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A 3-D GEOELECTRIC MODEL OVER MINERALIZED ZONE OF UGONOBA, EDO STATE, NIGERIA

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ABSTRACT

The occurrence of solid minerals in Ugonoba community was investigated using the 3D electrical resistivity method. Data was acquired using PASI 16GL Terrameter using the wenner electrode configuration with a view to delineating mineral deposits in the study area. During the reconnaissance survey, the outlook of some geological features in the form of outcrops on the surface formed part of the motivation for the geophysical survey within the Ugonoba area. Ten traverses of 200 m maximum spread and 10m electrode spacing with total depth of 40.07 m were obtained in the study area to form a square grid. The acquired data was first processed and inverted using RES2DINV software to generate ten 2-D model images and later collated into 3-D using the inversion code of RES3DINV software which automatically determines a horizontal 3D depth slice, cubes and block models of resistivity distribution. These models generated were interpreted and used to ascertain the true resistivity, lithologic formation, depth extent to any buried mineral and aggregate deposited in the study area. The extracted 3D model images revealed evidence of some geological materials/minerals in the study area which fall within the high resistivity range of 2500 Ωm to 14376 Ωm. It can therefore be inferred from the standard resistivity table that the lithology of study area is composed of non-metallic type of mineral resources which are: clayey sand, lateritic clayey sand, sandstone and limestone. The estimated quantity in metric ton for the dominant lithology (sandstone, granite and limestone) is ± 10% of 1,257,142.9 which can be commercially explored.

Keywords: Wenner-wenner array, outcrop, minerals, RES3DINV, block models.

INTRODUCTION

Mineral exploration is very essential and is the initial stage of a mining cycle which covers prospecting, mapping and surveying of a mineral deposit in any subsurface area (Haldar, 2012). In simple words, mineral exploration is the systematic evaluation of the mineral deposit with a view to mine it profitably and efficiently. However, exploration helps scientists to understand the earth and its interior. It also helps to detect the presence and position of ore minerals, geothermal, ground water reservoirs, hydrocarbons and other geological structures using surface geophysical methods to measure the physical properties of the earth (Alisa, 1990). Mineral exploration in Nigeria, which dates back to the geological expeditions by the colonial masters in the early part of the 19th century, has resulted in economic development and has generated revenue (Ajakaiye, 1985). In the early years of twentieth century, the continued efforts by explorers to look for more effective, less risky and more economical technique of sub-surface exploration led to the advent of geophysical exploration (Idowu, 2006). Alile *et al*. in 2017 carried out a 3D geoelectrical resistivity imaging for solid mineral investigations on two locations in Amahor, Edo State, Nigeria. The results obtained showed that the two locations considered were composed of lateritic soil, sand, sandstone, shale, limestone, clay, dolomite with resistivity ranging from 259 Ωm to 2159 Ωm. With the dwindling of the price of petroleum products in recent times, and with the abundance of solid minerals in over 450 locations in Nigeria, there is urgent need for geophysicist to continue to explore these abundant and untapped minerals for economic and sustainable development of this country. According to Alisa, (1990), minerals can be grouped into four, which include **metallic minerals** such as, gold, iron, zinc, aluminum, **non-metallic minerals** like limestone, gypsum, gravel, sandstone etc **liquid minerals** such as oil, water, **gaseous minerals** like gasses in buried cavity.

In order to identify and quantify for more potential minerals deposit that are essential for industry and economic growth of the nation, the study area (Ugonoba) was selected for geoelectrical investigation in order to delineate any mineral occurrence using 3-Dimensional Electrical Resistivity method. The objectives of the research are to generate 3D block models, 3D depth slices and cross-plot graphs from the raw data acquired from the survey location so as to identify the occurrence of mineral deposits and quantify the aggregate volume in the study area.

Study Area

The geoelectrical survey for the research was carried out within Ugonoba community which lies between Longitudes of 6^0 32’ 19.2’’ to 6^0 32’ 39.32’’N and Latitudes of 5^0 85’ 83.75’’ to 5^0 86’ 00.10’’E and 94.3m above sea level. The survey area is underlain by sedimentary rocks of Paleocene to recent age, and according to Reyment, (1989) he described that sedimentary rock contains about 90% of sand stone and shale intercalation.

Fig 1: Location of study area in Uhumwonde Local Government, Edo State (source: Ministry of Lands and Survey, Benin City 2009).

