The Evaluation of Anisotropic Properties of Parts of Ijebu-Igbo, Southwestern, Nigeria, Using Azimuthal Resistivity Survey (ARS) Method.

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Abstract

This research was carried out to determine the anisotropic properties of parts of Ijebu Igbo, southwestern Nigeria which falls within the southwestern Basement Complex of Nigeria and it is underlain by migmatite gneiss and older granites.

Physical parameters (water temperature, pH, salinity and total dissolved solid (TDS)) of 107 hand dug wells were measured. Thirty Azimuthal Resistivity Survey (ARS) were investigated along four azimuths; 0^0, 45^0, 90^0, and 135^0. An Ohmega terrameter was used for resistivity measurement in which the Schlumberger configuration was employed with a maximum electrode spacing (AB/2) of 100m.

The results showed that the physical parameters fall within the WHO standard. The iterated curves revealed 4 (KH and QH) to 5 (QQH and AKH) geoelectric layer curve types. The bedrock resistivity values range from 1467.3Ωm to 27,457Ωm with overburden thickness range of 0.6m to 61.5m. The anisotropic polygons showed N-S, E-W and NW-SE, and NE-SW directions. The co-efficient of anisotropy for all the stations varies from 1.09 to 1.61 with a mean of 1.2.

Areas with low bedrock resistivity, thick overburden, presence of two interconnected anisotropy polygon directions and high co-efficient of anisotropy indicate intense fracturing, thus, a potential sites for the drilling of water borehole.

Introduction

Electrical resistivity anisotropy for geological prospecting has not been extensively used in surface geophysics despite the usefulness of electrical methods for detecting fluid - filled fractures (Mamah and Ekine, 1989). Surface geological mapping and remote sensing methods including aerial photographs, side looking airborne radar (SLAR) and Landsat sensors are commonly employed in the identification of structural elements (Okurumeh and Olayinka, 1998). However, the usefulness of geological mapping is limited only to areas where the rocks outcrop. In Southern Nigeria, remotely sensed data is of poor quality due to the masking effect of dense clouds, thick vegetation and short SLAR wavelength with limited look direction of SLAR (Gelnelt, 1978; Koopman's 1982; Ezenabor, 1985b). There is also the problem of accurate correlation of identified structural features on the basis of air photos and actual position on the ground due to the position fixing error (Ezenabor; 1985a). Conversely, surface geophysical techniques can be an invaluable tool in mapping the structural features of the concealed crystalline basement rocks (Olorunfemi and Opadokun, 1987) and in the detection of microfabrics resulting from basement tectonic in sedimentary terrain (Mamah and Ekine, 1989). Electrical anisotropy of crystalline basement rocks is often attributed to structural elements like foliations, joints and fractures (Billings 1972; Malik, et al., 1983). It has been shown by Odeyemi, et al., 1985; Beeson and Jones, 1988; Esu, 1993 and Edet et al., 1994 that the well yield and its direction flow in fractured rocks is directly related to the density, frequency, orientation and inter-connection of structural features at depth.

Azimuthal resistivity surveys (ARS) are often conducted to determine the principal direction of electrical anisotropy. The identification and characterization of fractures is important in rocks with low primary (or matrix) porosity because the bulk porosity and permeability are determined mainly by the intensity, orientation, connectivity, aperture, and infill of fracture systems (Skyernaa and Jorgensen, 1993). Azimuthal resistivity surveying has been adopted by Slater et al, 2006, Skyernaa and Jorgenson, 1993, Taylor and Fleming, 1988 as a technique for determining the principal directions of electrical anisotropy. Typically, any observed change in apparent resistivity with azimuth is interpreted as invocative of anisotropy (generally fracture anisotropy). It is often assumed that the principal directions of hydraulically conductive fracture measured from electrical anisotropy may be inferred from the measured electrical anisotropy (apparent resistivity (ρa) as a function of azimuth and the strike of the fracture), since both current flow and groundwater are channeled through fractures in the rock.

