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APPLICATION OF GROUND MAGNETICS AND GEOELECTRICAL METHODS IN DELINEATING SULPHIDE DEPOSIT IN OSHIRI AREA, SOUTHEASTERN NIGERIA.

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ABSTRACT

The Asu River Group Shale in the Oshiri area was evaluated using ground magnetic and geoelectrical methods within existing mine. Some exploration programs in the area have resulted to failure due to the fact that project managers have not fully understood the use and importance of geophysics in enhancing the search for mineral deposits. The aim of the study was to delineate the sulphide deposits using ground magnetics and geoelectrical methods. Result of the ground magnetic survey delineated some shallow tectonic structures like fractures and faults which are capable of hosting metallic sulphide deposits. The residual magnetic intensity of the study area indicates very low magnetic field intensities around the central and southern portions of the study area. These low values indicate absence of magnetite in the near surface materials as suggested by previous studies in the area, but could be referred to as zones with shallow tectonic structures which could be faults and/or fractures capable of housing sulphide deposits. The ore-bearing veins within the sedimentary rocks have susceptibilities of ≤ -1.8 nT. The low, negative residual susceptibility zone in the southeastern portion of the study area was targeted for the induced polarization IP and electrical resistivity tomography. Four traverses of induced polarization IP and resistivity surveys were carried out with all the profile lines were in the NE-SW direction. Isolated chargeable bodies with values greater than 340msec and a correspondingly low resistivity values (10Ωm-50Ωm), were encountered across some of these profiles. This zone may represent zones with sulphide mineralization. These identified chargeable bodies occur at approximate depth and width range of between 25-30m and 50-70m respectively. The 1D stratigraphic models reveal an average thickness estimate of 11.0m. Using scalar geometric approach, an estimate of 103,513.75tonnes was obtained, representing a relatively economically viable quantity and a worthy target for investors.

KEYWORDS*:* Ground Magnetics, Geoelectrical Methods, sulphide deposits, Oshiri Area, Southeastern Nigeria.

INTRODUCTION

Mineralization of sulphide deposits of lead – zinc in the Benue Trough accompanied magmatism (Nwajide, 2013). Sulphides of lead and zinc (galena and sphalerite), associated with copper (chalcopyrite) are well known (Nwajide, 2013). Apart from the major ore minerals in the lead - zinc deposits, to some extent Bornite (Cu_5 FeS_4), Azurite [$2CuCO_3Cu(OH)_2$], Smithsonite ($ZnCO_3$) and Cerussite ($PbCO_3$) are also found as products of the super-genetic enrichment (Obiora *et al.,* 2016). They occur as lodes and veins infilling open space along a relatively narrow northeast-southwest belt extending through the Benue Trough from Ishiagu in the south to Gombe in the northern segment of the Benue Trough (Akande *et al.,* 1992).

The study area is part of the Lower Benue Trough of southeastern Nigeria and is dominated by vast deposit of sulphide minerals. Lead-zinc mineralization in the Lower Benue Trough occurred widely in epigenetic fracture-controlled veins within the Albian – Turonian sediments (Fatoye *et al.,* 2014). (Cratchley and Jones, 1965) suggested that the mineralization occurs along a narrow belt of approximately 30 to 50 km wide and extends for about 560 to 600 km length of the Benue Trough of Nigeria (Fig.1). However, according to (Wright, 1985) (Akande *et al.,* 1992) the ore mineralization is believed to be of hydrothermal origin emplaced at a low temperature as opposed to earlier ideas relating them to igneous activity which is wide spread in the Benue Trough. These authors noted that many of the occurrences are far from igneous centres,

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and fluid inclusion studies indicate temperatures of formation less than 150oc, from isotope studies of the lead, it is suggested that the deposits were formed from circulating ground waters (brines) that leached metals from the basement and from the sediments, and deposited them in favourable sites after the sediments were folded and faulted. It is made up of primarily four lodes namely Ameka, Ishiagu, Enyigba and Ameri (Farrington, 1952). The lodes occurs as open vein fillings of a series of steeply dipping N-S near vertical fault, cutting regional folds of Abakaliki Anticlinorium (Farrington, 1952). The earliest report on sulphides mineralization in the Lower Benue Trough highlighting the mode of occurrence and mineralogy of the lead-zinc deposits in the Abakaliki area was made by Tattam in 1930. This was followed by extensive surveys to determine the extent of mineralization in the Abakaliki and Ishiagu areas, (McConnel, 1949; Farrington, 1952; Orajaka, 1965). Akande *et al.* (1988, 1989) used a combination of field evidence, ore microscopy, electron microprobe, fluid inclusion and stable isotope studies on the lead-zinc deposits of the Middle and Lower Benue Trough, and suggested a basinal-brine expulsion model for the Benue ore fluids. The distribution of the sulphide deposits in the Benue Trough of Nigeria are restricted to the Albian – Turonian sediments but more widely distributed spatially (Fatoye *et al*., 2014). They occur along the entire stretch of the basin, but as secluded and widely separated bodies (Akande *et al*., 1989). (Chukwu *et al*. 2008; and Okonkwo *et al*. 2014) studied the occurrences of his ore body using single geophysical approaches, which are not reliable. (Arinze *et al*., 2019) integrated electrical methods with well logs, without any fracture delineating geophysical approach such as the magnetic method. Since the ores in the study area occur in fractures within sediments, a geophysical approach that can indicate the presence of fractures could give insight to the possible presence of the ores at the sub-surface. The Ground magnetic method has been previously applied successfully in search of sulphide deposits in fractured rocks in other parts of the Abakaliki area such as Nkaleke and Nkpuma-Ekwoku area (Obasi *et al.,* 2020; Adejuwon *et al*. 2021). Studies by (Fritz and Sheehan, 1984) and (Nabighian et al. 2005) has reviewed that magnetic method has evolved from its sole use for mapping basement structure to include a wide range of new applications, such as intra-sedimentary faults delineation, defining subtle lithological contacts, mapping salt domes in weakly sediments, and better defining targets through 3D inversion. Obasi *et al.,* 2020 has pointed out that the ground magnetic method was very efficient in detecting fracture in sedimentary terrain, hence, the reason for its application in this work. Geoelectrical methods in the form of resistivity and induced polarization (IP) methods have been previously applied successfully in the confirmation of sulphide deposits occurrence and fracture delineations in the Lower Benue Trough (Obasi *et al.,* 2020; Arinze *et al*., 2019; Adejuwon *et al*., 2021). Their application is based on the high conductivity and chargeability characters usually associated with the lead-zinc ores.

Most exploration programs in the study area (Oshiri) have resulted to failure due to the fact that exploration project managers have not fully understood the use and importance of geophysics in enhancing the search for mineral deposits. Developing an exploration strategy, designing model and selection of optimum exploration methods have been given little attention over the years. Also many authors have depended on one geophysical tool in their quest to define potential targets for ore mineralization in the study area, this has yielded less detailed result of the subsurface structure and mineralization. However an integrated geophysical methods has become an enhancing tool in ore mineral exploration and structural mapping and has proven to be a positive aid to some successful mines. Therefore it calls for such studies to be undertaken in the study area as it is highly imperative to select the optimum exploration tools in the pursuit for economic mineral deposits of interest. It is in this regard that ground magnetic and geoelectrical methods are used to delineate sulphide deposit in the area.

