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Baryte mineral exploration in parts of the lower Benue Trough, Nigeria

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The use of DC electrical method in baryte mineral exploration has been investigated in Buruku northeast of Markurdi, Nigeria. The objective of the study was to investigate the suitability and potential of electrical resistivity tomography (ERT) combined with vertical electrical sounding (VES) surveys in baryte mineral exploration over known deposits. Results show that the interpreted layer resistivities correlate with the 2-D observations. The study delineated averagely 28 m deep symmetrically mound-shaped resistive anomalies (1500 to 5500 Ωm) encased within low resistive sandstone formation along prospective traverses. These responses are characteristics of probable vein structures associated with baryte mineralization. Two dominant E-W and NW-SE resistivity anomaly trends were delineated. The E-W trends were more prominent and persistent than the NW-SE. They are 25 to 50 m wide and stretches to over 300 m in length. The association of mineralized veins with these trends suggests that the veins must be of early Cretaceous age. These mineralized veins correlate with locations of known baryte deposits in the prospect area which hitherto, have been exploited by artisan miners. This is an obvious indication of the utility and resolution of dc electrical method in baryte mineral exploration in the area.

Key words: Electrical resistivity tomography (ERT), Vertical electrical sounding (VES), resistivity, Baryte, vein and mineralization.

INTRODUCTION

Exploration and exploitation of solid minerals in Nigeria has remained comatose in the past decade, especially with the discovery of hydrocarbons in the Niger delta region. As the fortunes from hydrocarbons continue to dwindle with the growing instability in global demand and supply, attentions are now being focused on solid minerals as alternative sources of revenue and employment for the teeming population.

Most solid mineral occurrences in Nigeria are located in the Benue trough (Tate, 1959; Offodile, 1976). The trough is the failed arm of the triple junction formed as the African plate separated from the South American plate in the Pre-Cretaceous. It is a 1000 km NE-SW trending intra-continental Cretaceous basin resting unconformably on the basement complex. This is partitioned into the lower, middle and upper troughs with deposits of lead-

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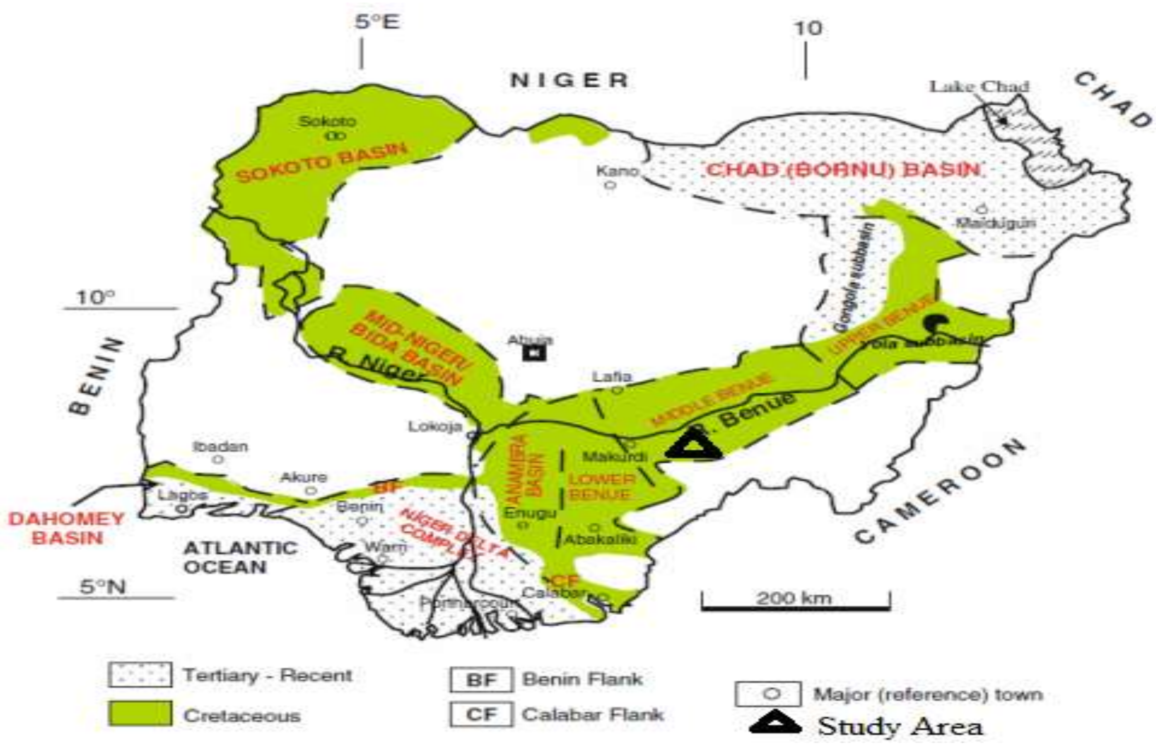

