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Aquifer depth determination of low permeability layers using geo-resistivity data: A case study of Enyigba mine area and environs, South Eastern Nigeria

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Abstract

Many geophysical methods have been applied to locate groundwater in Nigeria's rural and urban villages. Locating groundwater in low permeability formations like shales and siltstones is even more challenging due to the difficulty of mapping fracture zones within these formations. The fracture zones serve as potential aquifers in low permeability formations and have been the object of groundwater search in shales, siltstones and other low permeability formations. The electrical resistivity method has proven helpful in fracture mapping within low permeability formations due to the existing resistivity contrast usually observed between the fractured and non-fractured sections in the Shales and Siltstones. Three vertical electrical geosounding datasets (VES 1, VES 2 and VES 3) were acquired in the Schlumberger configuration, using a maximum current electrode spacing of 200m to delineate the fracture zones based on their electrical resistivities. The acquired datasets were processed and modelled using IP12 Win software, while the processed datasets were correlated with local geology to estimate the depths of the fractured shales in the area. Results show five modelled geo-electric layers with depths to the fractured shales ranging from 17-25m, while aquifer thicknesses range from 7 to 12m. Aquifer resistivities range from 58 - 115 ohm-m. The curves are primarily of the QH type. One of the Vertical Electrical Sounding Data points (VES 2) encountered an anomalously low resistivity zone at a depth range of 5 to 8m which was interpreted as a galena lode. The low resistivity zone has been confirmed through exploratory drilling to tie with Lead-Zinc lodes at a depth of 8m.

Keywords: *Geo-electric layers, Survey, Permeability, Enyigba, Aquifer*

1. Introduction

Enyigba mineral belt is located within the Lower Benue Trough in Nigeria. The Benue Trough is geographically divided into Lower, Middle and Upper regions and consists of an elongate rift structure with a dominant SW-NE trend and a sedimentary thickness ranging from 2000m to 7000m in the northern and southern fringes, respectively. Several research works have been done on applying the electrical resistivity method for groundwater search in several towns and villages in sub-Saharan Africa **[1],[2],[3],[4]. [5]** applied the electrical resistivity method to assess the groundwater potentials within Ikwo and environs. Their datasets did not cover the Enyigba area, and no definite statements were made concerning the depths of fractured shale aquifers within the Enyigba area. The electrical resistivity method has also proven helpful in estimating aquifer hydraulic parameters from vertical electrical

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sounding (VES) data **[6],[7],[8].[9]** carried out a hydrochemical study to evaluate the threat to water quality due to mining activities within the Enyigba area of South-Eastern Nigeria. Their results did not include suggestions on depths to the fractured Shale aquifers in the area. There is a need to ascertain the depth of fractured shale aquifers within the mining area to advise water prospectors and borehole developers on how to site boreholes in the area. The present study is also critical because of the peculiarity of the study area. Lead poisoning is a significant environmental problem that could occur if adequate safety measures are not put in place and its effects are usually very harmful to health. Previous research works have shown that the Lead-Zinc deposits in the Lower Benue trough are found in four primary lodes located at Ishiagu, Enyigba, Ameri and Ameka, respectively. The deposits originated from hydrothermal sources in the low-temperature regime of about 140°C **[10],[11],[12],[13],[14].** Galena and sphalerite deposits are closely linked with saline groundwater in the study area. The electrical resistivity method is suited for this purpose because water-filled fractures in indurated shales would be distinguished from the background host rocks by their characteristic low resistivity on a geoelectric section. In the present study, we have used the electrical resistivity method to map the depths of fractured Shale aquifers within the Lead-Zinc mining district of Enyigba, south-Eastern Nigeria.

