

Application of ground magnetic and very low frequency electromagnetic (VLF-EM) surveys for gold and base metal exploration around Ihale in Bunu – Kabba area of Kogi, North-central Nigeria

Olawale Olakunle Osinowo and Michael Oluseyi Falufosi

Department of Geology, University of Ibadan, Ibadan, Nigeria.

Corresponding author: wale.osinowo@ui.edu.ng,

waleosinowo@gmail.com; (+234 (0) 812 4109 193)

Abstract

This study integrates ground magnetic and Very Low Frequency Electromagnetic (VLF-EM) methods of geophysical investigation to probe the subsurface in terms of rock magnetic susceptibility and ground conductivity for the purpose of identifying mineralized pegmatite veins that could serve as host for gold and associated metallic deposits. Twenty five (25) carefully planned ground magnetic and VLF-EM profiles, each, were occupied east and west of a reference profile which was purposively established on an identified mineralized pegmatite vein around Ihale in Bunu – Kabba area of Kogi, north-central Nigeria. The acquired ground magnetic data were filtered using Gaussian, Butterworth and Reduction To Pole at Low Latitude (RTPLL) filters among others to remove regional field effect, cultural noise as well as simplify and focus the peaks of magnetic anomalies over corresponding sources due to the mid latitude effect of magnetic inclination on magnetic anomaly. The measured raw real and raw imaginary components of the EM fields were subjected to Fraser and Karous Hjelt filtering to remove harmonic and non-linear noise, make anomaly amplitudes to directly relate to the causative conductor, focus anomaly peaks as well as generate current density used to characterise the study area. Seven (7) zones of relatively high VLF-EM derived current density with matching high residual positive magnetic anomalies present closely correlate-able signatures with subsurface response obtained around the reference profile established where local mining activities indicate evidence of gold and associated metallic mineralization of the pegmatite vein. The delineated zones constitute targets for gold and associated base metal prospects development.

Keywords. Electromagnetic survey; Ground magnetic survey; Gold mineralization; Mineralized pegmatite veins; Ihale.

Introduction

Gold is a precious and economic metal that offers rewarding financial benefit because of its precious quality and stable value. The all time high demand and the rising price of this precious metal has engendered the rush for gold in Ihale and environs in Bunu – Kabba area of Kogi, north-central Nigeria, where low skilled local miners have built up a mining community to extract gold and other associated metals from a mineralized pegmatite vein. The success of gold extraction recorded from the various tunnels made around the vein created the interest to explore the area in order to identify other

mineralized veins that could host gold and other associated metals around the study area and thus provide useful information for better organized extraction of the resource to generate tax and employment for the development of the area.

Geophysical survey is known to generate subsurface image that presents distribution of measured physical parameter(s) along the occupied profile stations and could generate 3D subsurface model where the geophysical technique sampled progressively deeper sections of the subsurface, and the data gathering done along several carefully established parallel profiles. Magnetic and Electromagnetic

geophysical methods offer cheap and rapid means of gathering subsurface information about rock's magnetic susceptibility and conductivity [1]; [2]; [3]. Magnetic susceptibility of rocks plays dominant influence on the intensity and inclination of the induced field generated when rocks respond to the earth ambient field [4]. Variation in rock conductivity on the other hand is apt at delineating zones of preferential water saturation or occurrence of base metal deposits which often aid easy flow of current in the subsurface [5]. Careful selection of profiles that run perpendicular to the general trend of veins around the study area as well as purposive establishment of a profile as a reference profile on an established mineralized vein and the subsequent establishment of other profiles east and west of the reference profile aid identification of other pegmatite veins that could host gold and associated metallic deposit.

Geology of the Study Area

The study area is situated in Ihale, a settlement located few kilometres from Bunnu - Kabba area of Kogi in central Nigeria. The geology of Ihale and environs has been severally discussed to be part of the geology of south-western Nigeria which has been well described by [6], [7], [8] and others. The study area consists of two main rock types, namely; Basement Complex rocks in the west and sedimentary rocks to the east (Figure 1). The basement crystalline rocks include undifferentiated Basement Complex rocks which has been differentiated and identified to be predominantly migmatite gneiss (comprising of augen gneiss or porphyroblastic granite and biotite gneiss) and intruded by NE-SW trending pegmatite dykes. Other common rocks include Older Granite of plutonic series of Pan African (650 Ma) tectonic events and undifferentiated meta-sediment identified as low grade schists. [9].