Figure 1. Location and geologic map of the study area (Adapted from Anthony et al., 2013).

zinc-baryte mineralization concentrated mostly in the lower and middle troughs (Farrington, 1952; Offodile, 1976).

The study area is located in Buruku NE of Markurdi, within the lower Benue depositional sub- basin and covers a total land area of (3060 x 900) m^2. The topography in the study area is flat and gently undulating with little relief features which are somewhat dissected by valleys. The vegetation is typical of the Guinea savannah grass land with stunted shrubs and herbs in places (Figure 1).

The occurrence of baryte in parts of the trough has been reported by Farrington (1952), Tate (1959) and Offodile (1976), as epigenetic deposits arising from products of hydrothermal activity at shallow depths and low temperature. They occur as massive vein bound deposits and often times as a gangue mineral associated with lead-zinc mineralization in fractures, fissures, and open space fillings in sedimentary and igneous rocks. These veins are extremely varied in character and form. There are well developed in hard sandstone units and less likely in shales. The barytes in the trough are mostly the creamy white variety with a specific gravity of approximately 4.3, which is unusually heavy for a non-metallic mineral (Figure 2).

As the exploration for near-surface mineral deposits becomes more difficult due to complexities in geology, geophysical techniques are increasingly relied upon to identify areas of ore mineralization. Various geophysical techniques have been adopted in the search for geobodies associated with mineralization (Bishop and Emerson, 1992; Maxwell, 2002; Mansour et al., 2008). These methods have developed rapidly over the last decade and each depends upon detecting variations in one or more of the physical properties of rocks (Electrical resistivity, Density, Magnetic susceptibility and Seismic velocities), which varies within wide limits.

Geophysical methods will be effective only if a target anomaly has a physical property contrast with the surrounding rock material. Baryte has a high resistivity compared to its host rock. This makes it easily detectable by the electrical method because of the resistivity contrast with the host rock. This forms the basis for the adoption of the electrical method in this study.

Electrical resistivity methods have variously been used in the exploration of baryte veins by several researchers (Egeh et al., 2004; Karen, 2004; Bhattacharya et al., 2006; Oladapo and Oladapo, 2011; Luano et al., 2012; Akpan et al., 2014; Obi et al., 2014). Results of study show that high resistivity signatures were diagnostic of baryte vein structures to which baryte mineralization could be associated. The resistivity of barytes depends on the $BaSO_4$ content, impurities and the environment of deposition.

The present study is aimed at evaluating the utility and resolution of dc electrical method in characterizing near surface mineralized baryte targets over known deposits and subsequently, delineate concealed baryte veins in

Figure 2. Exposed baryte veinlet in the study area.

the area. 2-D electrical resistivity tomography (ERT) and vertical electrical resistivity sounding (VES) surveys were employed for the study.

Geology of the area

The study area is underlain almost exclusively by the Cretaceous Turanian Eze-Aku Formation. The formation consists of hard grey and black calcareous shale, limestone and siltstone (Figure 1). Locally, the shales grade into sandstone - Markurdi sandstones around Markurdi and environs. The formation is characterized by ferrugenized sandstones and to a lesser extent quartz rocks and calcite (Offodile, 1976).

Baryte occur in lodes and veins infilling open fractures within sediments associated with Pb-Zn mineralization in the trough. Baryte mineralization in the prospect area occurred as a hydrothermal event, directly connected with the Mesozoic Magmatism during the early Cretaceous. Possible sources are the leaching of barium out of country rock by hydrothermal brines. Convention cells of meteoritic water, with upward-moving hydrothermal fluid being concentrated along the line occupied by fractures, offer a possible mechanism (Farrington, 1952; Offodile, 1976).

Many mineralized veins occupy E-W, NW-SE, and N-S fractures within the prospect area. The E-W trends give the strongest and most persistent veins and the N-S trend the weakest. Mineralization is structurally controlled and more or less confined to the limit of these faults (Chaanda et al., 2010; Wright, 1976).