.**1.1 Geology of the Study Area**

The study area is located within the Lower Benue Trough. The width of the entire Trough varies and ranges from 130 - 250 km **[15],[14],[16].** The Trough has generated a lot of research interest. It has been the focal point of several research activities for more than thirty years **[17],[18],[19],[20],[13],[14].**The Benue Trough is an aulacogen formed due to the break-up of Gondwanaland and the opening up of the South Atlantic Ocean in the Early Cretaceous **[21],[22],[23].** Sedimentation in the Lower Benue Trough began with the deposition of the Albian Asu River Group on the Basement complex **[24],[25].** The major lithostratigraphic units of the Asu River Group are shales, siltstones, limestone and sandstone lenses **[15],[26].** Previous research works have shown that Lead-Zinc deposits in South Eastern Nigeria are localized within the Albian sediments **[27]**, and the development of the lodes was initiated at the end of the Santonian. The deformation that affected the Benue Trough in Mid-Santonian displaced the depositional axis to the west leading to the Anambra basin and Afikpo syncline to the east, respectively. The study area (Figure 1) is underlain by the shales of the Asu River Group **[15].** The shales are fissile, thinly laminated, highly fractured and weathered. The shales have been classified based by **[10]** into two units with colours ranging from dark to black to greyish brown, reddish and pinkish. The Shales are heavily faulted and folded with a ferruginized upper surface. Field observations show that the Shales serve as host rocks for the Lead-Zinc mineralization in the area.

