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PROSPECTING FOR METALLIC MINERAL DEPOSITS USING INTEGRATED ELECTROMAGNETIC AND ELECTRICAL RESISTIVITY TOMOGRAPHY IN AGBEDE, EDO STATE NIGERIA

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ABSTRACT

This study involves the application of Very Low Frequency-Electromagnetic (VLF-EM) and Electrical Resistivity Tomography (ERT) in locating and mapping of metallic mineral deposit potential in Agbede and its environs, Edo State Nigeria. The field geometry was made up of four traverses measuring 200 m, 210 m, 320 m and 310 m carried out in four localities (Kilometres 50, 54, 86 and 92 respectively along Okene-Benin Road) at a mean separation of 10 m with frequency band of 18.8 KHz and signal strength of 13 db. Two traverses in Kilometres 86 and 92 were utilized by ERT investigation due to VLF- EM results. The results of the qualitative interpretation of VLF-EM identified areas suspected to be of Metallic Ore importance. These form the basis for Electrical Resistivity Tomography (ERT) investigation. Results of the resistivity model and surfer plot geologic sections show that metallic mineral signatures of ERT imaging in Kilometre 86 are not well defined probably due to low data density records. However, the ERT images obtained from Kilometre 92 and line crosses of the electromagnetic anomalies, c_1, c_2, c_3 and c_4 revealed c_4 as metallic mineral. The ERT interpretations indicate that the c_4 anomalies in the VLF-EM curve are responses from closely separated conductors. These inferred metallic mineral deposits occur at 4.8 m and 7.5 m below the surface extending to depths of 8.5 m and 9.3 m respectively. The geologic section shows that they are laterally located at 123m, 128 m, 133 m and 137 m respectively along the transverse.

Key words: VLF – EM, Resistivity tomography, Metallic mineral deposits, Geologic interface, Agbede Edo State Nigeria.

INTRODUCTION

Metallic ores are ores of ferrous metals (iron, manganese, molybdenum and tungsten), the base metals (copper, lead, zinc and tin), the precious metals (gold, silver, and the platinum group metals) and the radioactive minerals (uranium, thorium and radium). Ore has traditionally been defined as natural material that contains a mineral substance of interest and that can be mined at a profit. Metallic minerals include tin, lead, zinc, gold, silver, copper and iron ores. Minerals can either be extracted from the surface of the earth or from deep in the earth. The process of extracting minerals from open mines is termed as quarrying while the process of extracting minerals from shaft mines is termed as mining. For example, in case of limestone and marble stones quarrying processes take place, whereas mining is done in case of iron, coal, gold etc Jhingan and Sharma (2008).

Mineral deposits are usually localized with unequal distribution in both space and time throughout the world Adekeye, (1999). A mineral deposit may therefore be considered a depleting asset whose production is restricted to the area in which it occurs (U.S. Geological Survey). High global demand for mineral commodities has led to increasing application of geophysical technologies to a wide variety of mineral deposits. Hence, the purpose of this study is locate and maps the metallic mineral deposit in Agbede and its environs with a view to produced geologically-based models using two different surface geophysical methods: Very Low Frequency- Electromagnetic (VLF-EM) and 2D electrical resistivity tomography (ERT) via Dipole-dipole arrangement. Geophysical measurements are taken on or near the Earth's surface using ABEM WADI and other relevant geophysical instruments. The obtained field data were analysed. Consequently, the analyses reveal the physical properties of the earth's interior vertically and laterally and delineate the subsurface geology with high precision Fadele, *et al*. (2013). Electromagnetic survey utilizes the subsurface response to the propagation of alternating current and magnetic force. The VLF is utilised because of its unique response, distinct data presentation; processing accuracy and acceptance in the exploration industries The VLF technique is inexpensive, very fast, and well suited to hard-rock Prospecting. Hence, it is commonly used for exploration of mineral deposits or delineating possible targets. EM methods have been instrumental in the location of many significant economic ore bodies Frischjnecht, *et a.*, (1991). The VLF-EM method is one of the most applied electromagnetic methods (Wright, 1988; McNeill and Labson, 1991). The VLF measures the field strength and phase displacement around conductive geologic structures such as faults and fractures. The 2-D electrical resistivity method has wide applications in environmental, engineering and shallow subsurface investigations van Schoor (2002). It is based on assumption that various entities like minerals, solid bedrock, sediments, air and water filled structures have detectable electrical resistivity contrast relative to the host medium Pánek *et al.* (2010). Typical resistivity ranges of geological materials Palacky (1987) are shown in Fig. 1.