METHODOLOGY

Field methods

The study area measuring (3060 x 900) m^2 was divided into twenty (20) traverses of length 900m with inter traverse spacing's of approximately 150 m (Figure 3). 2-D electrical resistivity survey was carried using constant separation profiling (or horizontal profiling) with Wenner alpha electrode configuration along each traverse perpendicular to the geologic strike (N-S). A digital read out Abem Terrametre SAS (signal averaging system) 1000C was used for the measurement of ground resistivity values. Measurements were made at sequences of increasing offset distance (a-spacing) along traverses ranging from 25, 50, 75, and 100 m, using twenty (20) electrodes. The electrodes were moved from one end of the line to the other in a lip frog manner till the traverse is completed. This was done for each of the traverses in the prospect.

Subsequently, vertical electrical soundings (VES) were carried out in selected traverses as confirmatory surveys based on the results of the 2-D resistivity survey. The Schlumberger electrode configuration with maximum AB/2 = 400m and MN/2 = 35 m were adopted, and a total of twenty (20) VES shot locations were occupied. The current electrodes were expanded about the mid-point of the suspected baryte vein on the surface and the potential electrodes (if necessary), to measure the vertical variation in resistivity. Data were processed and analyzed using resistivity softwares RES2DINV (2006) and IPI2WIN (2003) for ERT and VES respectively, for subsequent interpretation.

RESULTS PRESENTATION

The results of study are presented as 2-D electrical inverse model sections (Tomogram) and 1-D vertical electrical sounding model curves. These resistivity models generally exhibit root mean square (RMS) errors varying from 0.1 to 5.7%, a reflection of the degree of fit between the calculated and field data. This guarantees the use of the models for subsequent analysis and interpretation. The models were visually inspected and zones/layers of anomalously high resistivity values were isolated from the lows and characterized in space in the study area.

The 2-D resistivity models are characterized by extensive symmetrically mound-shaped high resistivity anomalous features encased in low resistive materials as host rock. Their resistivities vary from 1,500 to over 5,500 Ωm. A typical model inverse section along traverse 12 is shown in Figure 4. Two symmetrically mound-shaped high resistivity anomalies (>4,811 Ωm) were delineated to

