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Assessment of Porous Zones from the Basement Rocks of Biu Plateau Basalts, North-Eastern Nigeria Using Vertical Electrical Sounding Data

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Abstract: Fifteen vertical electrical soundings using the Schlumberger configuration with a current electrode spacing of AB/2 = 100m were conducted in Biu town, northeastern Nigeria. The field data were analyzed with IX1D inversion software to estimate porosity and identify porous zones. Results indicated four distinct layers with different thicknesses, resistivities, and weathering levels. The first layer is identified as alluvial topsoil, the second as weathered basalt, the third as fractured basalt, and the fourth as fresh basement. Resis-tivity values for the layers are: 2.16 to 149.00 Ωm for the topsoil, indicating porosity from secondary porosity or water content; 3.60 to 244.00 Ωm for weathered basalt; 16.50 to 372.20 Ωm for fractured basalt; and 55.04 to 449.75 Ωm for the fresh basement, reflecting high resistivity consistent with unaltered rock.

Key words: Porosity, Weathered Basement, Resistivity, Geo-electric layer, and Sounding

I. Introduction

The geoelectric method is one of the older geophysical techniques used by many researchers worldwide because it is an efficient and versatile way to map the subsurface structure, known as the electrical resistivity method. Electrical resistivity is by far the most variable and reliable property. The electrical properties of rocks can vary by as much as 10 orders of magnitude. Palacky (1987) found that different rock types can have resistivity values that differ by several orders of magnitude, which enhances the effective mapping of rock units. Archie (1942), Geonics (1980), Keller and Frischknecht (1966), and Gylfi and Knutur (2009) have established that porosity and water content (saturation) are key factors influencing the electrical resistivity of geological formations; others include the resistivity of water content, temperature, water-rock interaction and alteration, pressure, steam content in the water, and the presence of metallic minerals like sulfides.

The Biu Plateau belongs to a basement terrain underlain by basement rocks of the Precambrian period in northern Nigeria. The Plateau is mainly basaltic rock situated in the north-eastern part of Nigeria and lies between latitude 10° 30′N to 11° 00′ N and longitude 12° 00′E to 12° 30′ E (Fig. 1). Studies uncovered that basalt rocks in the study area are mostly jointed, fractured and sometimes weathered; these properties make the basalt in the study area to have a secondary form of porosity and permeability thereby making the basalt potential aquifers capable of storing water.