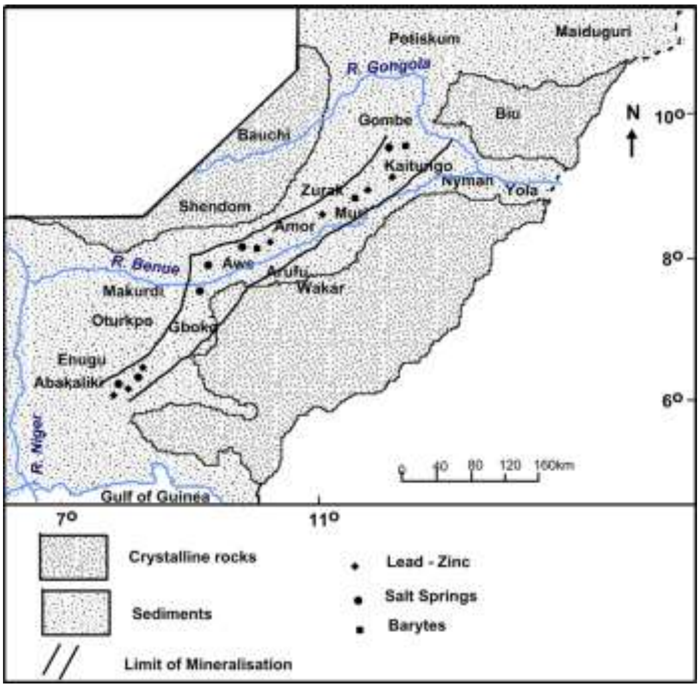


Fig.1: Map of the Benue Trough showing locations of ore mineralization (Cratheley and Jones, 1965)

STUDY LOCATION, DESCRIPTION AND GEOLOGY

Oshiri is located in Onicha Local Governent Area of Ebonyi State. Geographically, it is sited between latitudes $6^o07'25''$N and $6^o08'00''$N and longitudes $7^o56'30''$E and $7^o57'05''$E (Fig. 2). It is accessible through the Abakaliki-Onueke road, and a diversion at Onueka through the Ezzama-Oshiri road. The relief of the area is generally undulating and the major relief structures are hills formed by the pyroclastic bodies associated with shale (Obasi *et al.,* 2020). A digital elevation map extracted from the ground magnetic datasets using Geosoft Oasis Montaj software in the study area, (Fig. 3) also shows the elevation of the study area to be undulating and range from 32 m to 60 m above mean sea level. The high-lands trends NW-SE and occupies about two-thirds of the entire mapped area. The highest peak is at 60 m above mean sea level (MSL). The drainage pattern in the study area is dendritic and it is structurally controlled. The streams in the study area have many dendritic distributaries joining the main rivers from runoff and stream channels. Some of the streams are seasonal and are confined to shale bed. Ebonyi State lies between the savannah belts and the rainforest (Diagi *et al.,* 2019). The southern and northern areas of the State is endowed with large quantity of palm trees and fruit trees. The most common vegetation in the State is tree shrubs. Vegetation in the State has a mixture of savannah and semi- tropical forest with agriculture being the main occupation of the people (Diagi, 2017).

Oshiri forms part of the Abakaliki Antichrionium, and generally underlain by the Abakaliki shales of the Asu River Group. The Abakaliki shale of lower Cretaceous age is well exposed in the area. The sedimentary rocks are predominantly black calcareous (calcite-cemented) shale with occasional intercalation of siltstone. The shale formation belongs to the Asu-River Group of the Albian Cretaceous sediments. The Asu River Group which consists of alternating sequence of shale, mudstone and siltstone with some occurrence of sandstone and limestone lenses in some places and attains an estimated thickness of 1500 meters (Agumanu, 1989, Farrington, 1952). The Cretaceous sequence of the Lower Benue Trough consists of shale, limestone, minor intrusions and pyroclastics and belongs to the Asu River group of Albian age. These are the earliest sediments that were deposited uncomfortably on subsiding basement topographical depression in the Benue basin (Burke *et al.,* 1970). Kogbe (1989) described the sediments as consisting of rather poorly-bedded sandy limestone lenses. Extensive weathering and ferruginization have generally converted the black shales to a bleached pale grey colour with mottles of red, yellow, pink and blue (Orajaka, 1965; Ukpong and Olade, 1979). The rocks are extensively fractured folded and faulted. The rocks of the area consist of variably coloured shale and mudstone that has been imbedded by lead – zinc vein mineralization, baked shale as well as ironstone along the veins. The vein mineralization is hosted within the dark shale (Nnabo *et al.,* 2011).

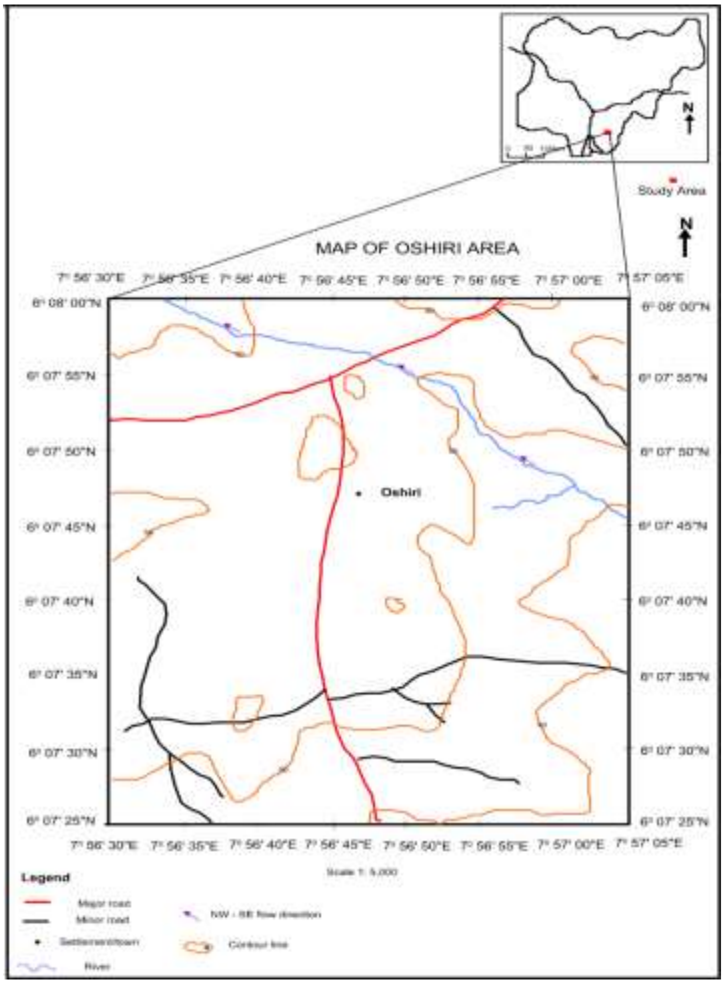


Fig. 2: Location map of the study area.