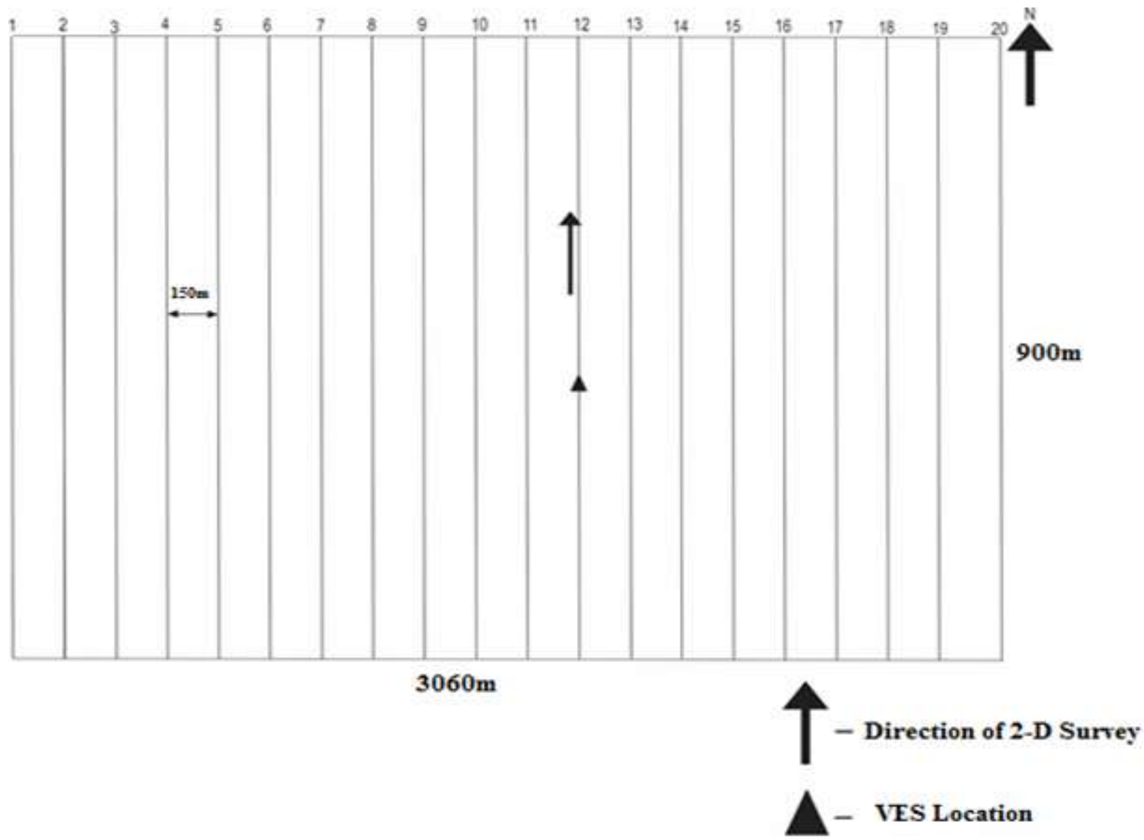

Figure 3. Traverse or grid lines for the electrical survey in the study.

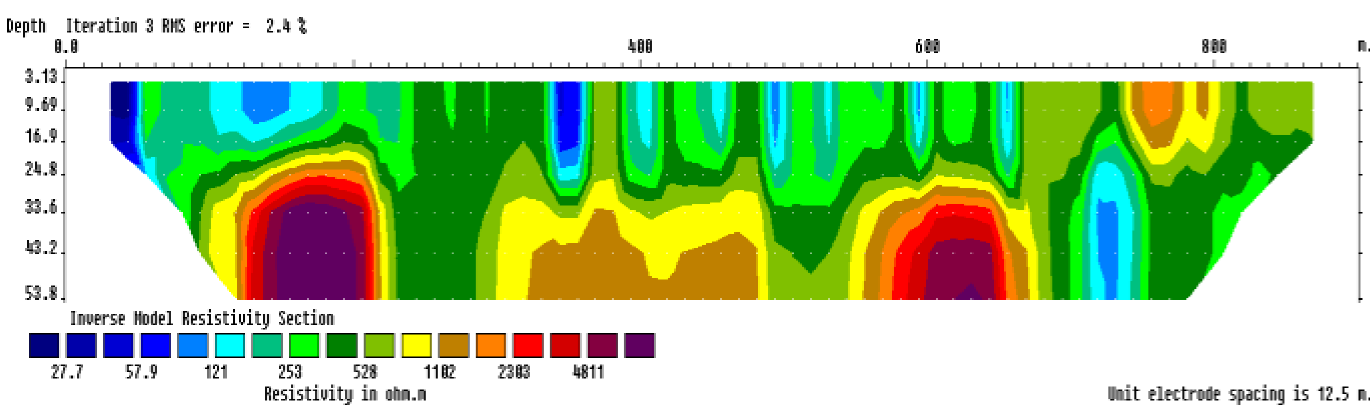

Figure 4. Typical 2-D profile along transverse 12 in the study area.

the north and south of the traverse flanked by low resistive host rock.

These are situated at 175 and 625 m surface points with tops at 24 and 28 m subsurface depths, respectively, with an average thickness of 43 m. The base of the structure extends beyond 53 m subsurface depth, which probably suggests mineralization at deeper depth. These resistive structures exhibits gradational variations in colour scale related to probably distinct zonation in mineral content with depth. The zonation is outward and upward from the base of the structures. This response is characteristic of a vein type structure accompanied by high resistivity to which baryte mineralized veins can be inferred.

Vertical electrical sounding (VES) survey conducted at 175 m surface point to the midpoint of the first resistive structure along traverse 12, revealed a 7-layer geoelectric section (Figure 5). The lithology varies from