Therefore, the aim of this work is to measure the physical parameters of groundwater from the hand dug wells in Ijebu Igbo, southwestern Nigeria, so as to determine its suitability for drinking and domestic use and also to carry out geophysical investigation of the area so as to study the resistivity anisotropy characteristics of the subsurface rocks in the area in order to delineate the fracture directions, this will help in studying its influence on the direction of ground water flow and also to study the behaviour of the fracture with depth.

Geologically, Ijebu Igbo is part of the southwestern Nigeria basement complex. The area studied is representative of both the migmatite gneiss complex and the older granite, which shows structural disposition (Rahaman, 1976). (Figure 1)

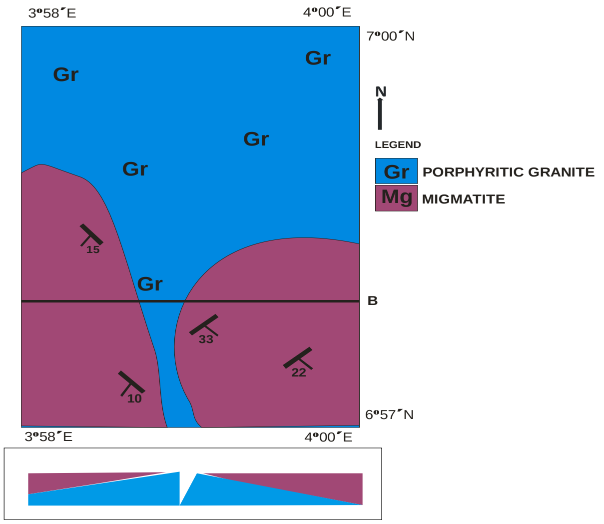


Figure1: Geologic Map of the study area.

Method

Water samples were collected from one hundred and seven (107) hand dug wells at different locations within the Ijebu Igbo metropolis and their physical parameters were measured at the well site. These physical parameters include; depth to water table, temperature of water, pH, TDS (total dissolved solid) and salinity.

Thirty (30) Azimuthal Resistivity Survey (ARS) which involved the measurements of electrical resistivity along four azimuths, namely; 0°, 45 °, 90 ° and 135° were carried out in the area. An Ohmega Terrameter was used for resistivity measurements and readings were taken automatically and the results are averaged continuously thus increasing signal to noise ratio. The Schlumberger configuration was employed, with a maximum current electrode spacing AB/2 of 100m. The apparent resistivity (ρa) values were derived as the product of the resistance read from the resistivity meter and its corresponding geometric factor (Zohdy, 1974). These were then plotted against their corresponding half electrode spacing (AB/2) on a bi-logarithmic paper. These field curves were manually interpreted initially by partial curve matching using master curves (Zohdy, 1974). Geoelectric parameters obtained from the partial curve matching interpretation were later used as an input model for computer-assisted iteration of WINRESIST program.

The reflection coefficients (r) of the study area were calculated using the method of Olayinka (1996); Bhattacharya and Patra (1968) and Loke (1999):

$$r = (\rho n - \rho(n - 1)) / (\rho n + \rho(n - 1))$$

Where ρn is the layer resistivity of the nth layer (i.e the last layer) and ρ(n-1) is the layer resistivity overlying the nth layer.

The result of the maximum current electrode spacing was used to produce the iso-resistivity map. The azimuthal apparent resistivity was measured for a given AB/2 separations and was plotted along their corresponding azimuths to generate anisotropy polygons for the area. The major or longest axis of the ellipse, observed in such anisotropy polygons, gives the direction of the fracture. The co-efficient of anisotropy (λ) (designated here as the degree of fracturing) is calculated from each anisotropy ellipse (fitted through each polygon) using the relationship

$$\lambda = a / b$$

where α and b are the major (longest) and minor (shortest) axes of the element. A useful parameter of anisotropic medium is the co-efficient of apparent anisotropy (λa) and is calculated by:

$$\lambda a = (\rho t / \rho s)$$

All the calculated λa values are then plotted against their corresponding AB/2 separations. The behavior of rock fracturing at various depths can thus be understood qualitatively from the variation of λa with depth (Habberjam, 1975).