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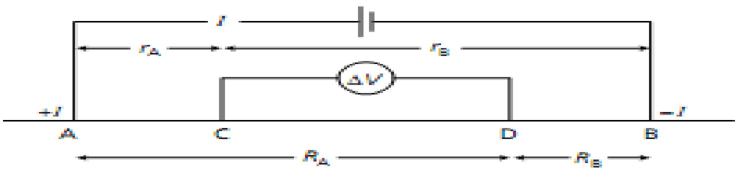
MATERIALS AND METHODS

- **Theoretical Background**

The fundamental equation for resistivity survey employed in this research is derived from Ohm's law, According to Ohm's law, when a current *I* flows through a conducting body it sets up a potential difference V between the ends of the body (Kearey *et al.*, 2002) and they are related in equation 1 as

$$I = \frac{V}{R} \quad (1)$$

where **V** = Potential difference (Volts), **I** = Current Supplied (Amperes) and **R** = Resistance offered by the medium (Ohms). The figure 1 showed the resultant potential difference (ΔV) between electrode potential C and D after injection of current through current electrode A and B.



- A and B – current electrodes
- C and D – potential electrodes
- I – current
  ΔV – potential differences

Fig 2: Resistivity Measurement (Kearey et al., 2002).

The equation for Ohm's Law in vector form for current flow in a continuous medium is given by

$$\mathbf{J} = \sigma \mathbf{E} \quad (2)$$

where σ is the conductivity of the medium (σ =1/ρ), **J** is the current density and **E** is the electric field intensity. In practice, what is measured is the electric field potential and the relationship between the electric potential and the field intensity is given by

$$\mathbf{E} = \nabla\phi \quad (3)$$

Combining equations (2) and (3), we get

$$\mathbf{J} = \sigma\nabla\phi \quad (4)$$

From figure 2, the current sources are taken as point sources and the current flows radially away from the source and also perpendicular to the equipotential surface of the earth, and the potential difference varies inversely with distance from the current source. The potential in this case is given in equation (4) (Loke, 2001).

$$\phi = \frac{\rho L}{2\pi r} \quad (5)$$

where r is the distance of a point in the medium from the electrode.

Two current electrodes were used during resistivity surveys (positive and negative current source) and at the mid-point between the two electrodes; the electric potential has a symmetrical pattern about the vertical plane and is given in equation (6) as,

$$\phi = \frac{\rho L}{2\pi}\left[\frac{1}{rc1} - \frac{1}{rc2}\right] \quad (6)$$

where the distance of point from first and second current electrodes are rC_1 and rC_2.

However, the potential difference between two points is measured and given in equation (7) below

$$\phi = \frac{\rho L}{2\pi}\left[\frac{1}{rc1p1} - \frac{1}{rc2p1} - \frac{1}{rc1p2} + \frac{1}{rc2p2}\right] \quad (7)$$

From the current (I) and potential values, an apparent resistivity (ρ_a) value is calculated.

$$\rho_a = K\frac{\Delta\phi}{I} \quad (8)$$

where, $K = \frac{2\pi}{\frac{1}{rc1p1}-\frac{1}{rc2p1}-\frac{1}{rc1p2}+\frac{1}{rc2p2}} \quad (9)$

where K is known as a geometric factor that depends on the arrangement of the four electrodes

Since $R = \frac{\Delta\phi}{I}$ (10)

therefore, from equations (8) and (10) the apparent resistivity value can be calculated using equation (11)

$$\rho_a = k\,R \quad (11)$$

The calculated resistivity value in equation (11) is not the true resistivity of the subsurface, but an "apparent" value and the relationship between the "apparent" resistivity and the "true" resistivity is a complex relationship. To determine the true subsurface resistivity from the apparent resistivity values is what is called "inversion" (Loke, 2001). In this research the geophysical software used for inversion processes are RES2DINV for 2D data and RES3DINV for 3D data.

- **Source of Data**

The raw electrical resistivity data was acquired in the study area using PASI 16GL digital Terrametrer with Wenner array configuration. Other materials used during acquisition are four metallic current and potential electrodes, connecting cables, power supply, hammers, GPS, Compass and two reels of tape.

Ten profile lines were acquired from the study area with 32 electrodes separated by 10m intervals with a maximum spread of 200m (total length) to generate a square grid line with 50m spacing between the lines.