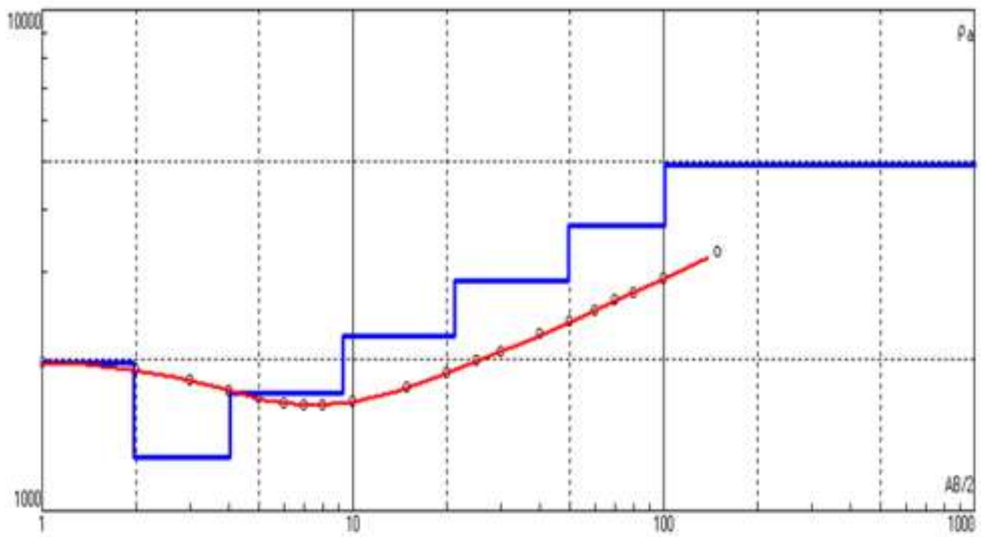

Figure 5. Typical VES curve along Transverse 12 in the study area.

Table 1. A typical interpreted VES model along Transverse 12.

Layer No.	Rho (Ωm)	Depth (m)
1.	1984	1.98
2.	1280.0	4.02
3.	1723.0	9.25
4.	2237.0	21.34
5.	2885.0	49.35
6.	3720.0	101.40
7.	4970.0	

top soil of sands/quartz and lateritic materials to sandstone successions with anomalously high resistivity signatures at increasing depth (Table 1). Baryte target were delineated at the depth of 21.34 m with high resistivities varying from 2237 to > 4970 Ωm and at depth extending beyond 100 m.

These results are comparable to the 2-D electrical resistivity observations. It therefore means that these symmetrically mound-shaped high resistivity anomalies are unlikely to be simply altered and deformed sedimentary rocks. There are therefore, interpreted as probable baryte mineralized veins in the prospect area.

Based on these observations, resistivity and depth contour maps of the isolated baryte veins were generated to characterize their quality and depth distribution in space in the prospect area. The depth contour map (Figure 6) revealed that the depths to the top of these structures are shallow in the western and mid-western parts (Bright shades) with depth range of 25 to 30 m, than the south, central and eastern parts (Dark shades) associated with depths exceeding 30 m.

The 3-D depth structure profile show a structural anomaly high along the E-W trend flanked by structural lows to the central and southern parts of the prospect (Figure 7). The highs correspond to shallow mineralized veins, while the lows to the deeply buried veins. The mineralized veins trends dominantly in the E-W and NW-SE and less in the NE-SW of the prospect. The VES shot points at the midpoint of the structures are indicated by vertical solid lines caped with the VES numbers (in red).

The resistivity contour map (Figure 8) show that the deeply buried veins to the southern, central and eastern parts of the prospect exhibits high resistivities than the western and mid-western shallow targets. This suggests that pure and high quality baryte mineralized veins exist in the southern, central and eastern parts at greater depths (>30 m) and poor quality baryte veins in the shallow western and mid-western parts (<30 m). The solid vertical lines are the centers of the veins along traverses capped with the depth to the top of the structures (in red).