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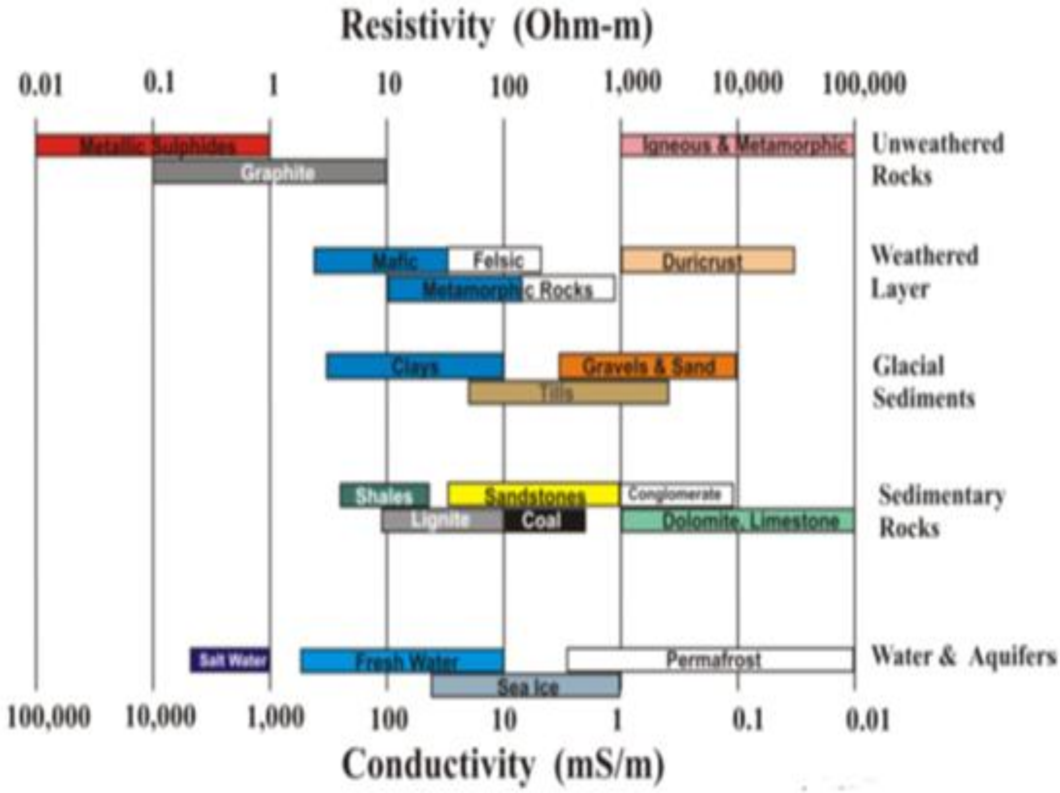

Figure 1: Typical Resistivity Ranges of Geological Materials Palacky (1987).

Site Description and Geology

Agbede is a town located in Etsako West Local Government Area of Edo State, Nigeria. It lies within latitude 6^{o} 24' N to 7^{o} 6' N and longitude 6^{o} 15' to 6^{o} 30' E (Figs. 2a and 2b). Generally, Agbede has region of high altitude which measured heights of about 152 m (500 ft) above sea level. Its terrain is rough and undulating and geologically referred to as the Benin Flank of the Anambra Basin Reyment (1965). Only a small portion of Agbede has flat surfaces. It has scarce observable igneous rock extrusions as compared to the other parts of Edo North. Rivers and Streams exist at both ends of Agbede and the central. The geologic setting of the area is typical of the Ameki Formation formed during the Eocene. The sediments are grayish-green, sandy clay with calcareous concretions and whitish clayey sandstones. Agbede is underlain by Imo Shale, with evidence of outcrops towards the Northern part of Agbede.