- **Processing of Acquired Data**

The data acquired on the field were processed using the necessary geophysical software. The RES2D INVERSION software was first used to do inversion of 2D data acquired and produced 2D images. The entire square set of 2D lines (10 traverses) was merged together to form a single 3D data set for the location. This was achieved by collating the measured 2D data (apparent resistivity values) to a 3D data format that can be read by the RES3DINV software (Loke and Barker 1996) using RES3DINV computer code. The coordinates, line directions, number of electrodes, electrode spacing and data levels of each of the 2D traverses were used in collating the apparent resistivity values with the aid of an input text file which can be read by the computer code. The collated 3D data sets were inverted using RES3DINV inversion code which automatically determines a horizontal 3D depth slice model of resistivity distribution using apparent resistivity data obtained from a 3D resistivity imaging survey. The 3D cube was processed using the Voxler software by collating the entire square set of 2D lines together to form a single 3D data set each. This software was also used to generate 3D apparent resistivity cross-plot.

The 2D and 3D images and maps generated from this geophysical software were interpreted and used to ascertain and identify the true resistivity, lithologic formation, depth extent to any buried mineral and also determine the aggregate volume in metric tons of any mineral deposited in the study area.

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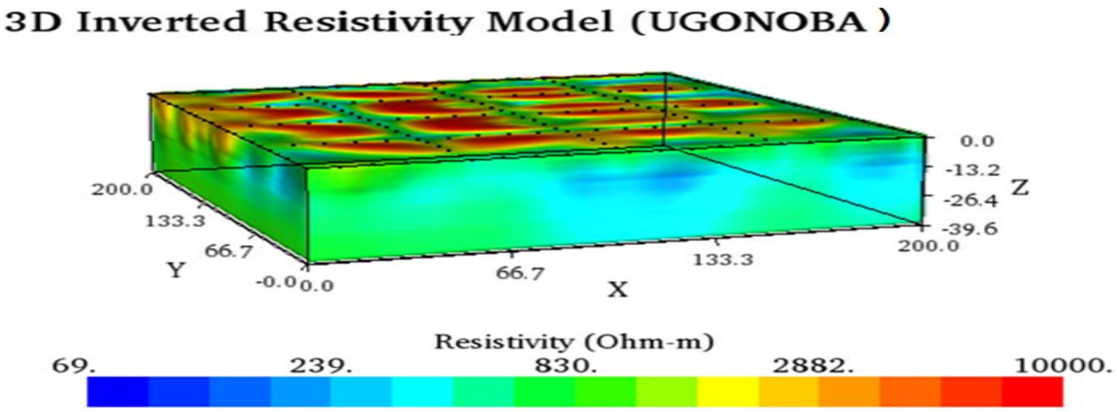
Table 1: Resistivities of some common rocks and minerals. Reference: (Telford et al., 1990)

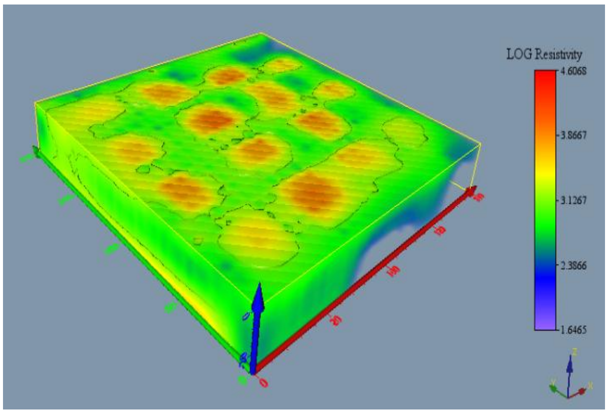
Typical Ranges of Resistivities for Common Materials/Minerals/Rocks	
Rock/Minerals Type	Resistivity Range (Ωm)
Rock/Minerals Type	**Resistivity Range (Ωm)**
Alluvium	1 - 1,000
Basalt	10 - $1.3x10^{7}$ (dry)
Lateritic Clay	120 -1500
Cobalt	$5.6x10^{-8}$
Copper	0.0000002 (native) - $1.7x10^{-8}$
Drill Mud or Hydraul-EZ	4.5
Fresh Water	10 – 100
Gabbro	10^{3} - 10^{6}
Gold	$2.4x10^{-8}$
Gravel	100 - 10,000
Igneous	10000 - 1,000,000
Limestone	100 - 10,000
Marble	10^{2} - $2.5x10^{8}$ (dry)
Mica	$9x10^{2}$ - 10^{14}
Nickel	$7x10^{-8}$
Salt Water	0.1 – 1
Sand (Both dry and wet)	1 - 10,000
Sandstone	100 - 10,000
Schist (Calcareous and Mica)	20 – 104
Graphite (Schist)	10 -102
Silver	$1.6x10^{-8}$
Soil	1 – 10
Shale	$2x10^{2}$ – $2x10^{3}$