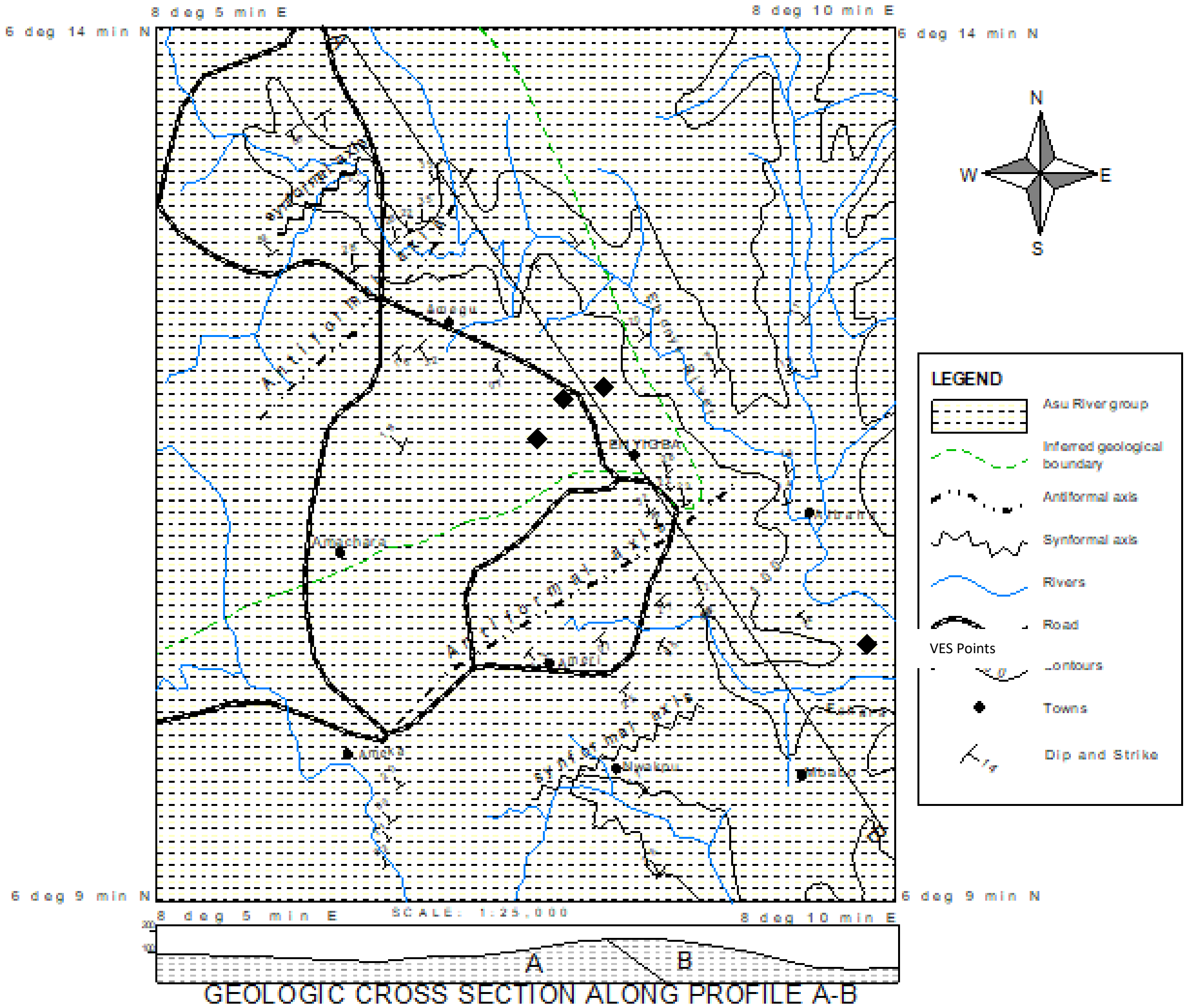

Figure 1-Geology map of the study area (Modified from **[10]**)

2.0 MATERIAL AND METHODS

The study began with a comprehensive literature search of earlier studies in the area and other areas with similar geology. This was followed by detailed geological fieldwork and the acquisition of electrical resistivity data for the study. Vertical Electrical Sounding (VES) datasets at three locations were conducted using the Schlumberger method to obtain resistivity-depth trends. The technique involves the passage of direct current through a pair of current electrodes (AB) and measuring the resultant potential drop using another pair of potential electrodes (MN), Figure 2.

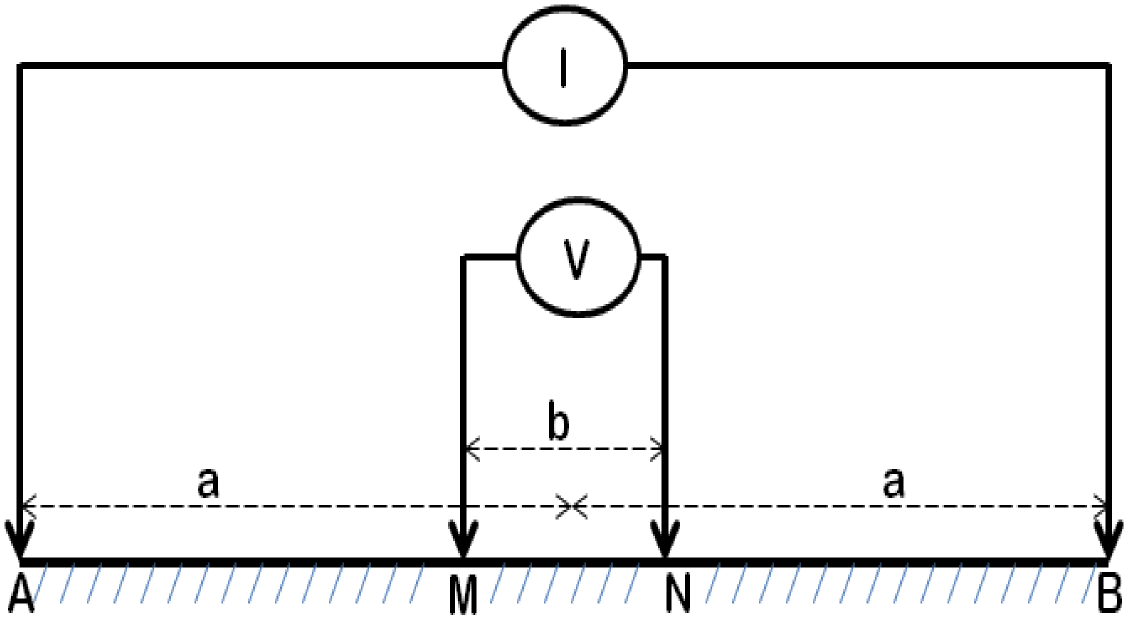

Figure 2-Diagram showing field configuration for the Schlumberger array

The geo-electrical data was acquired using ABEM SAS 1000, with a maximum current electrode spacing (AB) of 200m. The acquired apparent resistivity data (ρ_a) is plotted against half current electrode spacing to obtain the type curve at each sounding location. The apparent resistivity (ρ_a) for the Schlumberger array is given by

$$\rho_a = \pi R\left(\frac{a^2}{b} - \frac{b}{4}\right)$$ **[28],[1],[7]**

where a= AB/2= half current electrode spacing, b = MN = potential electrode spacing, R= resistance while $\pi\left(\frac{a^2}{b} - \frac{b}{4}\right)$ is the geometric factor. The geometric factor depends on the electrode configuration in use. The apparent resistivity (ρ_a) is usually obtained by multiplying the measured resistance with the geometric factor. Detailed quantitative modelling, determination of geoelectrical parameters and interpretation was done with the IX 1D interpex software.