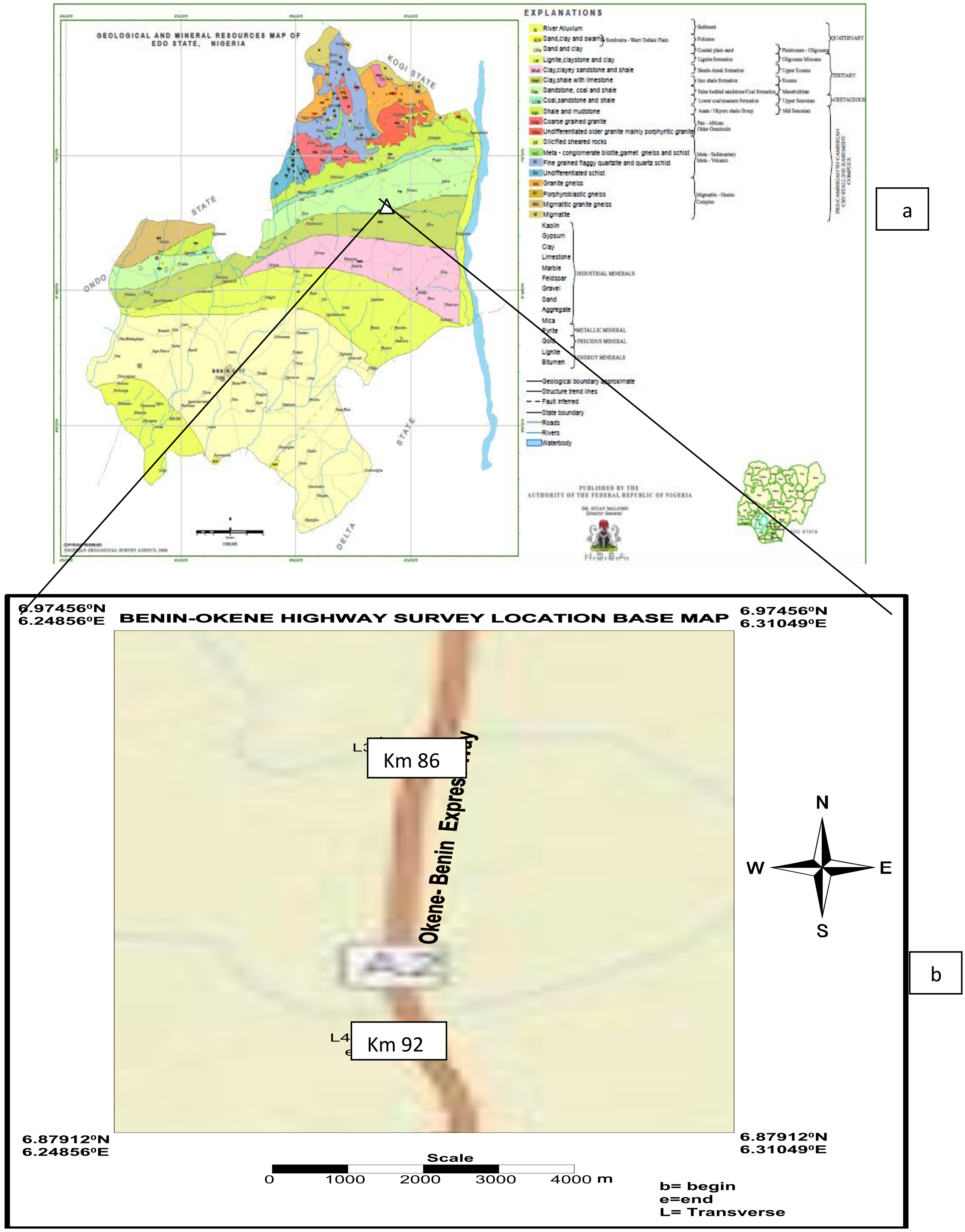

Figure 2: (a) Geological and mineral resources map of Edo State, NGSA (2006).
(b) Base map of study area Along Okene-Benin Express Road.

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The Imo Shale consists of clayey Shale, fine textured, dark grey and bluish-grey shale with occasional mixture of ironstone and sandstone bands (Fig. 3). Carbonized plant remains may be locally present. The Formation becomes sandy towards the top where it may consist of alternation of bands of sandstones and shale Omokhodion *et al.* (2014). The vegetation in Agbede is of rainforest type, characterized by short dry season and a long wet season. The wet season stretches for a period of seven months usually from April to October with heavy rainfall between July (462 mm) and August (359 mm). The dry season is for a period of five months with rainfall which ranges from 99.8 to 22.3 mm. The temperatures during the dry period are high and the mean annual temperature ranges from 25 to 33^{o}C.