Structural imprints commonly visible on exposed rocks include foliation, gneissosity, schistosity, and migmatitic banding which indicate rock strain, metamorphic differentiation and recrystallization, suggesting prolonged period of tectonic activities. Other visible structural signatures include minor faults, joints, fractures and pegmatitic intrusions emplaced within fractured zones that trend roughly NW – SE [10]. Field evidence indicate that the pegmatites are usually granitic or granodioritic in composition with extremely coarse quartz, muscovite and feldspars grains. The pegmatite veins ranges in thickness (width) from > 1 m - 10 m and sometimes measure more than 100 m in length. Pegmatites that intrude the granitic and schistose rocks around Ihale are mostly mineralized and often play host to economic minerals.

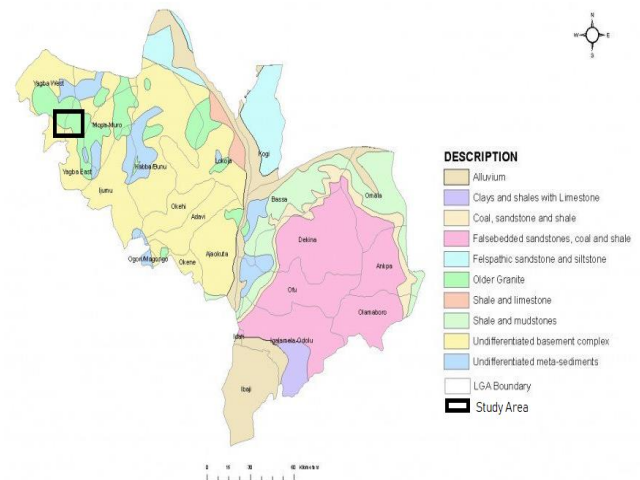


Figure 1. Geological map of the Kogi State, North Central Nigeria; insert study area [11].

Materials and methods

In this study two (2) different geophysical investigation methods were integrated to probe the subsurface in order to delineate regions of the subsurface having mineralized veins that could serve as host for gold deposit. Two geophysical parameters were employed in this study to characterise the subsurface and they include the magnetic and the electrical properties of the earth. The magnetic method probed the subsurface in terms of magnetic elements present in metalliferous veins which based on magnetic susceptibility of different rocks delineates veins with gold mineralization. Electrical and electromagnetic methods on the other hand measure ground conductivity or resistivity its inverse and due to the relative ease of electrical conduction across a mineralized vein is able to map occurrence of mineralized veins in the subsurface ([12]; [13]).

Ground magnetic measurements were taken using proton-precession magnetometer which consists of a simple sensor made up of a flask containing a proton-rich liquid (such as kerosene or water) unto which a magnetizing solenoid and detector coil are wound. The proton-precession magnetometer makes use of the small magnetic moment of the hydrogen nucleus (proton) to measure the precession of the proton atom to the earth magnetic field after the current in the magnetizing solenoid coil is switched off. The measured Total Magnetic Intensity data (TMI) in nanotesla (nT) which records both the regional and the local geologic effect across the occupied profile were quality checked for spurious magnetic data such that bear no significance to the local geology. The resultant TMI data were filtered to remove out ranged, especially high frequency noise that could be attributed to cultural effects such as electric cables

and surrounding metallic objects. Low pass Gaussian filter was applied to remove the regional and ambient field effects. The residual magnetic data were further reduced to pole at low latitude to simplify the complex magnetic anomalies which usually characterises mid-latitude magnetic data. Here the magnetic anomalies are usually -asymmetrically positioned over their causative sources due to low magnetic inclination effects at mid latitudes ([14]; [15]; [16]). The resultant magnetic data were further filtered using Cosine roll filter to smoothen the data and remove any data processing artefact that may be introduced due to the application of other filters.