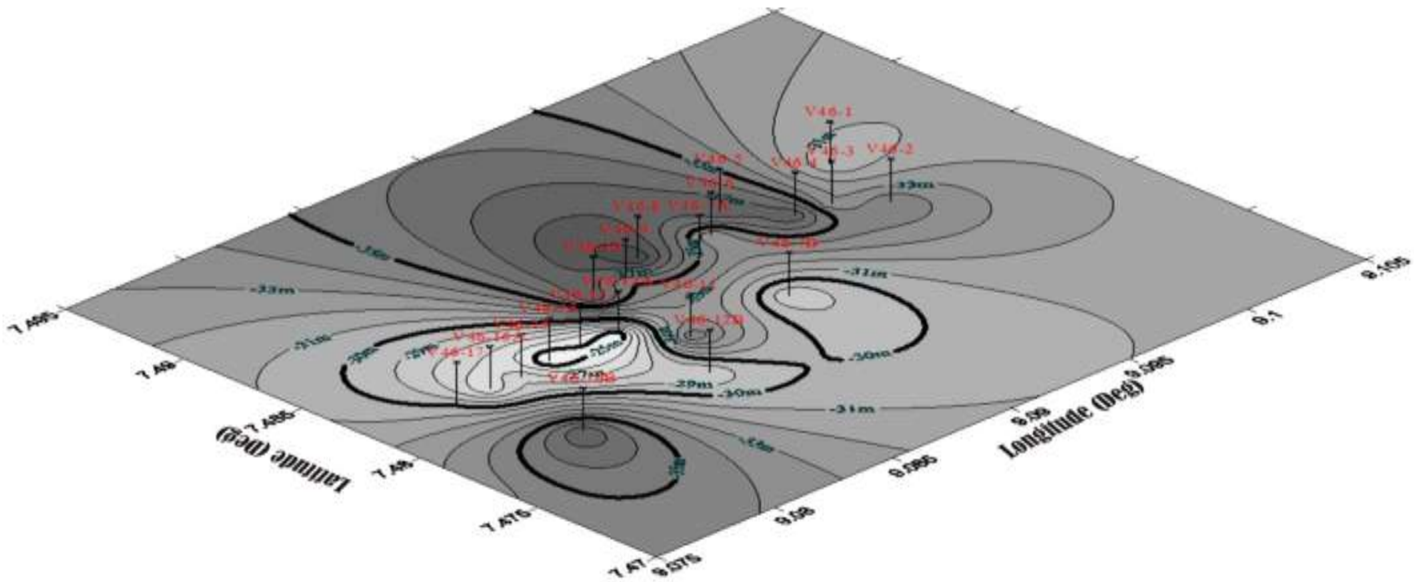

Figure 6. Depth contour map of the prospect area.

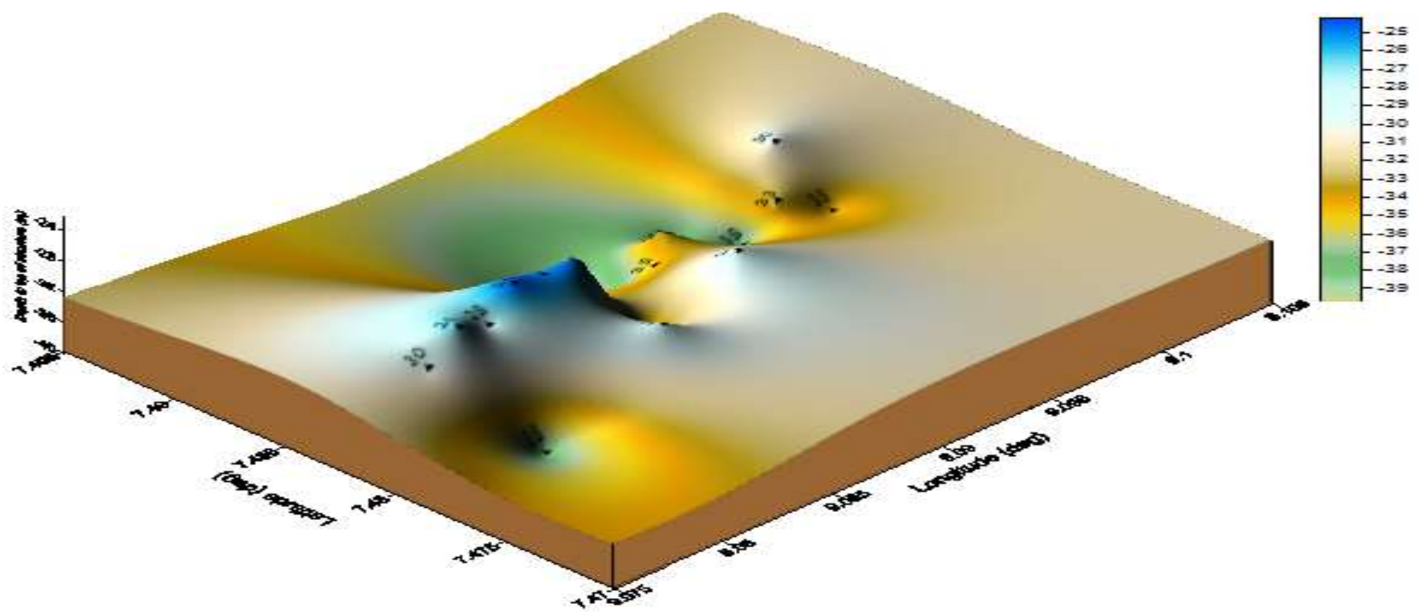

Figure 7. 3-D depth structure profile of the prospect area.