Figure. 3: Outcrop of Imo Shale Formation in Agbede.

MATERIALS AND METHODS

The VLF-EM method is an inductive exploration technique that is primarily used in mapping steeply dipping structures such as faults, fracture zones and areas of mineralization. In the reconnaissance mode, VLF profiles can be run quickly and inexpensively to identify anomalous areas which may require further Investigation; either with more detailed geophysical measurements and/or drilling and sampling. The method is based on measurement of the secondary magnetic field induced in local conductors by primary electromagnetic fields generated by powerful military radio transmitter in the very low frequency range (15-30 kHz). According to the theory of electromagnetic conductivity, conductive rocks at shallow subsurface are the secondary sources of electromagnetic field. In the secondary magnetic field, the primary electrical and magnetic fields are nearly vertical and horizontal respectively Santos *et al.* ((2006). Conductive body at subsurface will allow high current density penetration, while poorly conductive rocks will allow low current density penetration. Generally speaking, unconsolidated rocks are moderate conductors; and crystalline rocks are poor conductors because of their lack of porosity and absence of dissolved ions and water. Qualitative interpretation of VLF data is based on the methods of Fraiser (1966); Karous and Hjelt (1983). The Fraiser operators' uses dynamic frequency bandpass to attenuated noisy data and transform zero crossing to peaks, thereby yielding semi-qualitative contourable data. Karous-Hjelt operators transform the magnetic field associated with the current flow in conductive bodies to current density at the depth of the conductive body (rock) causing the magnetic field to yield a 2D conductivity model McNeill and Labson (1991); Beamish (1994, 2000). The instrument employed for this survey was the ABEM WADI, which measures the in-phase (Real) and quadrature (Imaginary) components of the induced vertical magnetic field as a percentage of the horizontal primary field. The VLF measurements were made along four traverses measuring 200 m, 210 m, 320 m and 310 m carried out in four localities (Kilometres 50, 54, 86 and 92 respectively along Okene-Benin Road) at a mean separation of 10 m with frequency band of 18.8 KHz and signal strength of 13 db. The method is based on measurement of the secondary magnetic field induced in local conductors by primary electromagnetic fields generated by powerful military radio ABEM WADI transmitter in the very low frequency range. The ABEM WADI system is portable equipment mounted on a belt worn by the user as he transverses profiles at given intervals with the receiver and antenna held at right angles to each other while conductivity readings are taken (Plate 1). The WADI is sensitive to transmitters around the world and it automatically picks the most suitable. For induction to occur, the structure was aligned roughly towards the transmitter Oluwafemi and Oladunjoye (2013). The VLF-EM data were interpreted using the Karous-Hjelt filter and applying 2-D inversion software to generate current density sections.

Electrical Resistivity Tomography (ERT) is used to generate models of subsurface electrical property distributions, from which subsurface geological structure and hydrogeological variations can be identified Chambers *et al*. (2002). Using this method, features with electrical properties differing from those of the surrounding material may be located and characterised in terms of electrical resistivity, geometry and depth of burial. The Omega resistivity meter was used in acquiring the electrical resistivity data using the dipole dipole configuration. A 2-D ERT using dipole-dipole configuration with inter station separation of 10 m, and an expansion factor that varied from 1 to 5 was carried out in two traverses Kilometres 86 and 92 (Fig. 2b)with a total spread of 200 m and 180 m (Figs. 5a and

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5b) respectively based on the results obtained from the VLF surveys. The apparent resistivity distribution of the subsurface structure was then inverted using the commercial RES2DINV® software to estimate the true resistivity structure. This produces a subsurface map of the "apparent" resistivity distribution (pseudo-section). The algorithm uses a 2D smoothness constrained, least-squares inversion with a Jacobian matrix calculation for the first iteration and then employs a quasi-Newtonian technique to reduce numerical calculations Loke and Barker (1996)

Plate 1: The ABEM WADI Instrument and Accessories

RESULTS

The results for VLF-EM data are presented both in profiles and pseudo-sections which was basically qualitative or semi quantitative. The plots of raw real measured on the field and the filtered real are presented as profiles and their corresponding Karous-Hiljet (K-H) in pseudo-sections are shown in Figs. 4a and 4b. Also, 2-D inversion modelling of the dipole-dipole data were analysed using RES2DINV® Software. This produces a subsurface map of the "apparent" resistivity distribution (pseudo-section and geologic section) Figs. 5a and 5b.