Measurement of ground conductivity to delineate mineralized veins, which often presents significantly higher conductivity value than the rocks that host them, was undertaken using ABEM WADI VLF-EM meter. The meter is apt at measuring terrain conductivity by determining the ratio of the real (Re) to the imaginary (Im) components of the propagating time varying low frequency (15-25 KHz) primary (Hp) (originating from far distant transmitting station) EM field and secondary (Hs) EM field generated when eddy current flow in subsurface conductor or conducting zone. The measured difference in field intensity and phase lag between the primary and the secondary EM field [17] is related to the ground conductivity where a phase lag of the secondary EM field relative to the primary EM field of about half a period (180°) indicate a conducting ground, while a resistive ground (poor conductor) will cause the secondary EM field to lags the primary EM field by 90° [18].

The acquired data were quality checked (QC) to eliminate noisy data and thereafter subjected to [19] filtering to generate the filtered equivalent of the raw real and the imaginary components whose anomaly peaks directly overlie the causative sources and the anomaly amplitude directly relate to the causative conductors [20]. The filters also reduce harmonic and nonlinear noise types commonly associated with power line harmonic radiations, Global System Mobile (GSM) telecommunication transmitters and global lightning [21]. Subsequently, the filtered data were subjected to [22] filtering which based on the concept that VLF-EM anomalies are caused by galvanic current response from conductive targets within the earth, transformed the measured in-phase component of the EM field into current densities at constant depths [20]. The VLFPROS MATLAB code for processing VLF-EM data developed by [23] was employed to apply [22] and thus generate 2-D pseudo-section of current density across the surveyed profiles.

Both the magnetic and electromagnetic data were collected through twenty five (24) occupied profiles

which run N-S of the study area (Figure 2). The profiles were established east and west of the reference profile at 50 m inter profile interval. The reference profile was established on a mineralized vein with evidence of gold mineralization, judging from thriving gold mining activities on the vein. Nine (9) profiles were established east (50E to 450E) of the reference profile, while fifteen (15) profiles (50W to 750W) were occupied west of the reference profile (Figure 2). The profile range in length from 70 to 125 m and measurements were taken at 5 m station interval.

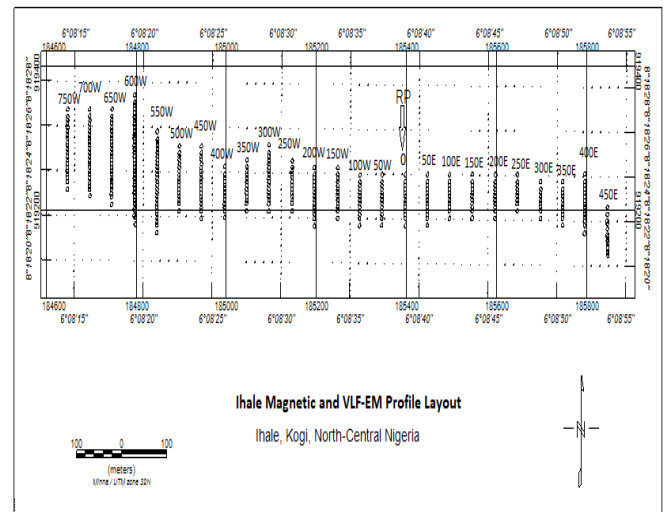


Figure 2. Ground Magnetic and VLF – EM profile layout across the study area (RP = reference Profile)

Results and discussion

The results of the ground magnetic and VLF-EM surveys carried out for the purpose of delineating mineralized veins that could host gold deposit around Ihale in Bunnu – Kabba area of Kogi, central Nigeria are presented as 2D magnetic distribution map, 2D VLF-EM current density profile sections and 3D subsurface current density model which show the distribution of magnetic intensity and VLF-EM derived current density along the occupied profiles as well as across the study area respectively. Total magnetic intensity map of the study area is presented in the figure 3. The map shows the magnetic intensity due to both regional and residual magnetic fields, that is, the core or ambient field effect, as well as intensity of induced magnetic field generated by high magnetic susceptible rocks upon interacting with the earth inducing magnetic field. The residual magnetic intensity map obtained after removing regional magnetic field, filter out cultural noise and simplified and centred magnetic anomalies over causative sources is presented in figure 4.

