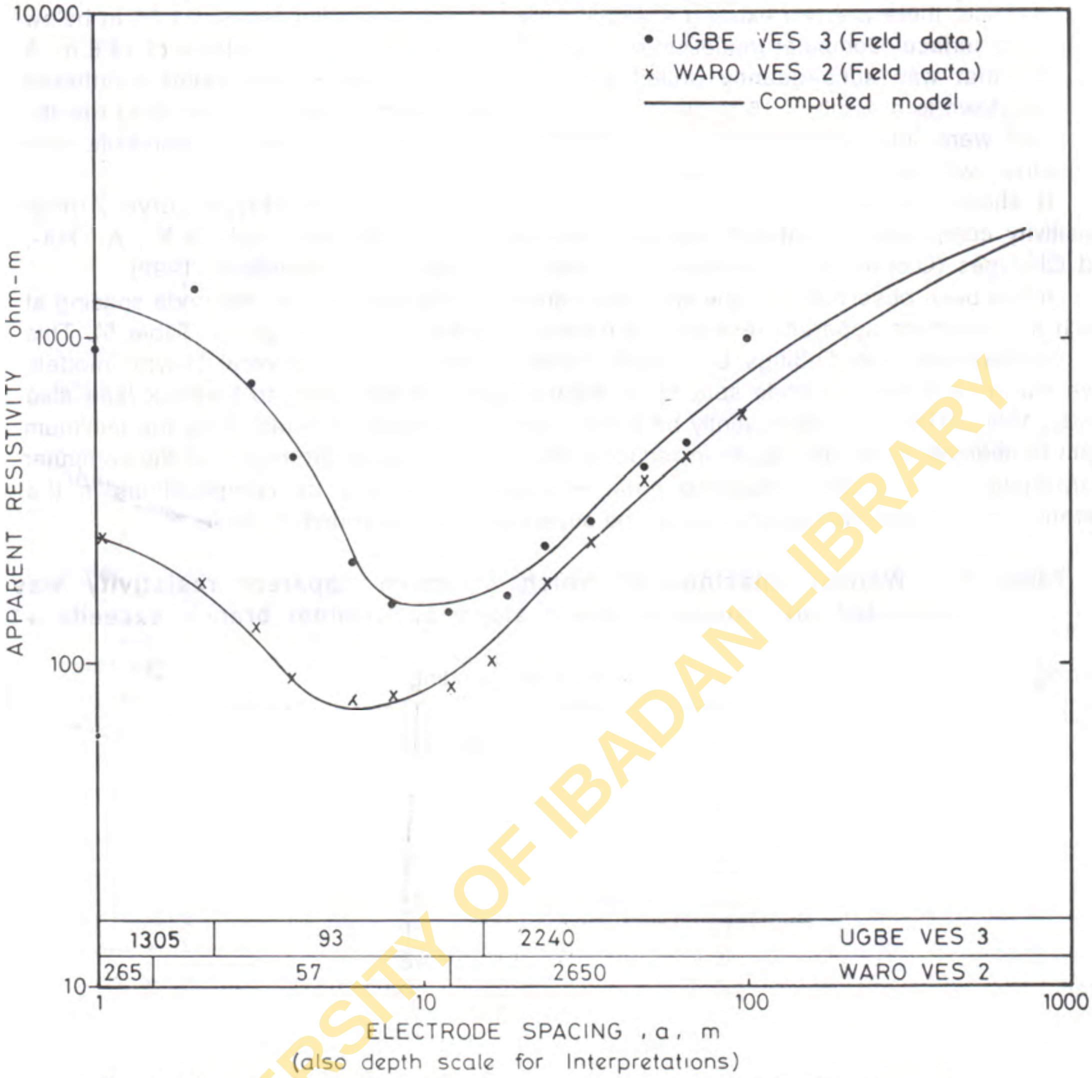

Fig. 3: Typical sounding curves from the study area and their computer Interpretation

CONCLUSION

The extent to which geophysical methods are used in selecting sites for the drilling of boreholes in southwestern Nigeria has been highlighted in this paper. The resistivity sounding method is preferred by the practitioners, with the belief that it would lead to increase in the success rate. It has been suggested that the maximum electrode spacing need not be more than 150 m and that the separation between sounding centres be as short as possible, preferrably not more than 100 m.