3.1 Data Processing and Interpretation

3.1.1. GEOELECTRIC SECTION AT VES 1

VES 1 (Figure 3) was acquired within the Enyigba mining area. The model revealed five geo-electric layers with the first layer corresponding to a lateritic overburden (top soil) with apparent resistivity of 138Ωm. The second geo-electric layer corresponds to a greyish shale layer with a resistivity value of 91Ωm. A third geoelectric layer with a resistivity of 34Ωm overlies a fractured shale aquifer layer with a resistivity value of 58Ωm at a depth of 25m and a thickness of 7m.

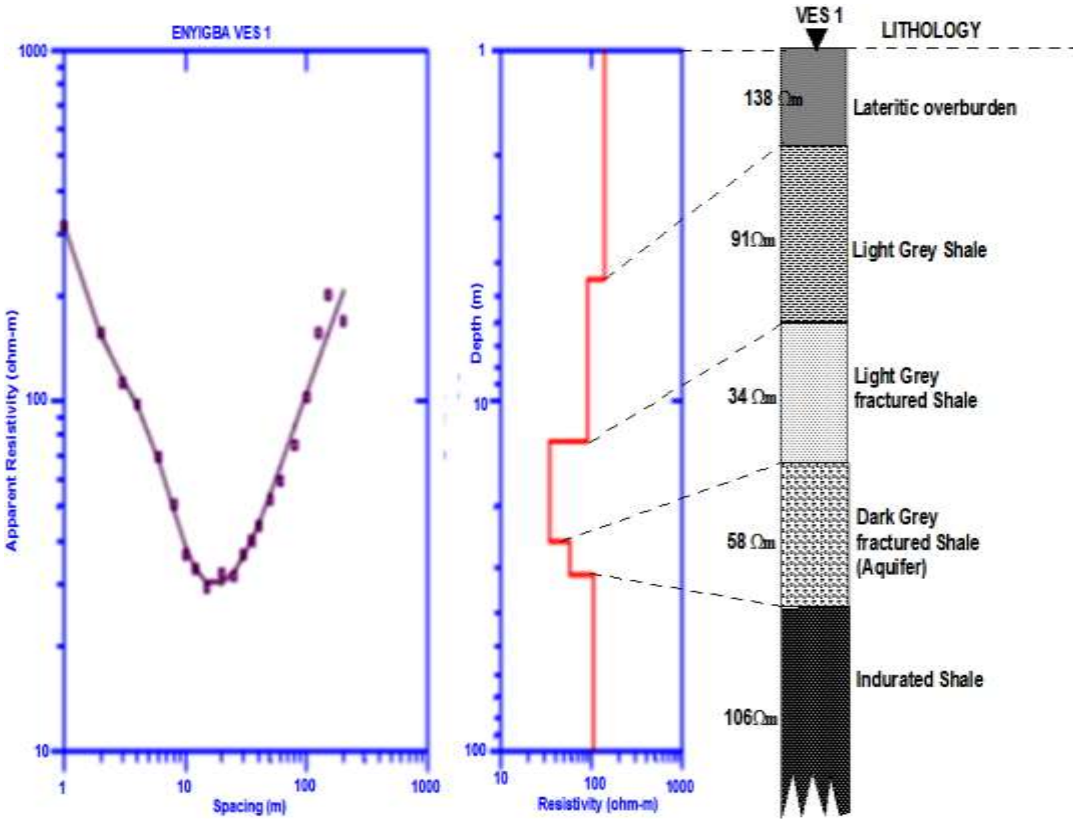

Figure 3- Geoelectric section, type curve and lithology log at VES 1

3.1.2. GEOELECTRIC SECTION AT VES 2

VES 2 (Figure 4) was carried out perpendicular to the trend of the lead-zinc mineralization in the study area, along a major road within the mine area. The computer model for VES 2 reveals five (5) geo-electric layers with the first layer corresponding to a lateritic overburden (top soil) with a resistivity of 721 Ωm. The second geo-electric layer corresponds to a brownish shale layer with a resistivity of 127 Ωm. The third geoelectric layer is a layer that has an unusually low resistivity value (9Ωm) than the ones underlying and overlying it. The low resistivity was attributed to the Lead-Zinc lode which intercepted the sounding curve at that location. This layer is underlain by a dry dark coloured fractured Shale layer with a resistivity of 441 Ωm. The layer is dry and the dark colour is indicative of organic richness. The above two attributes gave the layer its characteristic high resistivity. This high resistivity layer is underlain by a fractured shale layer which serves as the aquifer. The depth to the fractured shale layer is 17m with a thickness of 12m and an apparent resistivity is 115 Ωm.

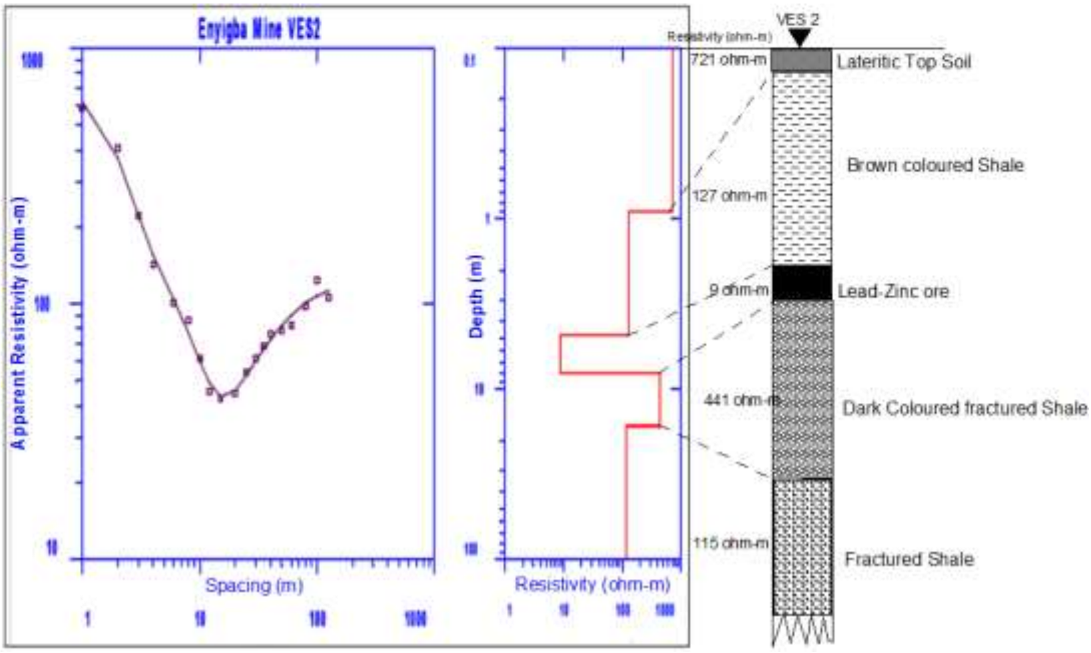

Figure 4-Comparison of Geoelectric section with lithology log at VES 2

3.1.3. GEOELECTRICAL SECTION AT VES 3

VES 3 (Figure 5) sounding was carried out along the Nwakpu-Noyo road in the study area. The computer model for VES 3 reveals five (5) geo-electric layers with a sequence comprising of topsoil with apparent resistivity of 386Ωm, a second geoelectric layer with a resistivity of 105 Ωm and an underlying layer with a resistivity of 86Ωm. The fractured shale layer which acts as the aquifer is the fourth layer with a resistivity of 59Ωm at a depth of 20m and a thickness of 11m.