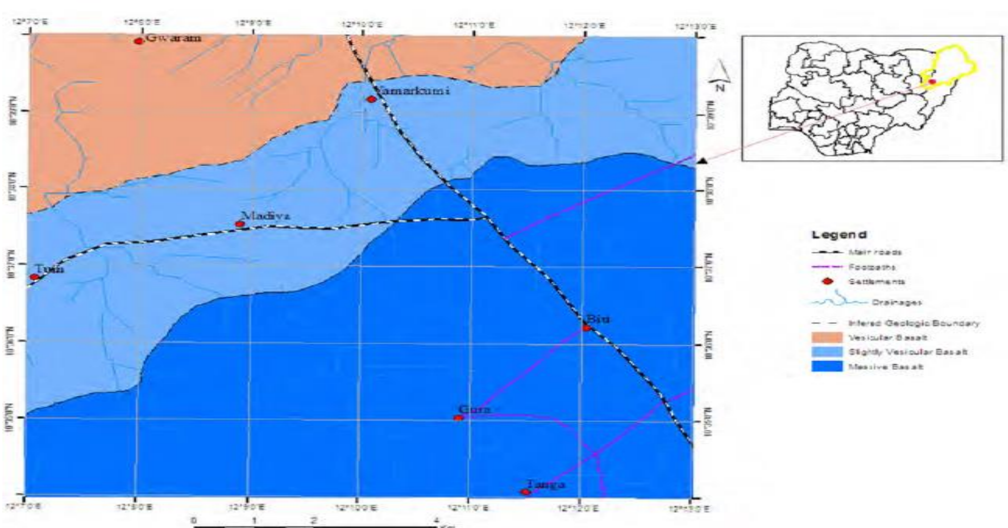

Fig. 1: Location geologic map of the study area

Groundwater confined in weathered basalt in the earth's crust can be tapped by a hand-dug well at shallow depths. The hand-dug wells are commonly located along drainage lines where the weathered zone is often thick in valley areas and can easily recharge the wells. The area is underlain by crystalline basement rocks, where its porosity is secondary in the weathering and fracturing of the parent rocks.

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Groundwater has electrical properties from the various dissolved salts it contains. The dissolved salts allow electric current to flow into the ground and consequently help in predicting the presence of water in the formation. Archie's law helps relate factors to the resistivity, which can be measured in a rock formation. The factors that affect porosity are: the formation factor, which includes the porosity of the rock and the resistivity of the contained water, as stated by Archie (1942).

$$Q = a\emptyset^{-b} f^{-c} Q_w$$

Where - porosity, f – fraction of pores containing water, is the resistivity of water, and a, b, and c are empirical constants, can vary considerably according to the quantity and conductivities of dissolved materials Kearey and Brooks, 1984).

This shows a direct relationship between the porosity of a rock and its electrical resistivity. The porosity of a rock is the amount of pore spaces (filled with fluids) to the volume of the rock (see Fig. 2). In sedimentology, the porosity of sediments or sedimentary rocks is reduced through compaction and lithification, which occurs over time.

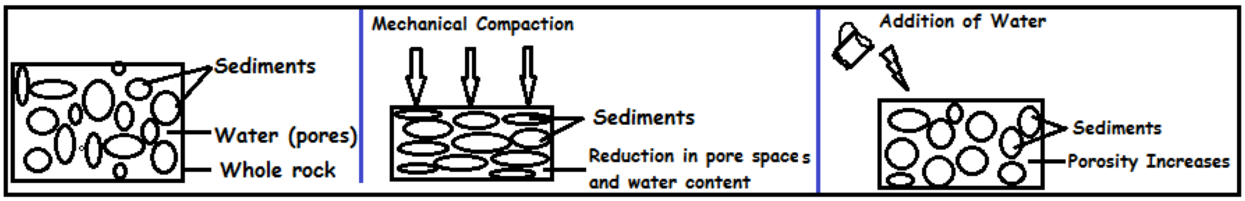

Fig. 2: Image of rock constituents describing what happens during water saturation, compaction, and lithification.

In 2023, Bello conducted Vertical electrical sounding (VES) in part of Biu town to determine the location and depth of the groundwater potential zone, and showed four geoelectric layers, namely: the top layer, the weathered layer, the fractured layer, and the fresh basement layer. Akande *et al.* (2016), Alhassan *et al.* (2017) carried out Vertical electrical sounding (VES) in northern part of Paiko, North Central Nigeria to determine the subsurface layer parameters (resistivities, depths and thickness) employed in delineating the groundwater potential of the area and established three to four discrete geoelectric layers, namely, the top layer, the weathered layer, the fractured/fresh layer, and the fresh basement layer.

In 2000, MacDonald and Davies, in their finding, show that crystalline basement rocks occupy 40 % of the land area of sub-Saharan Africa. In a basement complex rock formation, weathering is considered as an important component that determines the presence of porosity and permeability (Acworth, 1987; Oluorunfemi and Fasuyi, 1993; Edet and Okereke, 1997). The level of permeability and porosity within the weathered zone of crystalline rocks varies with the rock profile (Fig. 3). Depth affects porosity, i.e., decreases with depth, and permeability has a complicated relationship, depending on the extent of fracturing and the clay content (Chilton and Foster, 1995).