RESULTS AND DISCUSSION

After the entire square set of 2D lines (10 traverses) was merged together to form a single 3D data set, then the 3D data format was inverted using RES3DINV software code. The Figures 3 to 5 show the results and maps of all 3-D electrical resistivity inverse block models, top and bottom views of the block model and horizontal depth slices generated by RES3DINV and Voxler 2 software. These images are displayed as cross sections of the true resistivity distribution of the subsurface with depth along each of the profiles.

- **Presentation of 3D Block Models**





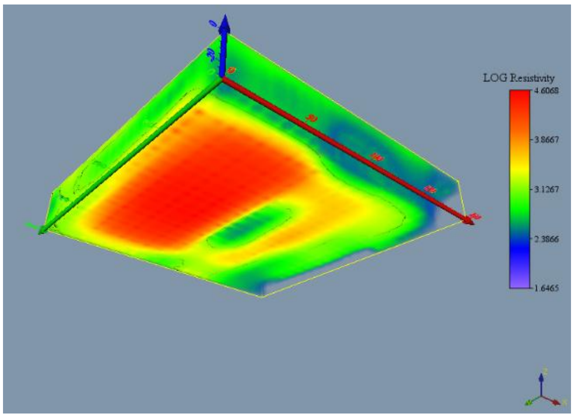


Figure 3: 3-D Inverted Resistivity Block Model of the Study area
Figure 4 & 5: Top view and Bottom view of the 3D-Block model

- **Discussion of Block models**

The Figure 3 is a 3D inverted resistivity block model of the investigated area and it shows the distribution of high resistivity signatures within the study area ranges from 2500 to 10000 Ωm (from the legend). The figures 4 and 5 display the top view and bottom view areas of the 3D block model. The high resistivity region displayed in the top view of the study area is sparsely distributed but latter formed together down to the subsurface and this can be confirmed from the depth slice in figure 6.

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- **3D Depth Slice**

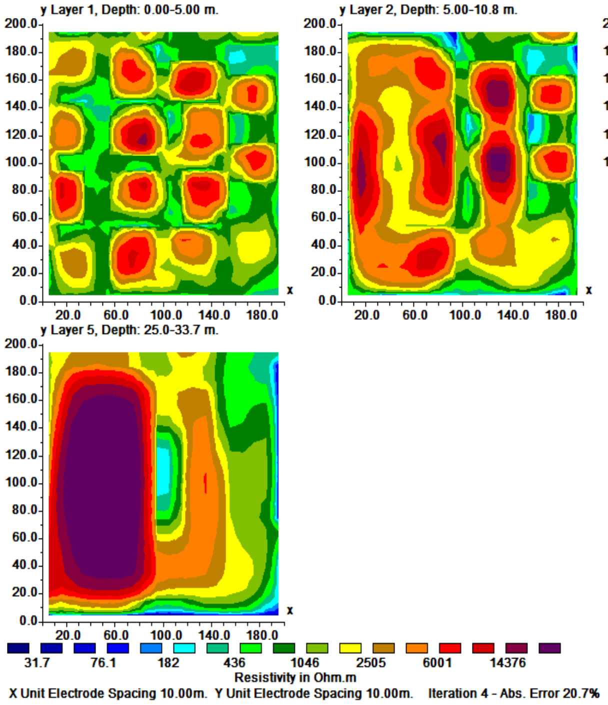

Figure 6: Five Layers Depth Slices obtained from 3D Inversion of Square grid

- **Discussion of Depth Slices**

The figure 6 shows the depth slice images which revealed how the 3D block is separated or sliced into five (5) geoelectric layers with total depth of 33.7 m. The depth ranges are as follows 0 to 5 m, 5 to 10.8m, 10.8 to 17.4 m, 17.4m to 25m and 25m to 33.7m and the thickness of these depth ranges are 5 m, 5.8 m, 6.6 m, 7.6 m, and 8.7 m respectively.