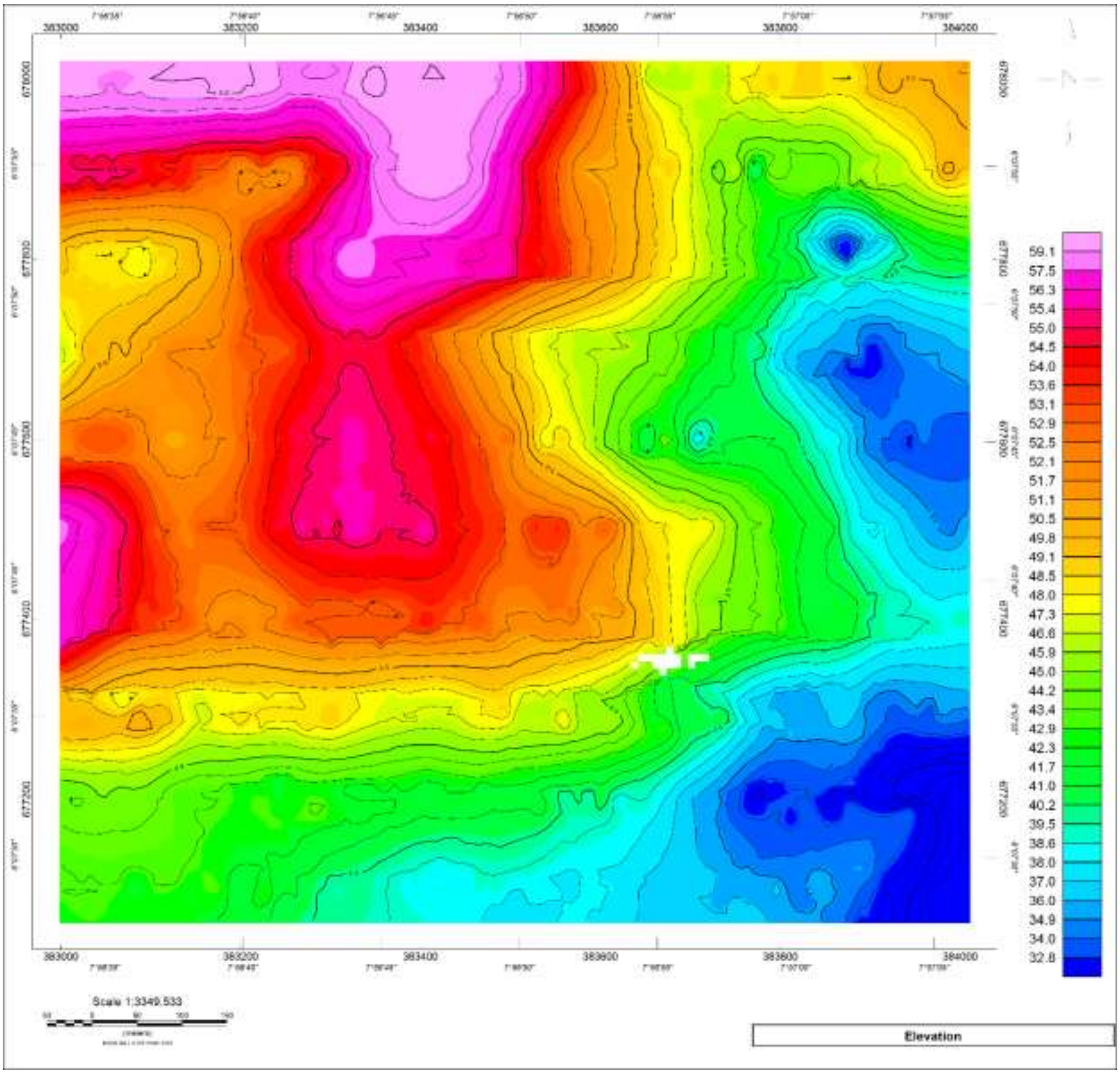


Fig.3: 2D digital elevation map DEM of study area

MINERALIZATION

The Benue Trough Pb-Zn mineralization occupies a 600km stretch of highly deformed Albian sediments from Abakaliki – Ishiagu (Ebonyi State) to Gwana (Gombe State) (Farrington 1952, Olade, 1976, Orazulike 1994,). The mineralization consists of a few occurrences of telethermal mississippi valley-type Pb – Zn deposits, localized as open – space fillings within steeply dipping fractures and veins associated with anticlinal structures (Abakaliki Anticlinorium) in shales. The sulphide deposits, principally galena and sphalerite, have been mined on and off for several decades (Kogbe, 1989), with associated minor chalcopyrite, bornite, pyrite and quartz. Within the Abakaliki pyroclastics, disseminated pyritic sulphide mineralization had been observed where the dominant mineral is pyrite with minor chalcopyrite and native copper. In the Ameka, Enyigba and Ameri areas there is clear evidence of post-mineralization deformation (Nwachukwu, 1972). Although the age of mineralization is not precisely known it is generally suggested that the lead/zinc lodes were developed at the end of Santonian folding (Wright, 1968; Nwachukwu, 1972). Benkhelil (1986) has given a detailed account of structural features associated with the Abakaliki mineralization. Mineralization here is related to NW-SE and N-S trending fractures which are transected in some places by N-S trending sinistral faults. The NE-SW trending fractures are barren (Obarezi and Nwosu, 2013; Mbah *et al*., 2015, Oha *et al.,* 2017). The result of the recent survey on application of the ground magnetic and electrical methods in the exploration of massive sulphide deposits in Nkaleke Area, therefore agrees with the view of NE-SW structures being barren (Obasi *et al* 2020)

The Abakaliki mineralization is considered the largest in the study area based on the size and density of lodes. The Enyigba lode, for example, has been traced for almost 2km and can be up to 30m wide with depths to anomalous bodies ranging from 80 – 400 m (Ema *et al.,* 2018). The ore assemblage consists mainly of galena, sphalerite, siderite, chalcopyrite, pyrite, bornite, and quartz. It occurs as open vein fillings of a series of steeply dipping N-S near vertical fault, cutting regional folds of Abakaliki Anticlinorium.

MATERIALS AND METHODS

Ground magnetic survey measurements were taken with AIDU AMC-7 High proton precision magnetometer instrument manufactured by Shanghai Aidu Energy Technology Company Ltd China. The magnetic instrument is made up of two major components, a magnetic recording device and a secondary machine known as the Automatic level probe which is moved along with the magnetic recording device from one point to another. It also has an in-built global positioning system (GPS) which records the coordinates of each measurement station. The fast measurement capacity and high accuracy of this instrument has favored it use for this work. Ten east-west trending profiles, with an inter-profile spacing of 100 m, were covered in this location. The base station was kept at about 1km away from the site at a magnetically quiet location. Readings were taken at every 10m spacing along the profile. At the end of the fieldwork, all acquired field data were transferred to the computer for data processing.

The 2D electrical imaging was carried out with a Geomative GD-10 Supreme Geoelectrical system manufactured by ST Geomative Co. Ltd., China. The equipment is made up of a meter system which records both the resistivity and chargeability of the subsurface at the same time. It uses an alternation source electric generator as its external power source. A connection of these components with its set of multiple electrodes provides information on the electrical characteristics of the subsurface in multiple layers otherwise known as 2D imaging. A total of four profile lines of about 250m each were covered with the equipment. By applying double dipole electrode configuration, the induced polarization IP and electrical resistivity tomography were carried out uniformly with inter-electrode spacing of 10 m along each profile, using multiple electrodes. The profiles were in the NE-SW directions, based on the orientation of the delineated magnetic lineaments across which they were taken.

The Vertical Electrical Sounding (VES) procedure, due to its superior vertical coverage was adapted using the Schlumberger configuration to determine the variation of apparent resistivity with depth. Four (4) Vertical Electrical Sounding were performed at four locations along the profiles within the study area with maximum current electrodes (AB/2) separation of 200m. These VES data were acquired by the use of Geomative GD-10 Terrameter. Apparent resistivity were measured and obtained directly from the Terrameter.

Specific Gravity Measurement

Three samples of sulphide ore deposit was collected from the mining pit in the study area for specific gravity analysis. The specific gravity of each of the sample was measured and their average determined. The samples were grinded to fine powder separately, the analytical weighing balance was switched on and allowed to warm for 30 minutes. The weight of the empty specific gravity bottle was taken at room temperature. The grinded samples was poured into the clean specific gravity S.G bottle and the weighing balance was zeroed and the weight of the sample in the S.G bottle is recorded.

The above steps was repeated for all the samples.