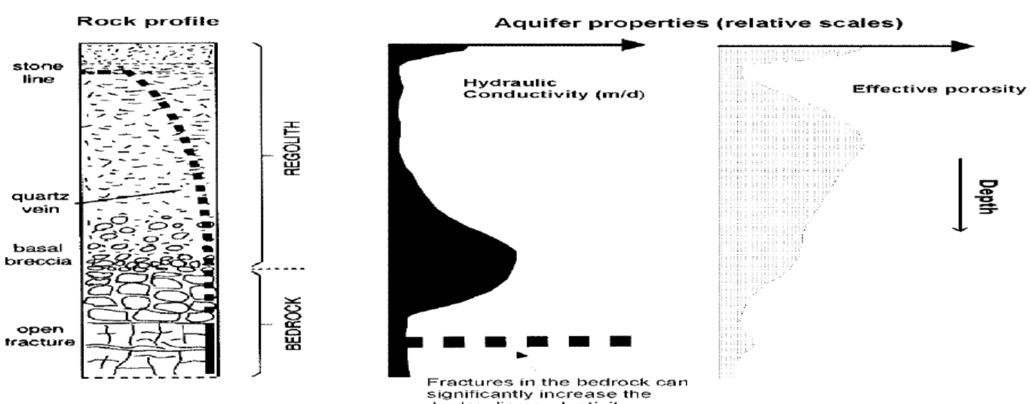

Figure 3: Variation of permeability and porosity with depth in basement aquifers (After Chilton and Foster, 1995)

In some cases, the bedrock has disintegrated into an extensive and relatively thick layer of unconsolidated, highly weathered rock with a clayey residue of low permeability (Morris *et al.*, 2003). This study focused on determining the effect of secondary porosity on electrical resistivity and analyzing the depth of porosity in the crystalline basement rocks of the Biu basalt rocks, northeastern Nigeria.

Geology Of Biu Plateau Basalt Area

The geology of the Biu Plateau basalts (Fig. 1) is part of the basement terrain underlain by basement complex rocks of the Precambrian period in northeast Nigeria. They are mainly basaltic rock. The Biu Plateau is situated on the structural and topographic divide between the upper Benue and Chad sedimentary basins. The structural divide is a broad E-W ridge or swell of basement, which extends to the western edge of the Biu Plateau.

In 1911, Falconer conducted a study that found the Biu Plateau is the largest area of volcanic rocks in Nigeria. Keer (1977) inferred that the rock belongs to the Tertiary-Recent Volcanic Province of Nigeria and Cameroon, which is identified by numerous widely scattered occurrences of alkali olivine basalt, joint with the less important trachyte and phonolite. Much of the volcanic activity in the Province is located along the "Cameroon Line", which extends north-eastwards from the Gulf of Guinea Islands, through the Cameroon mountain and the Bermuda Volcanic District of Western Cameroon towards Lake Chad (McCurry, 1976). However, the Biu Plateau, like the Adamawa Plateau of the Cameroon Line and many other smaller volcanic occurrences, is situated away from the Cameroon Line without an obvious structural control over its location,

They are mostly a result of "flood Basalts" in several flows and in fact cover nearly the area with its center around Biu, Turner (1978). The basalt in some places has made up a large number of flows. The dimension of the flows and the marked absence of pyroclastics in and around Biu, Tum, Marama, and Shaffa areas indicate that the eruption of Basaltic magma in these places was not violent. However, the Basaltic sequence in the North-western part of Biu is surrounded by several youthful scoria, cinder cones, tephra rings, etc., Pyroclastics are generally restricted to the area west of the Biu to Damaturu road, suggesting that the eruptions in these places are violent in nature. Obiefuna and Nggada (2014) inferred three types of Basaltic rocks in Biu basalts and their environs, and classified them as massive basalts, slightly vesiculated basalts, and vesicular basalts. The age variations between these basalts are due to the time of their eruption, the nature of their eruption, and also the manner in which they solidified. The basalt belongs to the Tertiary-Recent volcanic province of Nigeria and Cameroon and is characterized by numerous widely scattered occurrences of alkali olivine basalt together with less important trachyte and phonolite. It consists of intensive flows of basalts which are dense, fine-grained, and dark in colour. Some of them contain vesicles that are partially or filled with secondary minerals, probably calcite or zeolite.