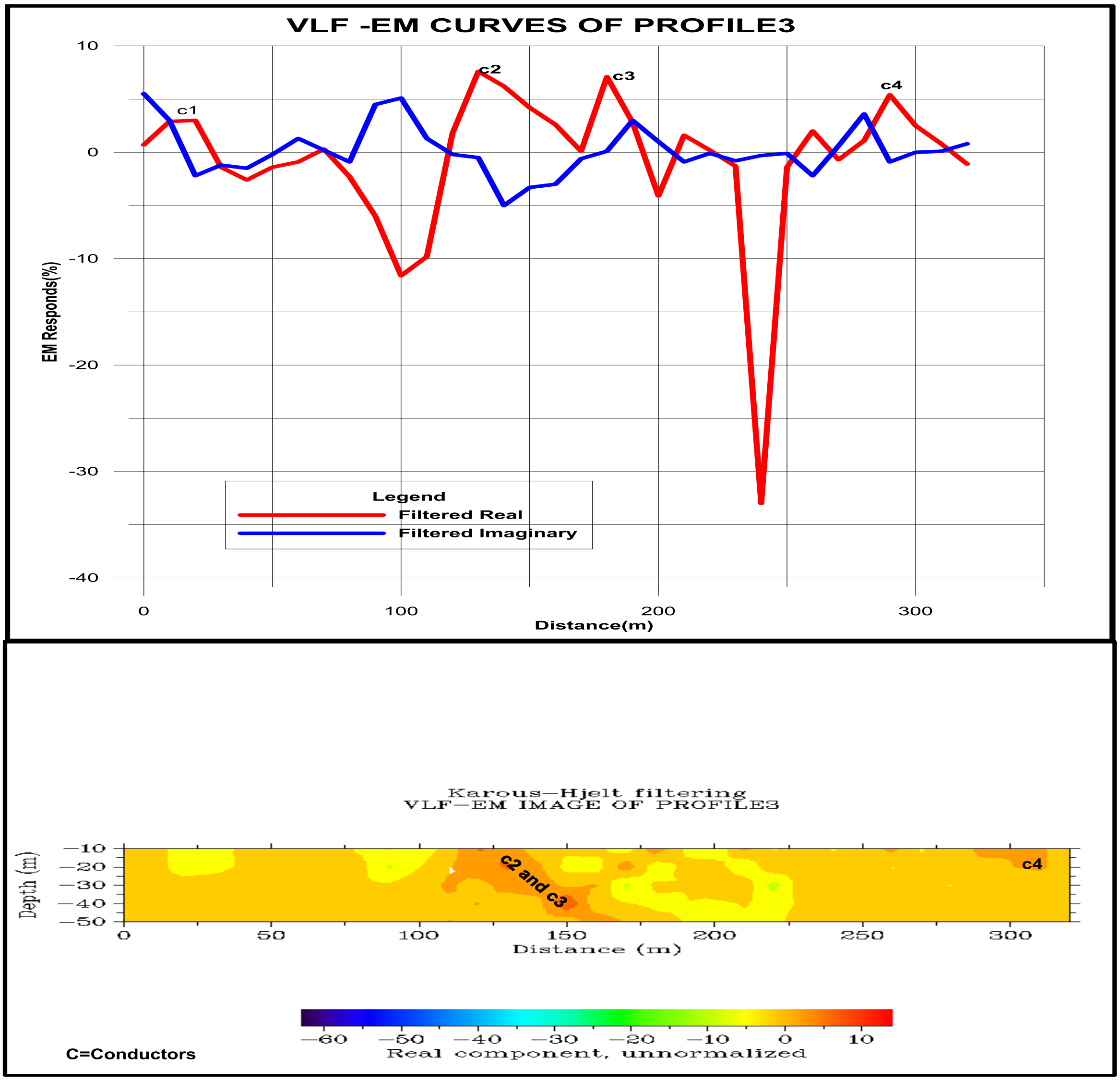

Fig. 4a: VLF-EM Curves and VLF-EM 2D Image in traverse 3