There are indications of high resistivity region from these depth slices, where the first two depth slice have the high resistivity range of between 2500 Ωm to 10000 Ωm, which are sparsely distributed. However, the layers three, four and five show distinctive geologic layers, considering the standard resistivity table (Table 1). These zones can be interpreted as non-metallic type of minerals which are suspected to be clayey sand, lateritic sand, sandstone and limestone, having high resistivity values ranging from 6001 Ωm to 14376 Ω m. These distinctive sandstone, granite and limestone can be located at the depth of 10.8 to 33.7 m. The geophysical signature of high resistivity of this type of mineralization is attested to in several studies on mineral exploration. Also, these suspected non- metallic mineral zones can be found in large quantities at the depth range between 25 m to 33.7 m.

Figure 7 displays 3-D apparent resistivity cross plot generated by Voxler geophysical software for all the resistivity values range between 150 Ωm to 10,000 Ωm of the subsurface minerals within the study area in Ugonoba community. The graph helps us to identify some areas within the study area that are sparsely distributed while some are well concentrated with the suspected minerals. The graph is plotted in log of resistivity values to base 10.

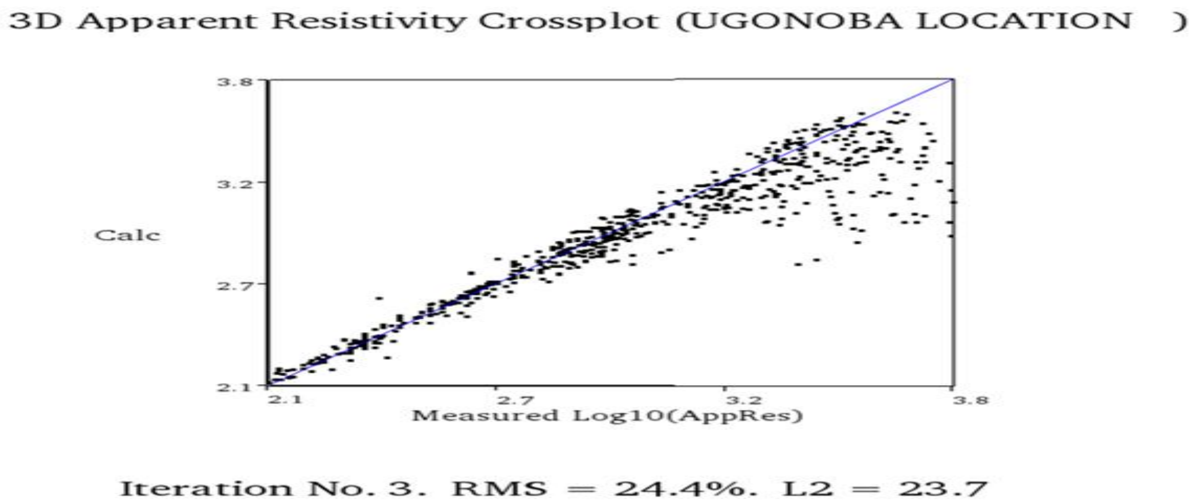

Figure 7: Apparent Resistivity Cross-Plot in Ugonoba Field

- **Volumetric Estimation of Dominant lithology**

From all the 3D block models generated, volume of the estimated quantity of dominant lithology (sandstone, granite and limestone) in the study area can be calculated as follows:

Given, **0.42 m^3 = 1 metric ton** (ton) and VOD = ±10% of Volume

Volume = L x B x H (m^3), the value per calibration in both length and breadth is 6.67m

For the Investigated area (Ugonoba): Volume = L x B x H (m^3)

The dominant lithology in this location is undifferentiated at the top soil level, therefore the volume can be calculated as follows

Volume = L x B x H (m^3)

200 x 200 x 13.2 = 528,000 m^3 = 1,257,142.9 metric ton

Volume of Dominant (VOD) = ± 10% of 1,257,142.9 metric ton

This metric ton of the sandstone, granite and limestone in the study area is in commercial quantity.

CONCLUSION

The electrodes used for this survey were arranged in square grids and all the 3D models of resistivity distribution displayed were automatically determined using a collated 3D resistivity imaging survey and inverted with RES3DINV code.

The suspected minerals delineated from the images of 3D geo-electrical resistivity models and depth slices fall within the resistivity range of 2500 Ωm and 14376 Ωm. From the standard resistivity table, it can be inferred that the lithology within the study area is suspected to be composed of the non-metallic type of minerals resources (i.e clayey sand, lateritic clayey sand, sandstone and limestone). In conclusion and from all the 3D images of block models, depth slice and cross plots, the study has identified the fact that the investigated area is composed of the non-metallic type of minerals resources and the volume of the dominant lithology in metric ton is

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1,257,142.9 and they are in commercial quantity.

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