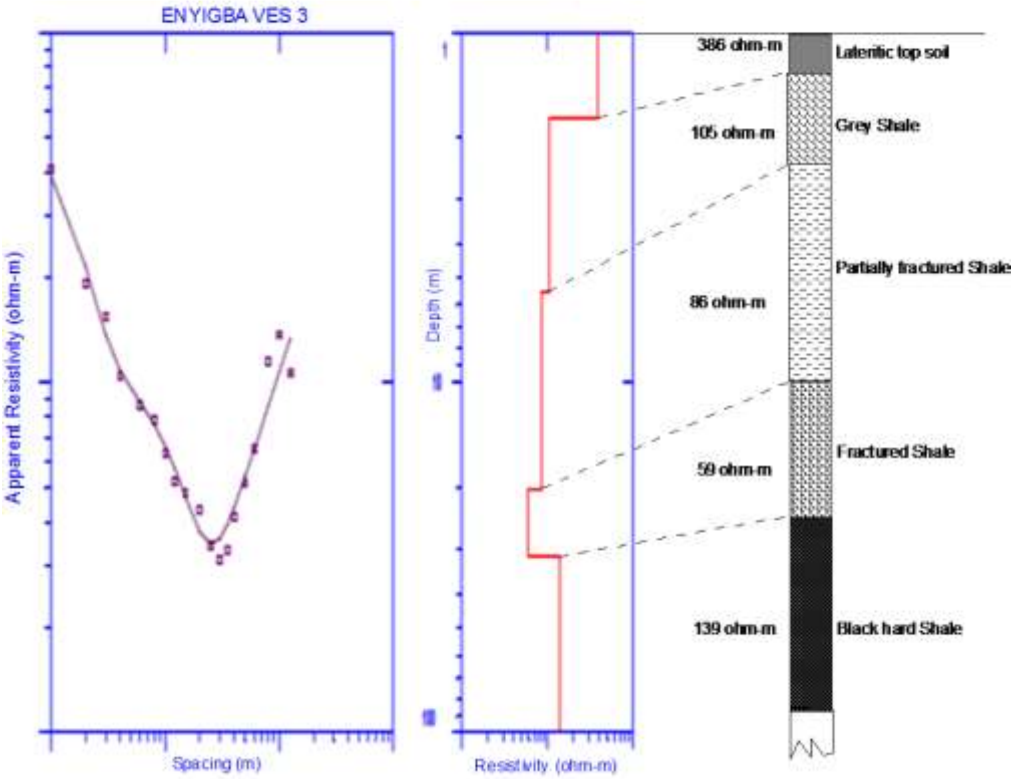

Figure 5-Geoelectric section, type curve and lithology log at VES 3

3.2 Discussion of Results

Table 1-Summary of Apparent Resistivity, Thickness and Depth to the Aquiferous Layers

S/No	Aquiferous/Metallic Ore Layer	Apparent Resistivity (Ωm)	Thickness (m)	Depth to Aquifer (m)
VES 1	4^{th}	58	7	25
VES 2	5^{th} /3^{rd}	115/9	12/3.2	17
VES 3	4^{th}	59	11	20

Aquifer thickness in the study area varies from 7 to 12m (Table 1), while depth to water ranges from 17 - 25m. The aquifer material is fractured Asu River shales of the Albian age. Drilling boreholes close to the Lead-Zinc lodes is not advisable to avoid contamination by the minerals. The variation in resistivities of the top soil layer in the three datasets is controlled by the degrees of laterization at the three locations.

4.1 Conclusions

The use of surface geoelectric measurements provides an inexpensive method to study the groundwater potentials of an area. Computer modelled interpretation of electrical resistivity data revealed the thicknesses and depths of the aquiferous layers. The depth of the potential aquifer zone was found to range between 17m to 25m in the study area, while the thicknesses range between 7m to 12m.

4.2. Recommendation

We advise proper geophysical investigation to delineate the lodes and site boreholes in areas free from Pb-Zn mineralization within the Enyigba area. We also recommend that adequate hydrochemical studies be carried out to determine the potability of the water for human and agricultural purposes.

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