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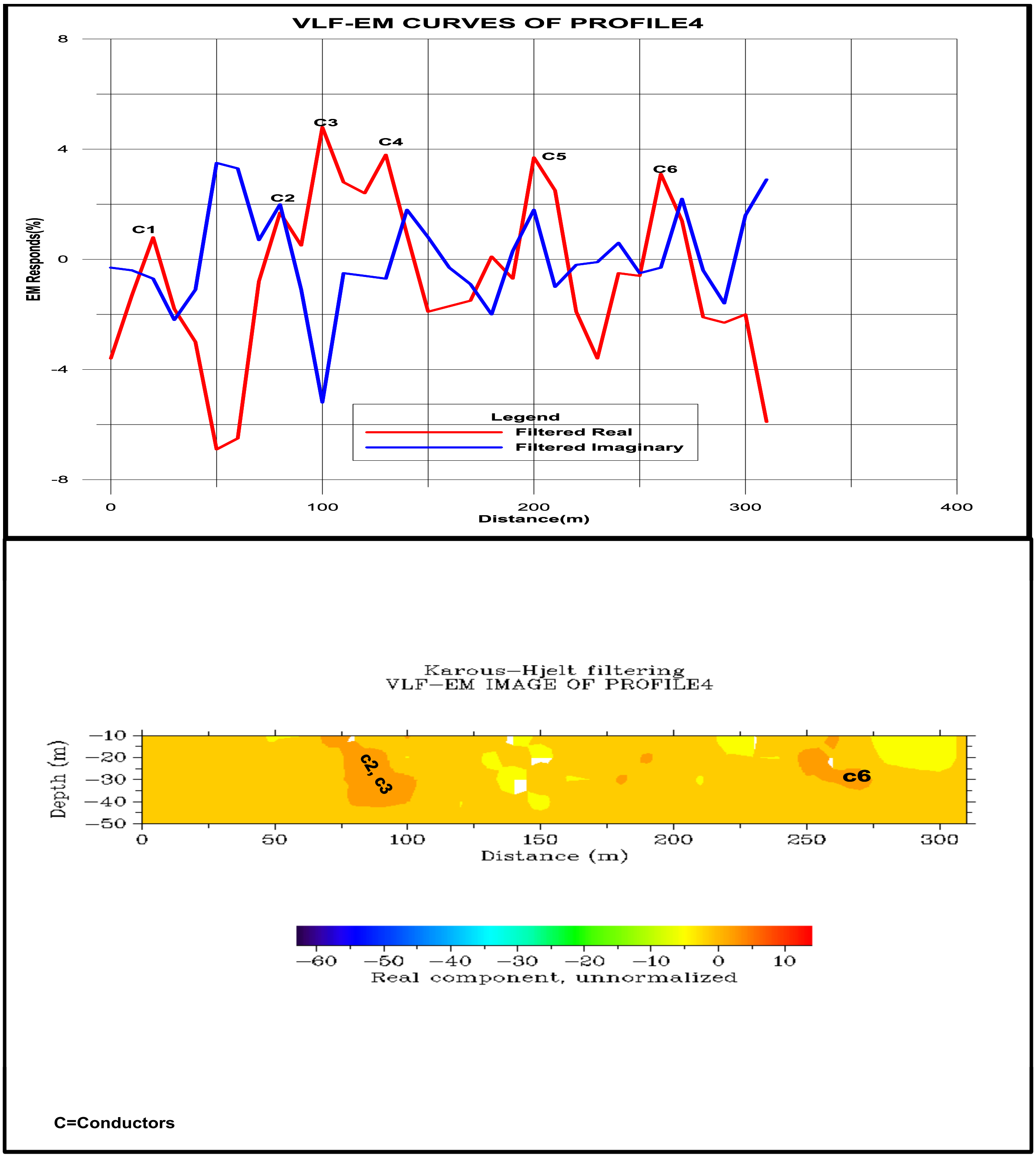