Results

The results of the physical parameters showed that the salinity of the wells in the study area ranges between 20mg/L-520mg/L, the pH value ranges between 5.58 – 8.06 with a mean of 7.2 and the TDS range between 120mg/litre - 360mg/litre which make the area good for domestic use as they fall within the WHO standard. The groundwater flow map showed that the groundwater flow directions are easterly while the groundwater gathers centrally in the area (figure 2).

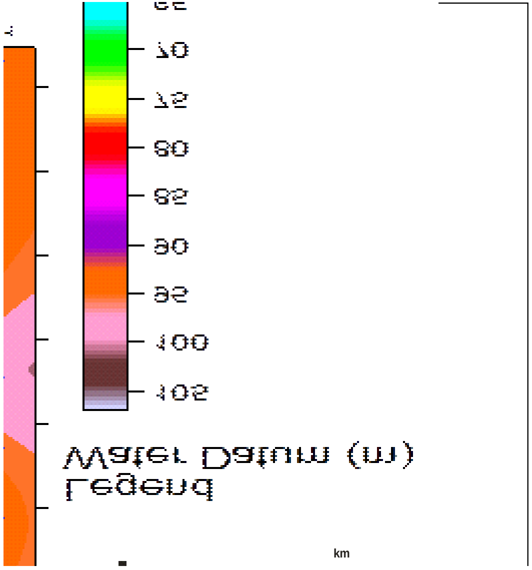


Figure 2: Groundwater flow map of the study area

The plots of ARS curves along the four azimuths showed that the effect of anisotropy is evident in these results as the four resistivity curves show some variations (figure 3). The iterated curves revealed 4 to 5 layer curve types. The four layer curves include the KH (i.e., $p1<p2>p3<p4$), HA (i.e., $p1>p2<p3<p4$) and QH (i.e., $p1>p2>p3<p4$) while the remaining five layer curves consists of the QQH ($p1>p2>p3>p4<p5$), and AKH ($p1<p2<p3>p4<p5$). The bedrock resistivity values range from 1467.3Ωm to 27,457Ωm (figure 4). The overburden thickness ranges from 0.6m to 61.5m (figure 5) while the reflection coefficient ranges from 0.5 to 0.9 (figure 6).

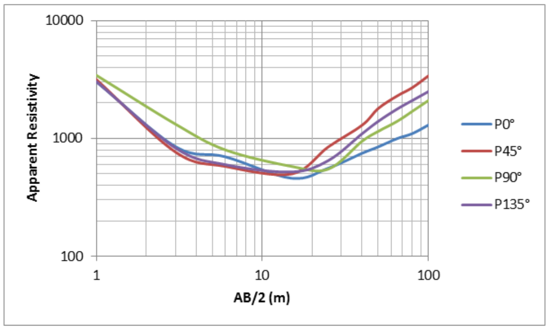


Figure 3:The azimuthal resistivity curve for station 9

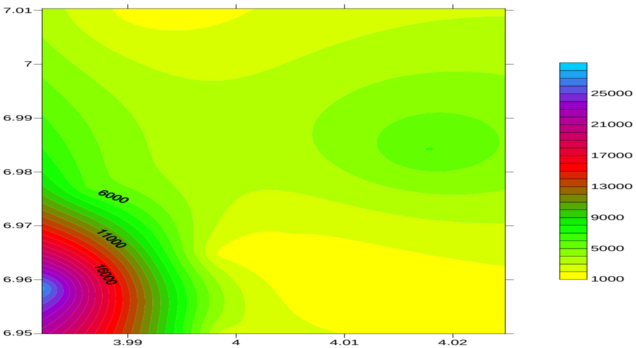


Figure 4: Iso-resistivity map showing the resistivity of different parts of the area.