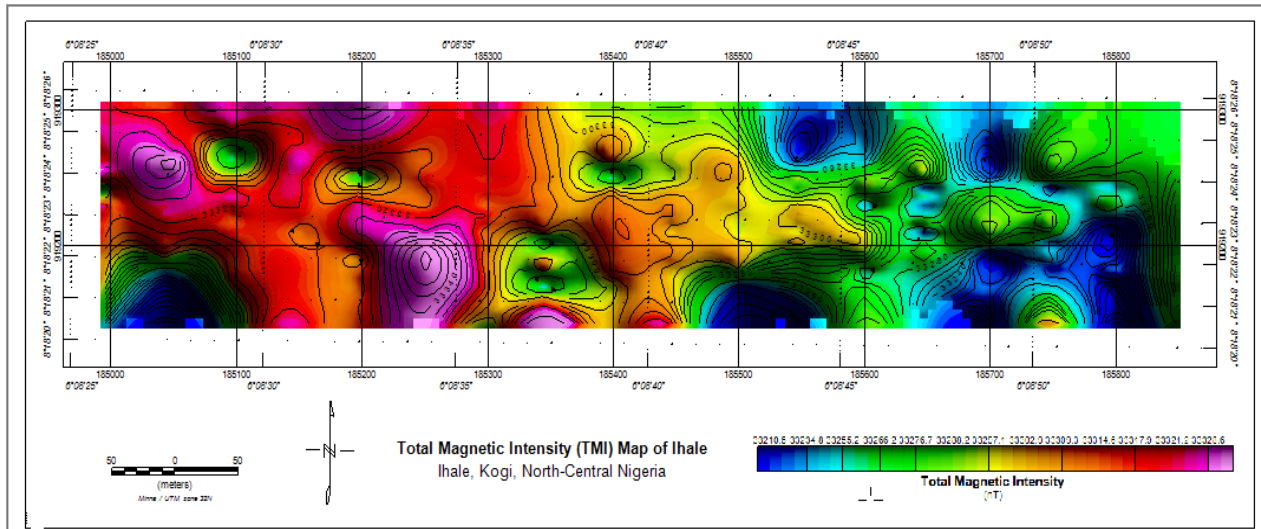


Figure 3. Total Magnetic Intensity Map of the study area

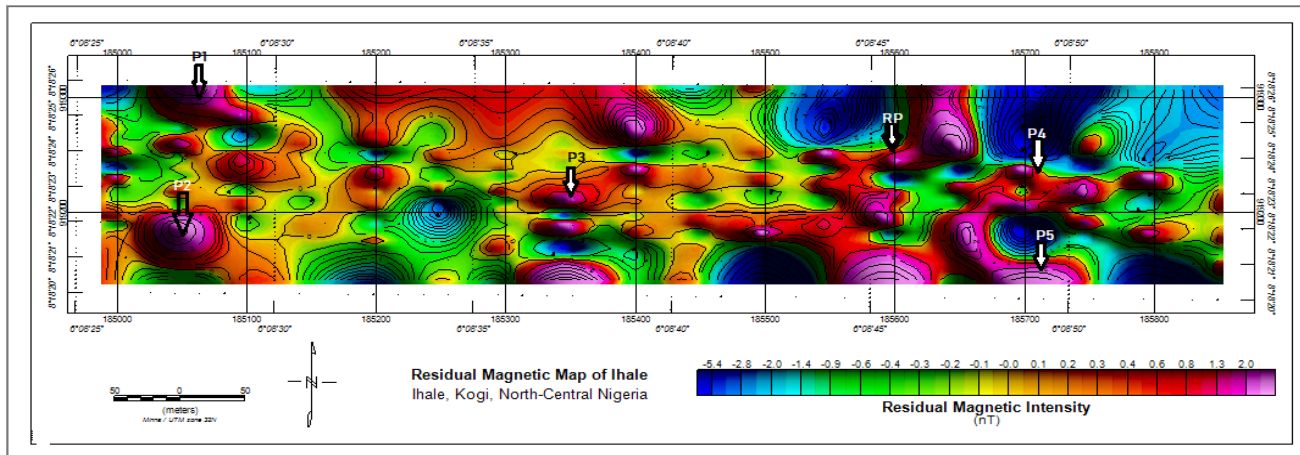


Figure 4. Residual Magnetic map of the study area.