DISCUSSION

2-D electrical resistivity tomography (ERT) and Vertical electrical resistivity (VES) direct current electrical methods were adopted in the exploration of baryte mineralized veins in the study area. Results show that the prospect area is characterized by complex geological structures with anomalously varying resistivities along traverses, related to regional and local anomalous values. The regional anomalies are related to the surface and subsurface variations in lithologic units and their contacts, while the local anomalies correspond to possible mineralized veins along the investigated traverses.

2-D electrical resistivity tomography (ERT) model sections exhibit symmetrically mound-shaped high resistivity structures encased by low resistive sandstones. This encasing sandstone seems the most promising host rock for vein mineralization in the study area. The geometrical and essentially symmetric nature of the

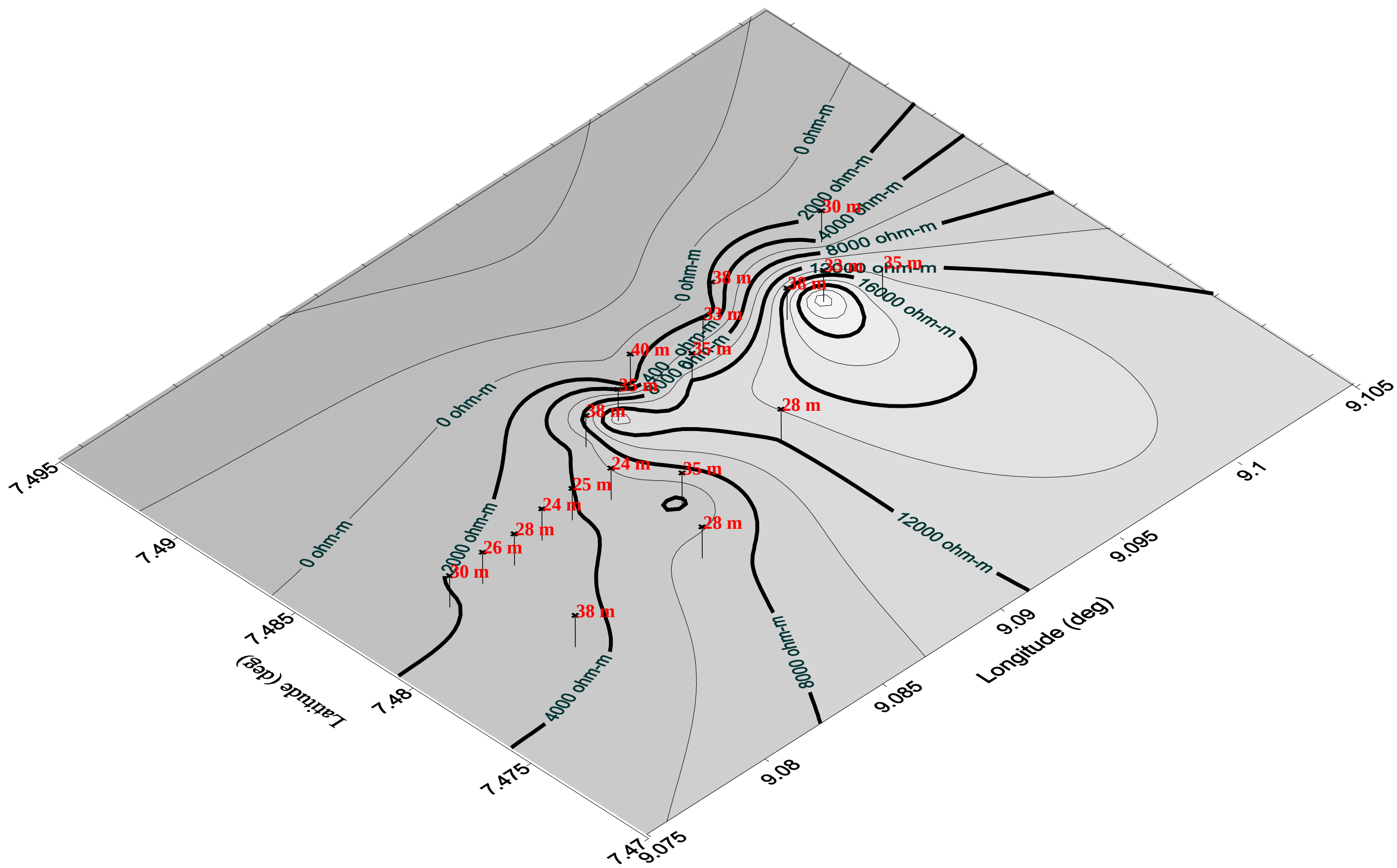

Figure 8. Resistivity contour map of the prospect area.