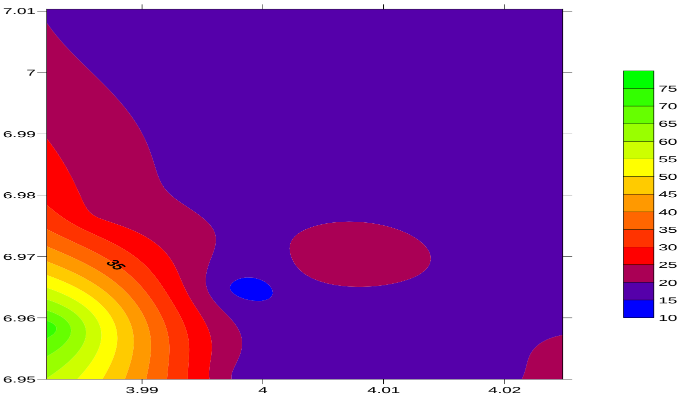


Figure 5: Isopach map showing the thickness of the overburden of the area.

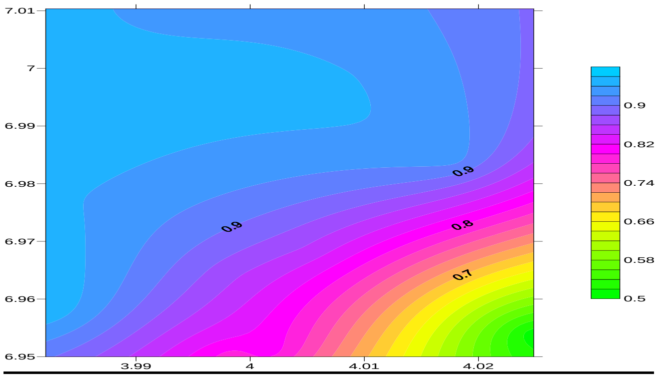


Figure 6: Reflection co-efficient map of the study area.

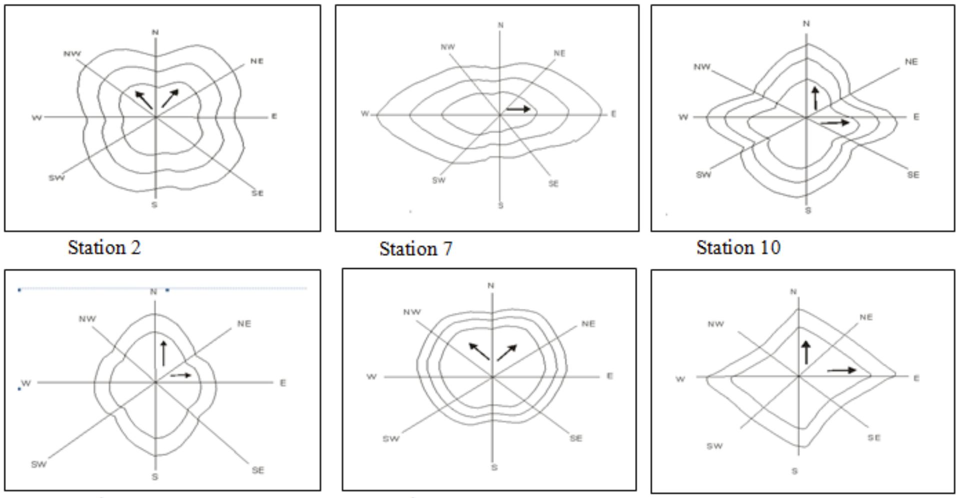
The anisotropic polygons plotted from the ARS data are shown in figure 7. The inferred structural trends in this area are N-S, NE-SW, NW-SE and W-E while some stations also show interconnection of two structure/fracture directions. The results of the directions from the polygons were then used to generate a fracture map which was compared to the measured structural trend of the study area. The co-efficient of anisotropy in this area varies from 1.09 to 1.61 with a mean of 1.2. (figure 8)

The results obtained from the plot of apparent anisotropy with depth revealed two results; some areas showed apparent anisotropy plots closing with depth (figure 9) which consequently outlines its support for engineering activities and unsuitability for hydrogeological activities while some areas showed the plot of apparent anisotropy opening with depth which outlines its support for hydrogeological activities and reveals its unsuitability for engineering activities (figure 10).