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REFERENCES

ACWORTH,R.I., 1981. The evaluation of groundwater resources in the crystalline basement of northern Nigeria. *PhD thesis*, University of Birmingham.

ADEGOKE-ANTHONY,C.W. & AJAYI,O.,1989. Drilling techniques for groundwater in the basement complex rocks of southwestern Nigeria. *Journal of Mining and Geology*, 25, 171 -181.

AKO,B.D., ADEGOKE,O.S., AJAYI,T.R., AJAYI,J.O. & RAHAMAN,M.A.,1986. Groundwater prospecting and exploitation in Nigeria. *In: Proceedings of the First Annual Symposium and Exhibition on Groundwater Resources in Nigeria*, Lagos, Nigeria, pp 3-44.

BARKER,R.D., WHITE,C.C. & HOUSTON,J.F.T.,1992. Borehole siting in an African accelerated drought relief project. *In: WRIGHT,E.P. & BURGESS,W.G. (eds). Hydrogeology of crystalline basement aquifers in Africa. Geological Society Special Publication* No 66, pp 183-201.

BEESON,S. & JONES,C.R.C., 1988. The combined EMT/VES geophysical method for siting boreholes. *Ground Water*, 26, 1, 54-63.

DAVID,L.M., 1988. Geoelectric study of shallow hydro-geological parameters in the area around Idere, southwestern Nigeria. *PhD thesis*, University of Ibadan.

FARQUHARSON,F.A.K. & BULLOCK,A., 1992. The hydrology of basement complex regions of Africa with particular reference to southern Africa. *In: WRIGHT,E.P. & BURGESS,W.G. (eds). Hydrogeology of crystalline basement aquifers in Africa. Geological Society Special Publication* No 66, pp 59-76.

HAZELL,J.R.T., CRATCHLEY,C.R. & JONES,C.R.C., 1992. The hydrogeology of crystalline aquifers in northern Nigeria and geophysical techniques used in their exploration. *In: WRIGHT,E.P. & BURGESS,W.G. (eds). Hydrogeology of crystalline basement aquifers in Africa. Geological Society Special Publication* No 66, pp 155-182.

Le GRAND,H.E., 1952. Solution depressions in diorite in North Carolina. *American Journal of Science*, 250, 566-585.

OLAYINKA,A.I. & OLADIPO,O.A., 1994. A quantitative assessment of geoelectrical suppression in four-layer HA-type earth model. *Journal of Mining and Geology,* 30, No 2

OLAYINKA,A.I. & OLORUNFEMI,M.O., 1992. Determination of geoelectrical characteristics in Okene area and implications for borehole siting. *Journal of Mining and Geology*, 28, 403 -412.

OLORUNFEMI,M.O., 1990. The hydrogeological implication of topographic variation with overburden thickness in basement complex area of southwestern Nigeria. *Journal of Mining and Geology,* 26, No 1, 145-152.

OLORUNFEMI,M.O. & OLORUNNIWO,M.A., 1985. Geoelectric parameters and aquifer characteristics of some parts of southwestern Nigeria. *Geologia Applicata E Idrogeologia*, 20, 99-109.

VAN KUIJK,J.M.J., HAAK,M.J. & RITSEMA,I.L., 1987. Reduction of equivalence in layer -model interpretation by combination of electrical resistivity soundings and electromagnetic conductivity measurements; some case histories in groundwater survey. *Journal of African Earth Sciences,* 6, No 3, 379-384.

WHITE,C.C., HOUSTON,J.F.T. & BARKER,R.D., 1988. The Victoria Province Drought Relief Project, 1, Geophysical siting of boreholes. *Ground Water,* 26, 309-316.

ZOHDY,A.A.R.,1989. A new method for the automatic interpretation of Schlumberger and Wenner sounding curves. *Geophysics*, 54, 245-253.