electric anomalies suggests that the source is a massive and narrow vertical body buried at depth. Vertical electrical sounding (VES) shot at the midpoint of these suspected mineralized baryte targets along prospective traverses exhibits increasing anomalously high resistivity signatures with increasing layer depths, which correlates with baryte mineralization.

The study revealed the presence of averagely 28 m deep suspected baryte mineralized veins in the prospect area, with high resistivities of 1500 to 5500 Ωm. Formation resistivities greater than this, are interpreted as intruding plugs of fresh basement rocks in the sedimentary sequence. The width of the mineralized veins varies from 25 to over 50 m, and extends to over 300 m in length in prospective traverses. The veins are wider than normal probably because of the lithology and competence difference which affects the inclination of fault planes and vein development in the sediments.

Baryte targets are shallow in the west and mid-western parts (< 25 m) than the southern, central and eastern parts (> 30 m) of the prospect. The deeply buried veins to the southern, central and eastern parts of the prospect exhibits higher resistivities than the west and south western shallow veins and as such, are probably of higher quality and economic value. This could be attributed to dipping associated with the prevailing structural trends concomitant with increasing mineral content along the down thrown part of the veins.

Dominant E-W and NW-SE resistivity anomaly trends were delineated. The E-W trends were more prominent and persistent than the NW-SE trend. These electrical anomaly trends stretches to over 300 m in length and generally exhibit minor variations in path length, while maintaining their dominant trend axes. This suggests structural control of mineralization in the prospect area. The striking association of mineralized veins with the E-W and NW-SE fault trend suggests that the veins must be of early Cretaceous age (Tate, 1959; Farrington, 1952; Offodile, 1976). This implies that baryte may have been emplaced by space filling rather than by replacement along E-W steeply dipping to vertical veins cut by minor SE mineralized veins. This suggests a tensional regime culminating in mineralization along structural trends in the prospect area.

According to the works of Oladapo and Oladapo (2011), Luaano et al. (2012), Oden (2012), Akpan et al. (2014) and Obi et al. (2014), high resistivity/low conductivity anomalous values are diagnostic of baryte

mineralized veins to which barytes can be associated. The resistivity of baryte mineralized veins ranges from 1300-3999 Ωm, which may likely vary within a wide margin dependent on impurities and $BaSO_4$ content. The high resistivity of the barytes is due to its very low intergranular porosities associated with its high density. The authors also reported baryte veins having thicknesses ranging from 17.1 to 60.7 m, with an average thickness of 38 m, predominantly NW-SW and NE-SW trends and subsurface baryte target depth of 37.4 m in the study areas. These observations compare fairly well and validates the results of the present study in the area.

These mineralized veins correlates with locations of abandoned and working mine pits exploited by artisan miners through surface mining. The artisan miners are merely exploiting exposed surface veins which do not persist over long distances and depth. However, the potential for massive and persistent mineralized baryte veins is high at greater depths based on the results of this study.

Conclusion

The combination of 2-D and VES dc electrical methods proved to be effective and robust in delineating baryte mineralized veins in the study area. The study revealed the presence of averagely 28m deep and 1500 to 5500 Ωm resistive electrical anomalies related to baryte mineralized veins along E-W and NW-SE resistivity anomaly trends.

The association of baryte mineralized veins with these fracture systems is indicative of the fact that the veins must be of early Cretaceous age. This suggests that baryte mineralization in the prospect area probably, postdates these fracture systems at shallow depths. This implies that baryte may have been emplaced by space filling rather than by replacement along E-W steeply dipping to vertical veins cut by minor SE mineralized veins, suggesting a tensional regime culminating in mineralization along structural trends.

These mineralized veins correlates with locations of abandoned and working mine pits exploited by artisan miners through surface mining. This indicates the utility and resolution of dc electrical method in baryte mineral exploration.

Conflict of Interests

The authors have not declared any conflict of interests.

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