The residual magnetic map indicates regions with high amplitude positive and negative anomalies as well as some medium to low amplitude positive and negative anomalies. High amplitude positive anomalies correspond to regions with relatively high magnetite rich rocks having high magnetic susceptibility [24]. Some of the regions that present relatively high magnetic intensity value coincide with identified mineralised pegmatite veins. For example, high magnetic intensity signature around the reference profile (RP arrow) coincide with pegmatite vein that triggered this survey, where local mining activities confirmed that the pegmatite vein is mineralised with base metals ores or metallic deposits of sphalerite, galena and gold.

Five (5) additional zones (P1 – P5) of relatively high magnetic intensity having magnetic signature similar to the magnetic signature of the reference vein (RP) are noticeable on the residual magnetic intensity map of Ihale. The delineated zones (P1 –

P5) present magnetic intensity anomaly which dominantly runs NE-SW and E-W with magnetic intensity values ranging from 45 nT to 68 nT. Three (3) of delineated anomalous zones are situated west of the reference vein (Profile 10, Figure 2), while the remaining two (2) occur east of the reference vein.

Two dimensional (2D) VLF-EM current density sections generated by applying [22] filter to the filtered real component of the measured VLF-EM field recorded along the occupied profiles are presented in figure 5 (a – c). The figures show variation in current density with depth along the profile. The 2D plots imaged the subsurface in terms of current density distribution and probed up to 40 m depth, especially for fairly long profiles. The current density has a linear relationship with ground conductivity and ranges in value from - 20 to 40 across the study area.

Figure 5a presents 2D current density of profiles 1 to 9 (with the exception of profile 3 which could

not be resolved by the Karous and Hjelt filter due to very few data points) which were recorded east of the reference profile (profile 10).

The 2D sections identified some regions of low and high current density values, with high values delineating regions of relatively high conductivity that could be attributed to occurrence of fractured zones and pegmatite veins, while region with low current density values could indicate resistive zones within the basement rocks having little or no fractures. The fractured zones and pegmatite veins are normally zones of high conductivity due to their ability to host water or metallic deposits. Figure 5 (b & c) presents the 2D current density distribution section of the reference profile (profile 10) as well as

other profiles occupied west of the reference profile (Profiles 11 – 24).

The reference profile which was established on a mineralized vein shows relatively high current density value (between 10 – 20) with the zone of high current density corresponding to the region of active local mining operation on the vein. Most of the delineated relatively high current density zones present a form like veins that are either inclined to the north or south of the profile which runs in north – south direction. Generally, prominent zones of relatively high current density characterise profiles close to the reference profile while those occupied farther away present less prominent conductive zones (Figure 5c).