Weight of empty specific gravity bottle W1
Weight of specific gravity bottle + sample W2
Weight of sample W3
Volume of specific gravity bottle V
Density = Mass/Volume
Specific gravity S.G of a substance = Density of substance/Density of reference substance
Density of water = 0.998g/cm3

Sample A
W1 = 13.760g, W2 = 56.788g, W3 = 43.028g, V = 10cm3
Density = mass/volume = 43.028g/10cm3 = 4.3028g/cm3
Specific gravity of sample A = 4.3028g/cm3 / 0.998g/cm3 = 4.3114
Sample B
W1 = 13.760g, W2 = 56.897g, W3 = 43.137g, V = 10cm3
Density = mass/volume = 43.137g/10cm3 = 4.3137g/cm3
Specific gravity of sample B = 4.3137g/cm3 / 0.998g/cm3 = 4.3223
Sample C
W1 = 13.760g, W2 = 38.633g, W3 = 24.873g, V = 10cm3
Density = mass/volume = 24.873g/10cm3 = 2.4873g/cm3
Specific gravity of sample C = 2.4873g/cm3 / 0.998g/cm3 = 2.4923
Average specific gravity of the samples A + B + C = 4.3114 + 4.3223 + 2.4923 = 11.126/3 = 3.7087
Average Density of the samples A + B + C = 4.3028 + 4.3137 + 2.4873 = 11.1038/3 = 3.7013g/cm3 (3701.3kg/m3)

a.

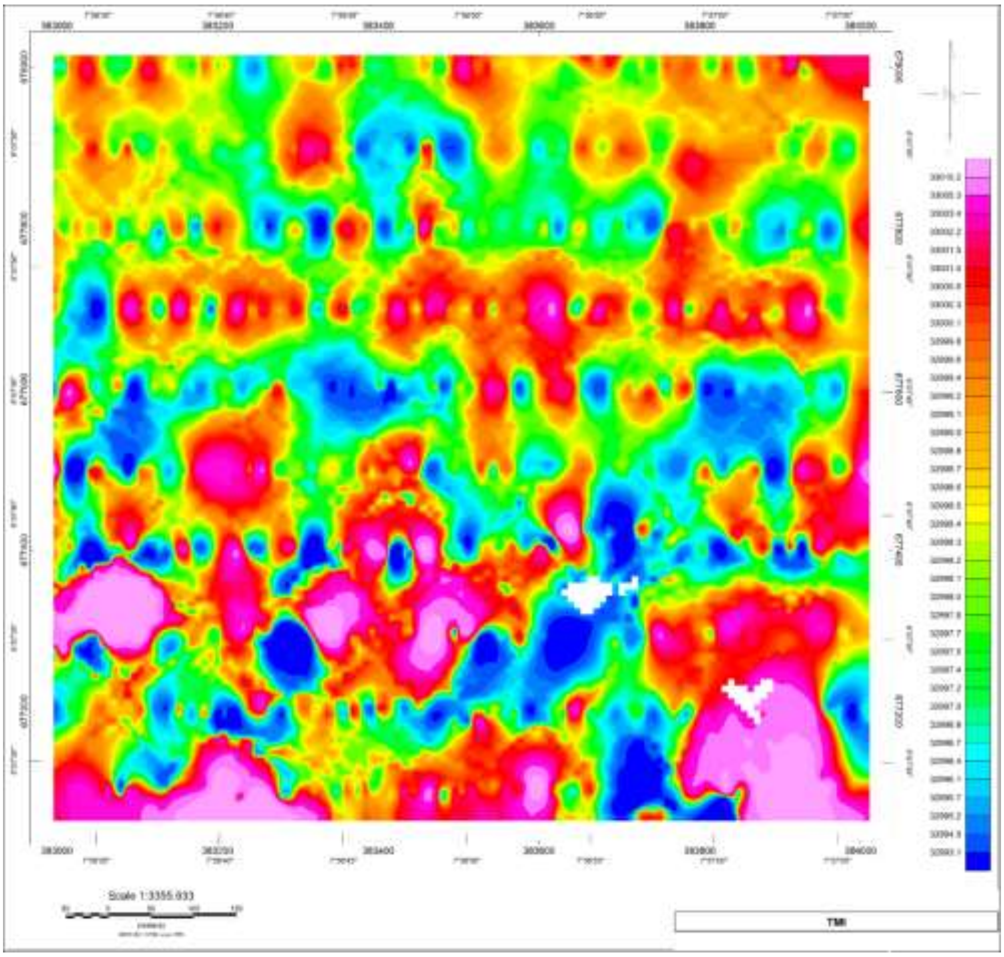


Fig.4a: Total magnetic field intensity map of the study area

b.

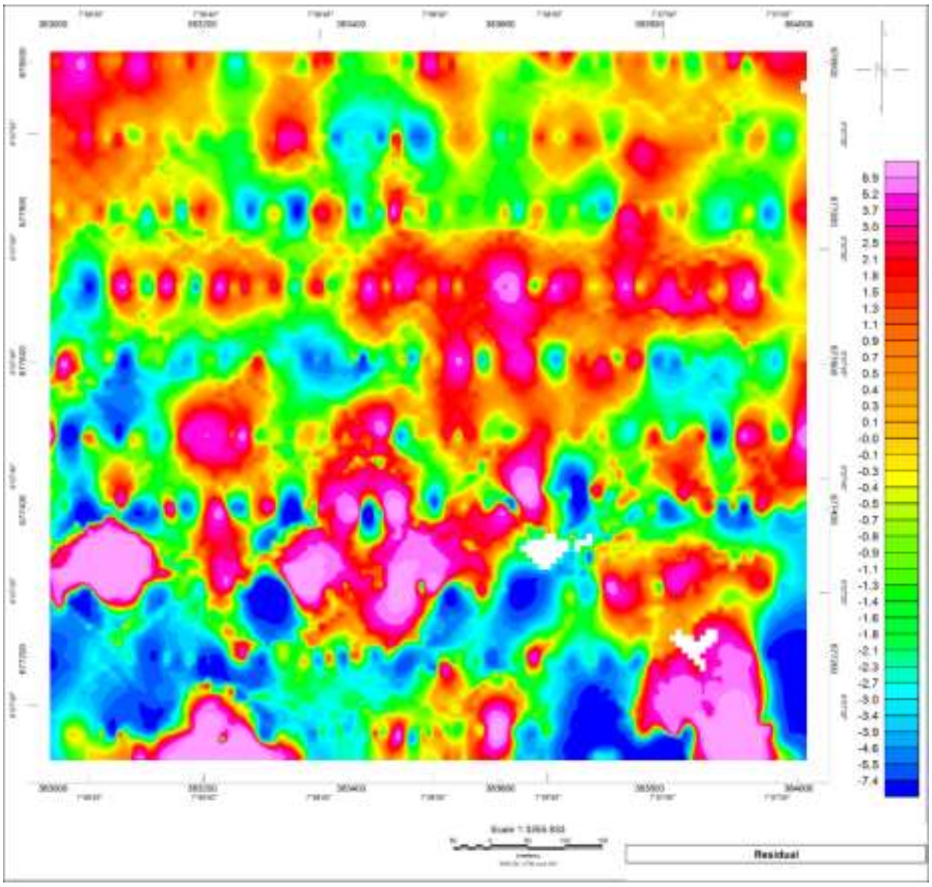


Fig. 4b: Residual magnetic intensity map of the study area

DATA CORRECTION AND PROCESSING

Diurnal Variation Correction

The base station method was applied to carry out diurnal correction through the correlation of field data recorded at the base station with that at the field. In order to correct for diurnal effect in the magnetic readings, a base station within the area of the survey and free from magnetic interference was selected. Repeated readings were taken approximately after every one hour of the magnetic measurement for the diurnal correction. After the data collection, the diurnal effect was calculated and the magnetic data were filtered using polynomial filtering. The 2nd order polynomial using the least-squares technique gives the line of best fit. The magnetic data were enhanced using the Oasis Montaj software.