The depth to bedrock is not strongly dependent on the co-efficient of anisotropy. However, areas with low bedrock resistivity, low reflection coefficient, thick overburden, presence of two interconnected anisotropy polygon directions and high coefficient of anisotropy may indicate intense fracturing, thus, a potential sites for the drilling of water borehole. Based on this, it can be inferred that the southern and the southern eastern parts of the map exhibit the highest ground water potential while the north and northwestern parts exhibit less ground water potential.

Conclusions

Azimuthal apparent resistivity measurements are potentially a powerful method for characterizing fractured rock since they measure parameters, which cannot be obtained from traditional profile measurements. Localities with low mean bedrock resistivity and a high coefficient of anisotropy may indicate intense fracturing and such localities are potential sites for the drilling of water-supply boreholes. This method seems to provide a useful tool for the identification of fracture systems and related anisotropic conductivity patterns in jointed crystalline rocks. This will help to identify the pathways of contaminant transport and will also be important for groundwater protection and waste disposal.



Station 2 Station 7 Station 10

Station 14 Station 20 Station 25

Figure 7: The plots of some of the Anisotropy Polygons of the study area.

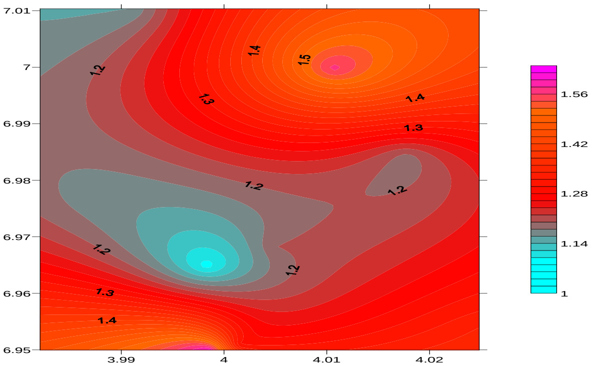


Figure 8: Anisotropic co-efficient map of the area.

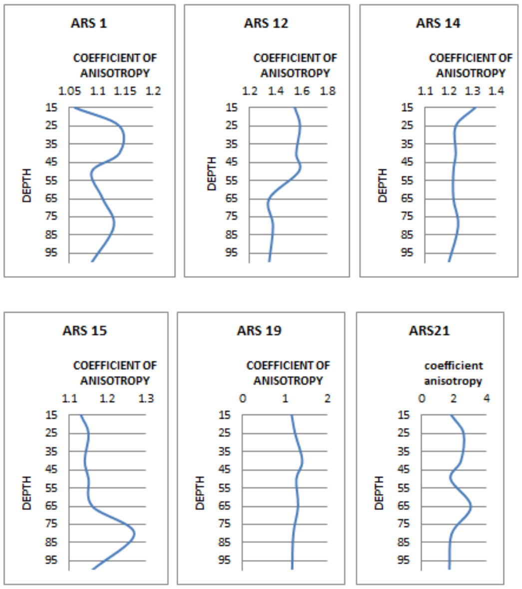


Figure 9: The graph stations of areas showing where the coefficient of anisotropy is closing with depth.

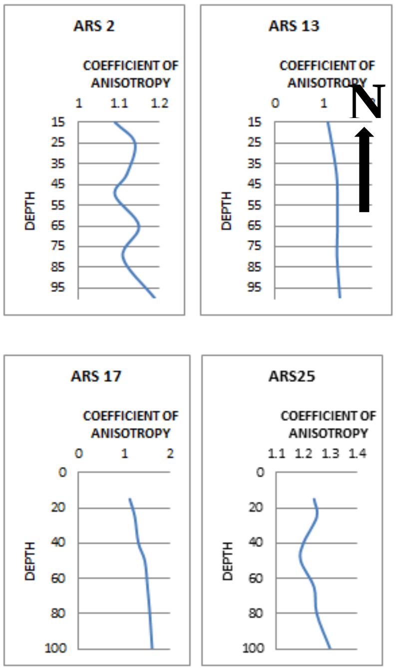


Figure 10: The graph stations of areas showing where the coefficient of anisotropy is opening with depth.

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