The most peculiar thing about the Biu Type of basalt is the degree to which the olivine has been altered. Some olivine crystals are completely changed, while some are partially altered along their margins and cracks. The rate of alteration of the Biu basalt suggests that it is older than the Miringa Type, which is Pliocene in age. The massive basalt is dark coloured and fine-grained in texture with whitish feldsparthic minerals. It also contains phenocrysts of olivine and secondary minerals such as calcite and iron oxide. It dominated the study area. It occupied the south, north-eastern and southwestern part of the study area. The slightly vesicular basalt has smaller number of vesicles, and their cavities are smaller in size and scattered. They are light to dark gray in colour. It occurs diagonally from the western to the north-eastern part of the study area. The vesicular basalt has cavities that vary considerably in shape and size. They are spherical, ellipsoidal, cylindrical, and irregular in shape. They are found in the north-western part of the study area.

The lateritic soil formed from the weathering of the basalt is brownish to reddish brown in colour, except in some cases where they are found to occur as light gray to dark gray clay. The water resources of the study area can be divided into surface and groundwater resources. The surface water of this area occurs in the form of streams and lakes. They serve as sources of water for both drinking and domestic use. Most of the streams are seasonal. The streams and lakes are recharged by direct precipitation during the rainy season.

II. Materials And Methods

The following are the materials used in this study for data collection which include ABEM SAS 300C terrameter, four metallic electrodes, electrical cables, measuring tapes, hammer, portable Geographic Positioning System (GPS) device, a source of direct current (battery), IX1D inversion software, and other accessories. Chilton and Foster (1995) used resistivity methods to locate vertical and horizontal fractures and weathered zones in West and East Africa.

Data acquisition and interpretation

Fifteen (15) Vertical Electrical Sounding (VES) were carried out in the area using a Schlumberger configuration with current electrode separation of AB/2 = 100 m. The instrument used for data acquisition was the ABEM SAS 300C Terrameter, which measures the variation in electrical resistivity of the subsurface by introducing electric current through current electrodes (AB) and picking the potential difference between the potential electrodes (MN). The collected data were then processed through curve matching to generate the initial models for computer interpretation using IX1D inversion software, which reveals the thickness and electrical resistivity values of the subsurface layers (Telford *et al*, 1990). The final results of the analysis are shown in Table 1 below.

Table 1; Interpreted results of the geoelectric parameter of the Biu area VES No

VES NO			Layer Resistivity (Ohm-m)				Layer Thickness (m)				r.m.s %
	Lat. 10°	Log. 12°	ρ_1	ρ_2	ρ_3	ρ_4	h_1	h_2	h_3	h_4	
1	37′34″	27′12″	12.73	101.47	372.20	449.75	4.86	15.35	8.43	∞	1.03
2	34′30″	13′25″	37.73	11.47	73.20	149.75	2.43	11.49	8.33	∞	1.34
3	34′48″	13′19″	70.30	11.60	16.50	307.40	1.30	11.60	9.00	∞	0.95