Removal of Geomagnetic Field

After subtracting the diurnal effect from the original magnetic data observed, the geomagnetic field was calculated by using the mathematical model of earth magnetic field called International Geomagnetic Reference Field (IGRF) model 2000-2015 in potent software, a product of Geosoft Oasis Montaj software. This model is calculated based on the dates, elevation and geographical locations (latitudes and longitudes) of the observed magnetic data with the generated average geomagnetic field of 33,000 nT, inclination of −25.4˚ and declination of 0.5˚. The IGRF values were subtracted from the observed magnetic values for each station to determine the residual magnetic field due to anomalous contribution from local magnetic sources in the area.

To estimate the geometry of geologic structures and depths to causative bodies, mathematical functions were applied to the total intensity magnetic field data. These were source parameter imaging (SPI) (Eq. 1, Thurston and Smith 1997)

$$\text{Depth} = 1/k_{max} \quad (1)$$

Where: $k = \frac{1}{|A|^2}\left(\frac{\partial^2 M}{\partial x \partial z}\frac{\partial M}{\partial x} - \frac{\partial^2 M}{\partial x^2}\frac{\partial M}{\partial z}\right)$

Where M is the total magnetic field, x is the horizontal direction, z is the vertical direction, and |A| is the analytic-signal amplitude.

Anomalous areas identified in the result of the ground magnetic survey were further evaluated simultaneously using the geo-electrical methods. However the equipment was able to pick both induced polarization and resistivity data at the same time. The resistivity/induced polarization data retrieved from the system in 'dat' format were all processed with the aid of the RES2DINV inversion software which automatically determines a 2D model for the subsurface using a forward modelling subroutine and a nonlinear least-squares optimization technique. A plot of the acquired field data was made against the measurement points, and it aided the generation of the 2D models with a display of the subsurface inhomogeneity within the study area.

The results are presented as 2D tomograms and induced polarization inverted models having units of ohm meter (Ωm) and millisecond (msec) respectively. A visual inspection of the generated color spectrum bands of both the resistivity and chargeability tomographic models aided the delineation of the sulphides bearing veins within the subsurface.

The Vertical Electrical Sounding data collected was modeled in 1D using WinResist iterative software, and interpreted quantitatively to determine the nature of the underlying geological formations, presented with its possible geological meanings, resistivity values and layer thicknesses. The purpose of these resistivity transects is to provide the quantitative value of the thickness variations of the sulphide deposits beneath the subsurface.

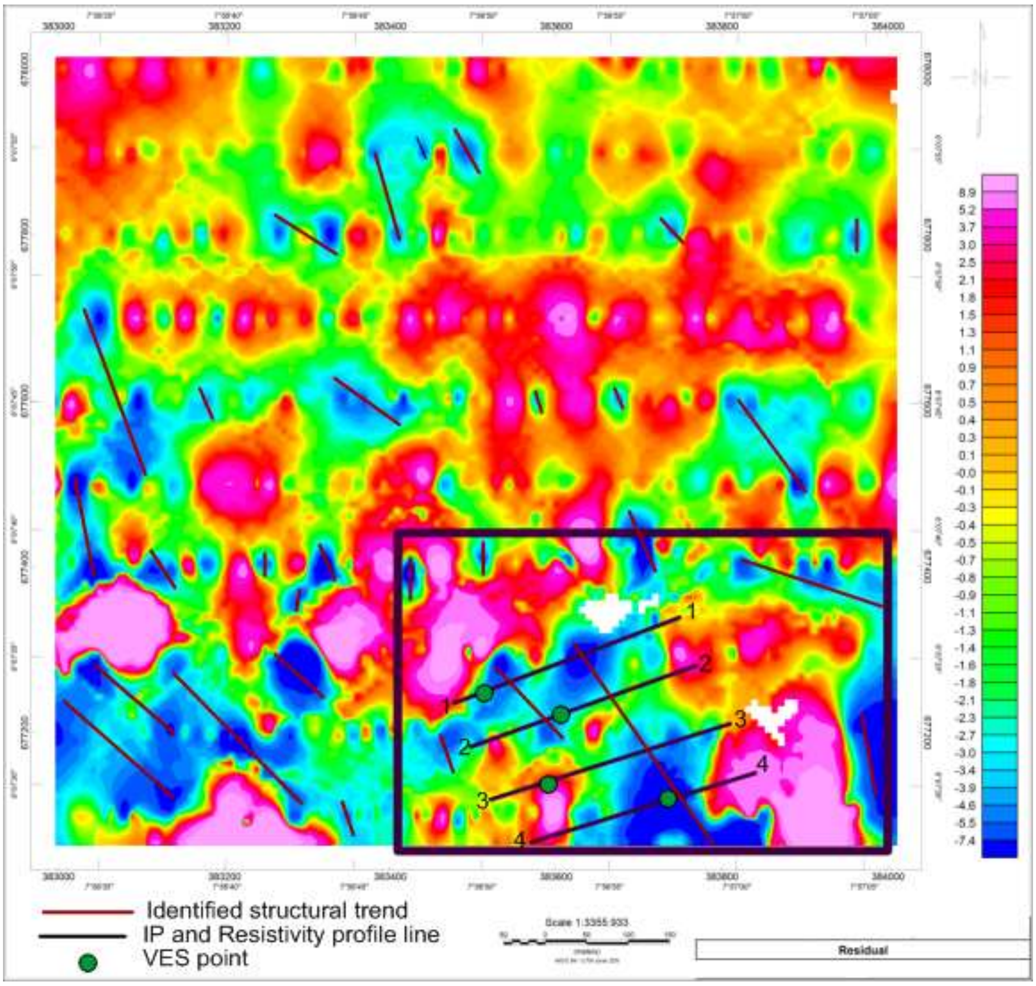


Fig. 5: Residual magnetic intensity map of the study area with identified structural trends, esistivity/induced polarization IP profile lines and VES points.

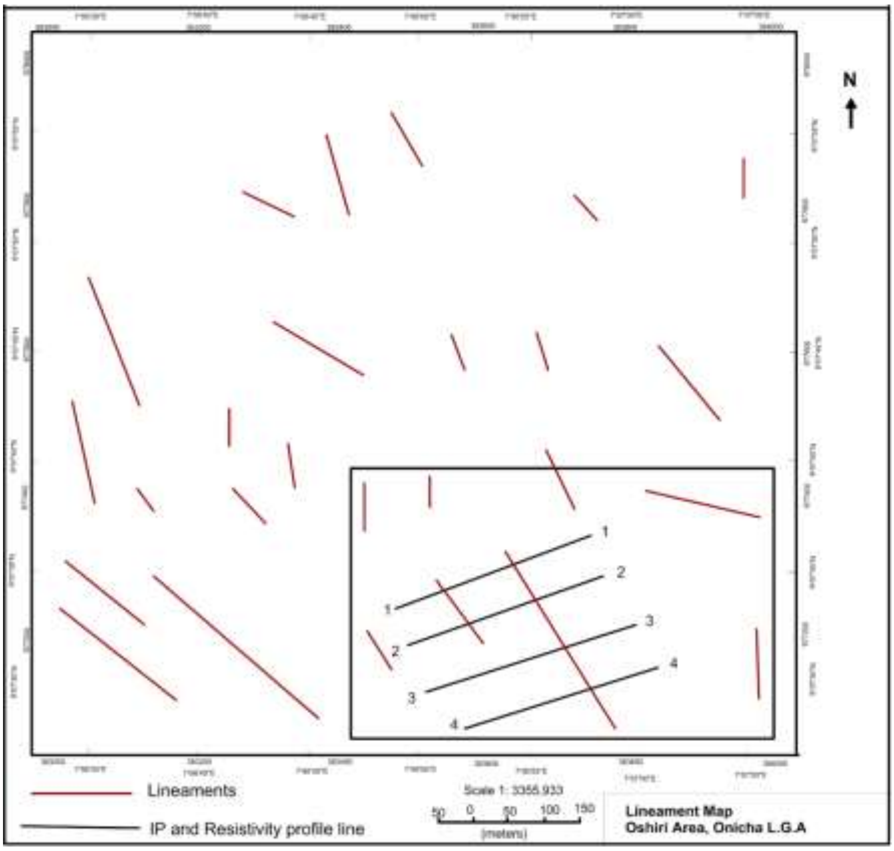


Fig.6: Lineament map of the study area indicating lines of resistivity/induced polarization IP Profile.