Fig. 4b: VLF-EM Curves and VLF-EM 2D Image in traverse 4

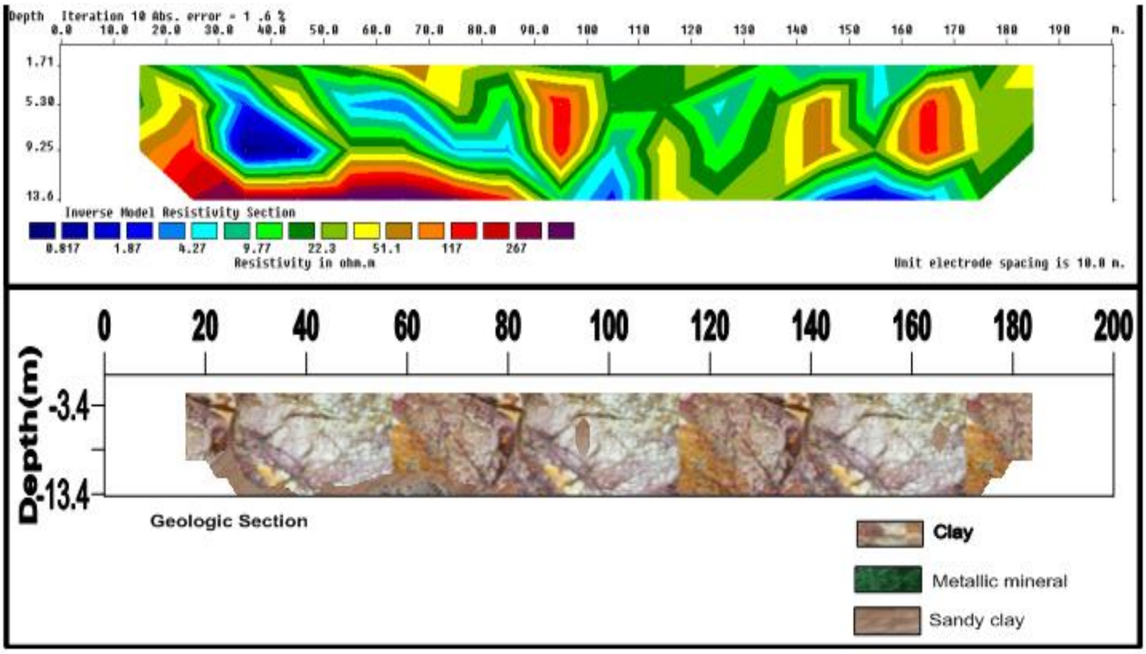

Fig. 5a: Inversion model resistivity and geologic section along traverse 3

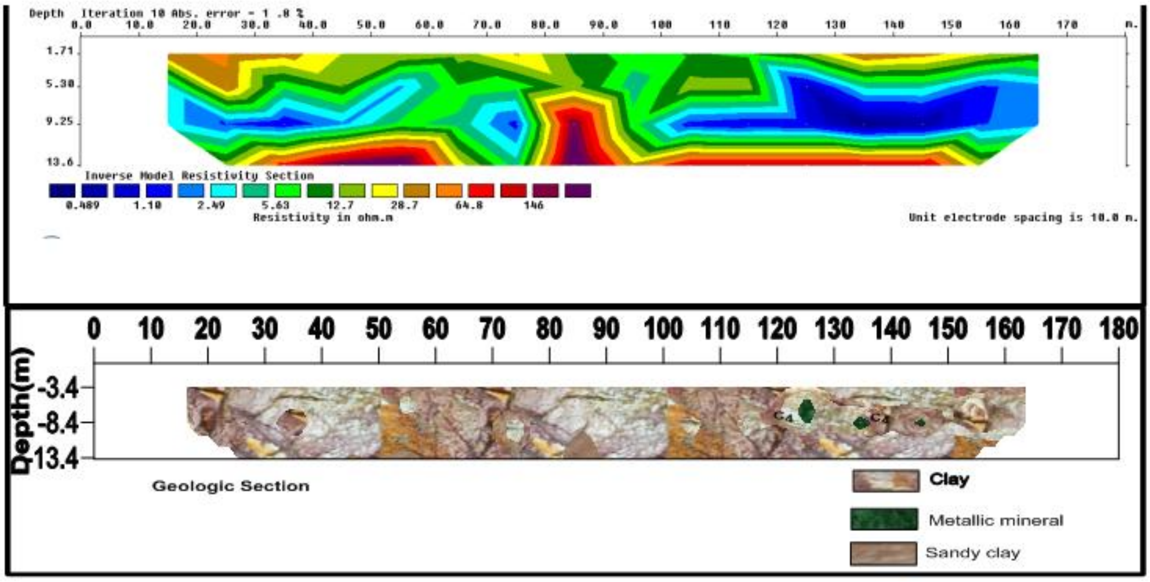

Fig. 5b: Inversion model resistivity and geologic section along traverse 4.