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4	35′18″	12′25″	07.53	15.34	86.38	220.15	2.35	15.29	7.99	∞	1.46
5	35′51″	12′51″	19.08	106.84	234.39	429.25	2.06	31.32	2.90	∞	1.69
6	37′11″	11′18″	09.05	65.92	253.19	409.22	2.37	2.73	5.34	∞	2.50
7	37′23″	11′09″	06.68	72.12	198.39	329.13	1.76	5.02	8.19	∞	0.84
8	37′27″	11′14″	05.88	68.98	234.39	428.25	1.66	19.60	10.88	∞	1.42
9	37′07″	11′23″	02.16	65.92	244.39	389.25	0.95	26.21	11.17	∞	0.98
10	36′45″	12′34″	12.15	62.87	234.41	329.11	2.92	22.70	10.17	∞	0.98
11	38′09″	11′24″	37.73	11.47	73.20	149.75	1.35	8.05	17.87	∞	2.29
12	38′00″	11′19″	149.00	47.66	41.27	57.69	0.71	13.81	13.30	∞	1.70
13	37′55″	09′57″	58.80	244.00	15.63	55.04	5.22	11.07	16.51	∞	0.80
14	35′48″	09′44″	52.16	108.19	173.74	226.74	4.95	21.08	7.30	∞	2.40
15	36′52″	10′31″	08.49	03.60	45.67	429.29	2.51	15.34	11.08	∞	1.63

III. Discussion On The Results

Table 1: The interpreted resistivity data that illustrate four geoelectric curves (layers) from the area. The qualitative interpretation includes comparison of the relative changes in the apparent resistivity and thickness of the detected layer(s) on the sounding curves. It gives information about the number of layers, their continuity throughout the area and reflects the degree of homogeneity or heterogeneity of an individual layer. The first layer has a thickness ranging from 0.71 to 4.86 m and a resistivity between 2.16 and 149.00 Ωm, which is considered to be the topsoil. VES points with high resistivity values within the first layer indicate the presence of sand as top soil, and those with relatively low resistivity values indicate the presence of clay or intercalation of clay with sand (Telford *et al*. 1990). The second layer is the weathered basalt zone, the VES points revealed varying degrees of weathering (porosity) with resistivity values ranging from 03.60 to 244.00 Ωm indicating porous zones due to secondary porosity or water content. The thickness of these layers also varies from 2.73 to 31.32 m. The resulting weathered zone can vary in thickness from few metres in arid areas to over 90 m in humid tropics (MacDonald and Davies, 2000). The layer is slightly weathered if the resistivity values are relatively high or on the other hand a highly weathered zone has relatively low resistivity values (Telford et al., 1990). Therefore, the reduction in the resistivity values of the second geoelectric layer is due to secondary porosity induced by secondary processes such as weathering or fracturing in the parent rocks.

The resistivity values for each VES increases as the separation distances is being increased. This implies that; deeper depth has higher resistivity while shallow depth has lower resistivity. The observed increase in resistivity at deeper depth could be responsible to reduction in porosity or water content which is justifiable based on the sediments of the shallower depth. The third layer is inferred to be fractured basalt with resistivity values varying between 16.5 and 372.2 Ωm and a thickness ranging from 2.9 to 11.17 m. While the fourth layer revealed a fresh basement rock with resistivity values from 149.8 to 449.8 Ωm, its thickness could not be penetrated; as a result, the rock was not affected by the effect of secondary processes. Below the weathered zone, the rocks become progressively less weathered and more consolidated, therefore acting as the contact between the weathered zones and the fresh basement rock. This layer revealed high resistivity values ranging between 1480 and 4089 Ωm with thickness values ranging from 4.7 to 49.7 m. The aquifer in the study area is therefore defined by the highly weathered zone and the slightly weathered/fractured zones, which correlate with Conred *et al* (1978).

IV. Conclusion

The interpreted results inferred four layers identified from all VES data conducted in the study area. The first layer was defined as clayey, while the second and third layers were interpreted as weathered basalt rocks and fracture basalt, respectively, based on the VES data obtained in the field. The high resistivity value obtained from interpreted data revealed that the fourth layer is a fresh basement rock. The VES data generated from the area was interpreted to have unveiled more knowledge of the subsurface geology of the area, therefore help limit its porosity, water retention, and transmission capacity without recourse to any sedimentological studies. It is generally assumed that the basalt rocks in the study area have very little primary porosity, and secondary porosity has been identified as the major source of porosity in the parent rocks of the Biu Plateau basalt.

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