RESULTS AND DISCUSSION

The total magnetic intensity (TMI) map generated in this work is presented in Fig. 4a. High magnetizations were observed towards the southwest and northeastern portions of the study area, while the low values occur mainly in the central and southeastern portions. An evaluation of the lineament map of the study area, which was generated from the ground magnetic data using oasis montaj software (Fig. 6), indicates that some of the structures that host the sulphide deposits in the area trends NW-SE direction with some of the lodes in concordant to the strike of the structures hosting them.

The majority of the anomalies in Fig.5 especially the low susceptibility anomalies trend NW-SE, while the others trend N-S. Such structural trends have been earlier identified in Abakaliki area (Obarezi *et al* 2013, Obasi *et al* 2020).

The residual magnetic intensity map (Fig.3b) of the study area indicates very low magnetic field intensities around the central and southern portions of the study area. These low magnetization indicates area dominated by shale/argillites and have been interpreted as zones with shallow tectonic structures within the sedimentary pile which could be faults and/or fractures capable of housing Pb-Zn sulphide deposits. Their values are ≤ -1.8 nT. The intermediate magnetic field intensity values from the map (-1.6 to 2.5nT) have been interpreted as representing the unfractured, baked sedimentary rocks belonging to shales of Asu River Group which underlie the study area. The Asu River Group shales which host the ores contain some iron minerals in the form of pyrite, chalcopyrite, marcasite, and siderite (Umeji 2000, and Arinze *et al.* 2019) which gives them higher susceptibility when they exist independently without the occurrence of the sulphide lodes. However, geochemical study of the sulphide ores in the study area shows that they are of poor magnetic properties (Ogundipe and Obasi 2016). Hence, associating the occurrence of the ores with zones of low susceptibility was deemed appropriate. The highest magnetic susceptibility peaks in the study area are ≥ 3.0nT, this high magnetization could be caused by highly baked ferruginous materials

The low, negative residual susceptibility zone in the southeastern portion of the map was targeted for the induced polarization IP and electrical resistivity tomography. Four traverses of induced polarization IP and electrical resistivity surveys were carried out. The result of the 2D electrical resistivity and induced polarization IP tomograms for the study area profile is represented in Fig.7 (a-d). All the profile lines were in the NE-SW direction. Some lines were obstructed by residential houses, and as a result were slightly deviated from their original directions. A reasonable assumption, particularly for 2-D surveys over elongated geological bodies, is that the subsurface resistivity distribution varies both in the vertical, as well as in the horizontal direction along the survey line and assumed not change in the direction that is perpendicular to the survey line (Loke *et al.,* 1996).

Sulphide minerals are characterized by its higher chargeability than average chargeability of subsurface materials. Previous studies done in the area, reviewed that the mineralization is hosted mostly within the dark shale or shaley limestone. Isolated chargeable bodies with values greater than 340 msec and a correspondingly low resistivity values (10 Ωm-50 Ωm), were encountered across some of these profiles. This differing responses across these bodies may be representative of either two distinct chargeable bodies or the same body occurring within different lithology.

Some of these bodies correlated across the profiles with the already established NW-SE and N-S trend of sulphide mineralization within the area. From the inverted models, these identified chargeable bodies occur at approximate depth and width range of about 25-30m and 50-70m respectively (Fig 7a-7d).

A

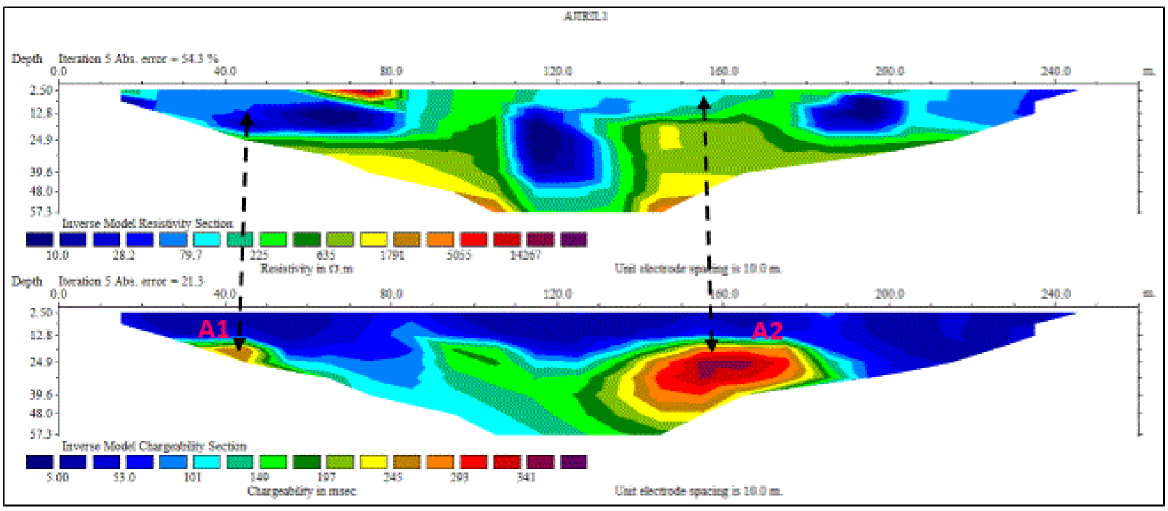
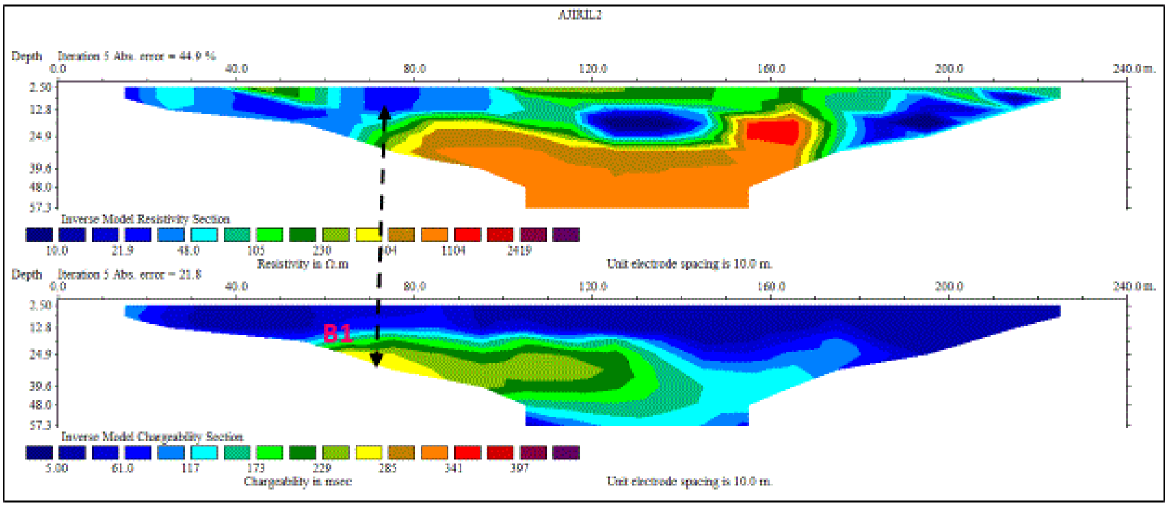


Fig. 7a: profile 1, resistivity are ≤ 50 Ωm while chargeability values are all ≥ 250msec (depth approximately 30m)Fig.