DISCUSSION

(a) VLF – EM Profiles and Map

The plots of raw real measured on the field and the filtered real are presented as profiles and their corresponding Karous-Hiljet (K-H) pseudo-sections are shown in Figs. 4a and 4b. High positive values indicate presence of conductive subsurface structures while low or negative values are indicative of resistive formations, Sharma and Baranwal (2005); Ozegin and Okolie (2016). In Fig. 4a, the VLF-EM Curves revealed locations of fracture zones. These openings are filled with materials different from the rock forming the bedrock, which then produced electromagnetic anomalies

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indicated as $c_{1,}$ $c_{2,}$ $c_{3,}$ and c_4 at distances 20 m, 130 m, 180 m and 270 m respectively. These points are zones of interest in mineral deposit abstraction in the area. The corresponding pseudo-section is a measure of conductivity of the subsurface as a function of depth. The conductivity is shown as colour codes with conductivity increasing from left to right (i.e. from negative to positive). Different features of varying degree of conductivity trending in different directions were delineated on the section, for instance, between stations 100 and 150m; a highly conductive body at an approximate depth of 50 m is shown. In figure 4b, the positive peak anomalies c1, c2, c3, c4, c5 and c6 on the filtered real curve, revealed vertical and/ or near vertical conductors. These anomalies are 20 m, 80 m, 100 m, 130 m, 200 m and 260 m from the starting station (zero mark) of the survey profile. On the pseudo-section, the c2 and c3 are not differentiated as separate conductors rather they are masked as single feature of red shade of lateral locations (about 75 m and 105 m marks), giving lateral extension of 30 m. The anomalies c1 and c4 are not masked on the pseudo-image suggesting that these anomalies probably occur very deep and are out of the depth range (10-50 m) of the pseudo-image or the resistivity is high to be manifested as anomalies. These anomalies may indicate clay, metallic ore or sand filled fracture in the bedrock.

(b) Dipole-Dipole pseudo-sections

The inversion model resistivity shows three distinct layers, these can be inferred from the geologic sections (Figures 5a and 5b). In figure 5a (traverse 3), which trends NE-SW direction to a length of 200 m and imaging depths of 13 m shows low resistivity values ($\leq 0.8 \leq 1.8$ Ωm) between stations 3 – 5 and 15 – 16, which is indicative of metallic mineral signature. In figure 5b, with the same trend direction as in traverse 3 to a length of 180 m and imaging depths of 13 m has low inversion resistivity values ($\leq 0.4 \leq 1.0$ Ωm) between stations 12 – 15 reaching a depth of about 9.3 m from the surface, which reveal metallic mineral evidenced by resistivity values that are less than 1 Ω m.

A geophysical survey was conducted in Agbede and its environs to locate and map its metallic mineral deposit potential. The survey revealed two major areas with resistivity values less than 1 Ωm which indicate presence of metallic deposit (Figs. 5a and 5b). The inferred results are in locations 3 and 4 along traverses 3 and 4 respectively. Resistivity tomography, with moderate acquisition time, gives information both for the target and the near surface geological formations. The ERT image (Fig. 5a) obtained for line crosses the electromagnetic anomalies indicated as $c_{1,}$ $c_{2,}$ and c_3 (Fig. 4a) did not reveal metallic mineral. However there is metallic mineral signature at the ERT image (but not well defined in the model resistivity section and surfer plot geologic section). This is probably due to low data density recorded over the deposit that does not permit vivid image. From the location 4, the ERT image obtained for line crosses the electromagnetic anomalies indicated as $c_{1,}$ $c_{2,}$ c_3 and $_{C4}$ revealed c_4 (Fig. 4b) as metallic mineral. This is evidenced by resistivity less than 1 Ωm. The c_4 anomaly in the VLF-EM Curve seems to be a response from closely separated conductors as seen in the ERT interpretation which inferred metallic mineral deposits occurs at 4.8 m and 7.5 m below the surface and extend to depths of

8.5m and 9.3m respectively. They are laterally located at 123 m and 128 m, 133 m and 137 m respectively from the geologic section.

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