B



7b: profile 2, resistivity are ≤ 40 Ωm while chargeability values are all ≥ 230msec (depth approximately 25m)

C

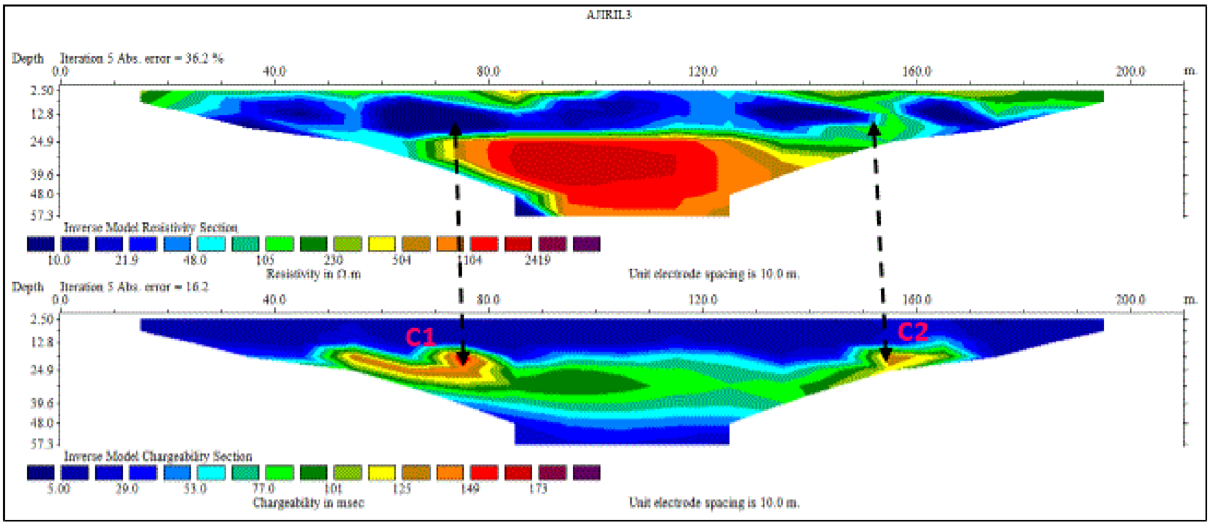


Fig. 7c: profile 3, resistivity are ≤ 25 Ωm while chargeability values are all ≥ 150msec (depth approximately 25m)

D

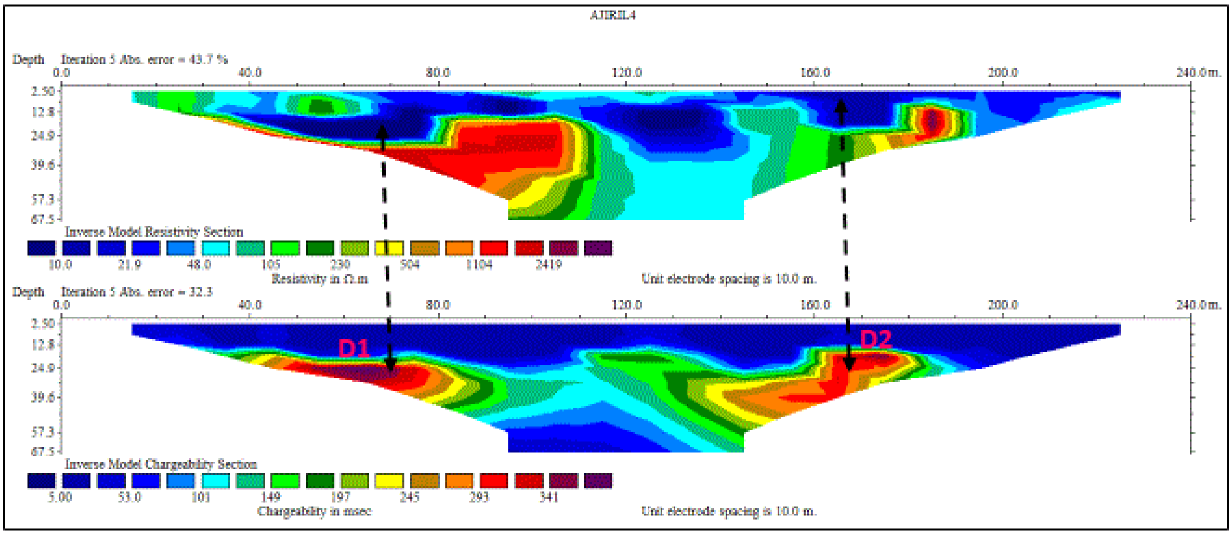


Fig. 7d: profile 4, resistivity are ≤ 25 Ωm while chargeability values are all ≥ 350msec (depth approximately 30m)

Geo-electric layer model from 1-D VES curves

The results of the four soundings obtained in the study area are displayed in 1-D model Fig. 7 (a–d). From a combination of the curves of the three-layer type (i.e. H, A, K, and Q), Patra and Nath (1999) reported that there can be only eight types of four-layer curves. These may be designated as HA, HK, AA, AK, KH, KQ, QH, and QQ. The VES models showed HK, QH and KQ curve types for four-layer sounding curves ‘‘ρ_1, ρ_2, ρ_3, ρ_4’’ gotten from the Vertical Electrical Sounding VES with some variations in resistivity signatures but close similarity in their layer thicknesses, a function of the variation in the resistivity of geo-electric layers along the profiles.

The variation in the resistivity trend displayed by all four electro-stratigraphic models could be an indication of a non-uniform sub-surface geology beneath the VES stations or as result of the undulating topography as shown by the digital elevation map extracted from the ground magnetic datasets. Four geo-electric layers were delineated across the station (Table 1). The stratigraphic series are suspected to be lateritic material, sand/shale heterolith, sulphide ores and weathered shale. The resistivity range of the lateritic materials inferred from the 1-D model is between 304.6 Ωm and 71.1 Ωm. VES 1 and 2 revealed a uniform overburden thickness of approximately 10.0 m, while VES 3 and 4 showed a significantly different thickness of 5.0 m. The thinness of the topsoil shows that the deposits are superficial and can be accessed easily using the open cast technique. Beneath the layer of overburden, at slightly shallower depth is a thicker zone of slightly lower resistivity values (175.4–57.9 Ωm) consisting predominantly of shales/sand heterolith. At much deeper intervals, the models show close similarity between signatures by indicating a third localized geo-electric strata of significantly contrasting resistivity compared to the previous layers. This low resistivity zone is an ideal signature which could be an indication of sulphide deposit occurrence. The non-uniform geometry of the ore bodies could be clearly demonstrated by the thickness variations between the deposits. The average thicknesses of the deposits inferred from the sounding curves is 11.0m.

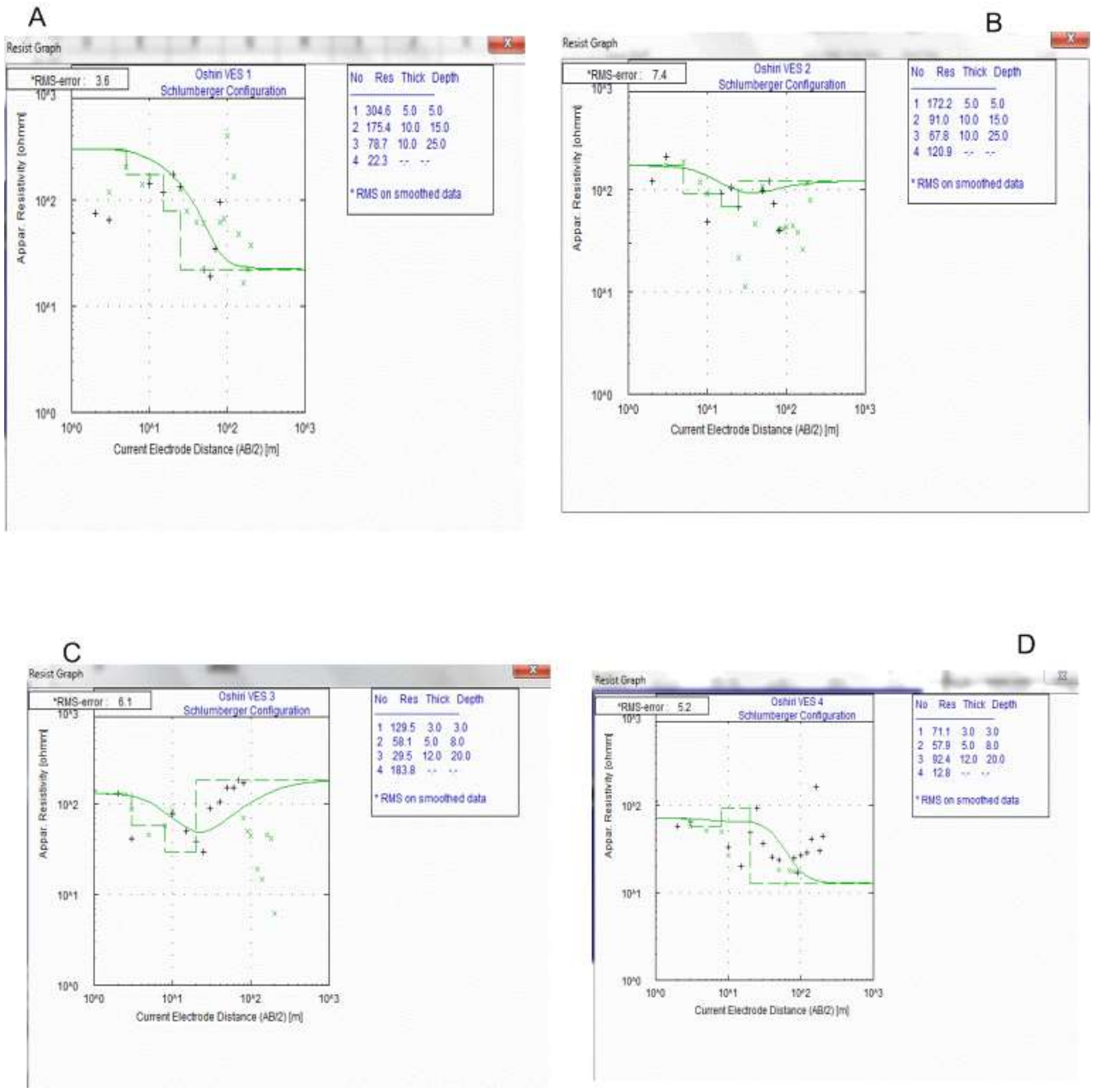


Fig. 7: Geo-electric parameters for (a) VES 1. (b) VES 2. (c) VES 3. (d) VES 4.

Table 1: Stratigraphic parameters from the VES models.

VES location	RMS error	Apparent resistivity(Ωm)				Layer thickness (m)				Depth (m)				Curve type
		1	2	3	4	1	2	3	4	1	2	3	4	
VES 1	3.6	304.6	175.4	78.7	22.3	5.0	10.0	10.0	-	5.0	15.0	25.0	-	KQP1>p2>p3>P4
VES 2	7.4	172.2	91.0	67.8	120.9	5.0	10.0	10.0	-	5.0	15.0	25.0	-	QHP1>p2>p3<P4
VES 3	6.1	129.5	58.1	29.5	183.8	3.0	5.0	12.0	-	3.0	8.0	20.0	-	QHP1>p2>p3<P4
VES 4	5.2	71.1	57.9	92.4	12.8	3.0	5.0	12.0	-	3.0	8.0	20.0	-	HKP1>p2<p3>P4

Volume estimation

The volume of the ore bodies as extracted in Surfer 12.0 environment using the Trapezoidal, Simpson and Simpson 3/8 rules show that profile A has a volume of 3032.257m3, 3032.663m3 and 3032.453m3. Profile B has a volume of 8958.069m3, 8958.089m3 and 8958.200m3. Profile C has a volume of 6321.198m3, 6320.841m3 and 6320.843m3. Profile D has a volume of 9799.667m3, 9799.619m3 and 9799.648m3, respectively (Arinze et al, 2019). Deposit from profile D has higher dimensions than A, B and C since volume is a function of both thickness and area coverage (Volume of deposit = Average thickness × Area). The volume computation reports computed are shown in Table 2. The accuracy of the volume computations by the three different methods is determined by the difference in the volume calculation of the individual methods. Since the three volume calculations for all the lodes are reasonably similar, the true volume is close to these values. The net volume is therefore reported as the average of the three values (Arinze et al, 2019).

Table 2: Estimated volume of sulphide deposits.

Sulphid deposits	Volume (m^3)			Av.Volume (m^3) of A, B, C and D	Thickness (m)	Area (m^2)
	Trapezoidal rule	Simpson's rule	Simpson's 3/8 rule			
Profile A	3032.257	3032.663	3032.453	3032.458	10.0	303.246
Profile B	8958.069	8958.089	8958.200	8958.119	10.0	895.812
Profile C	6321.198	6320.841	6320.843	6320.961	12.0	526.747
Profile D	9799.667	9799.619	9799.648	9799.645	12.0	816.637
				Average volume of deposits =7027.796m^3	Av.thickness of deposits =11.0m	Total area of deposits = 2542.442m^2

Reserve estimation

The reserve of the deposits was numerically estimated by applying a scalar-geometric approach involving the arithmetical relationship between the reserve, thickness, area and density of the sulphide deposits as shown below:

Reserve estimation of the sulphide deposits = thickness of the deposits (m) × area of the deposits (m2) × density of the deposits (kg m-3). Divide by 1000 to convert to tonnes.

Reserve estimation of the sulphide deposits = 11m × 2542.442m2 × 3701.3kg/m3

= 103513746.3kg/1000 = 103,513.75 tonnes.

The total estimated reserve of the sulphide deposits is 103,513.75 tonnes which is relatively of viable economic quantity and a worthy target for investors.

CONCLUSION

The integrated ground magnetic, induced polarization and electrical resistivity methods including specific gravity measurement were used to investigate Pb-Zn potential in Oshiri. Ground magnetic method contributed in mapping litho-structural trends of the area. The induced polarization and resistivity method reveal the presence of isolated chargeable and conductive (low resistivity) bodies occurring close to the Earth's surface, trending NW – SE. From the fore going, it is concluded that these isolated chargeable bodies may be due to the presence of sulphide mineralization, and their near surface occurrence makes the area favorable for exploitation. The reserve is of economic value as the total estimated reserve of the lodes is about 103,513.75 tonnes which is a relatively viable economic quantity and a worthy target for either government or private investors. The shallow depth of occurrence also supports open cast mining which is relatively cost effective. Despite showing fairly good potential in terms of quantity, it is recommended that these deposits be qualitatively accessed to ascertain the exact concentration of lead-zinc in the ores before a final investment decision is made. Additionally, core drilling should be carried out above in order to provide a more realistic estimate of the deposits.

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