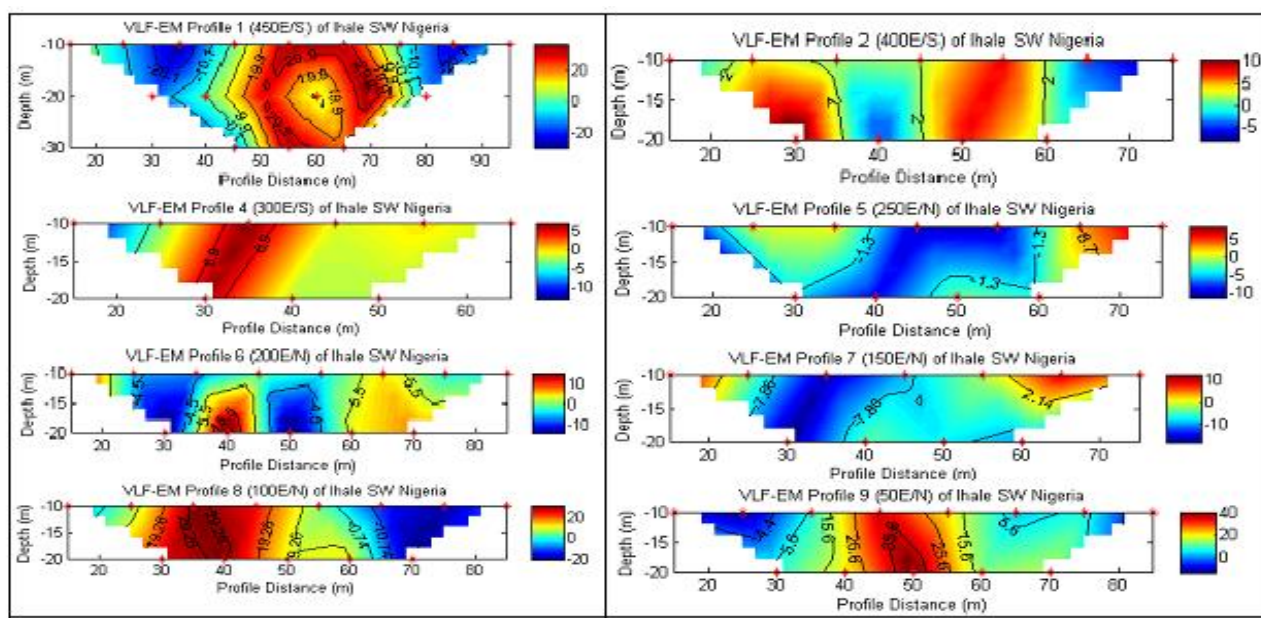


Figure 5 (a). 2D VLF-EM current density sections of profile 1 – 9

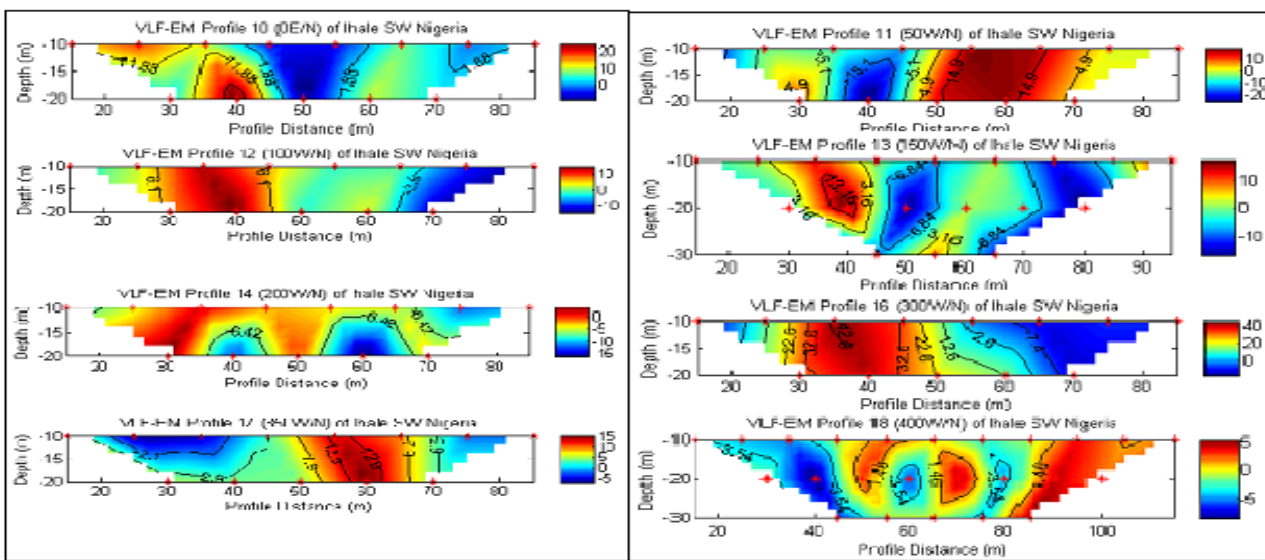


Figure 5 (b). VLF-EM current density sections of profile 10 - 18

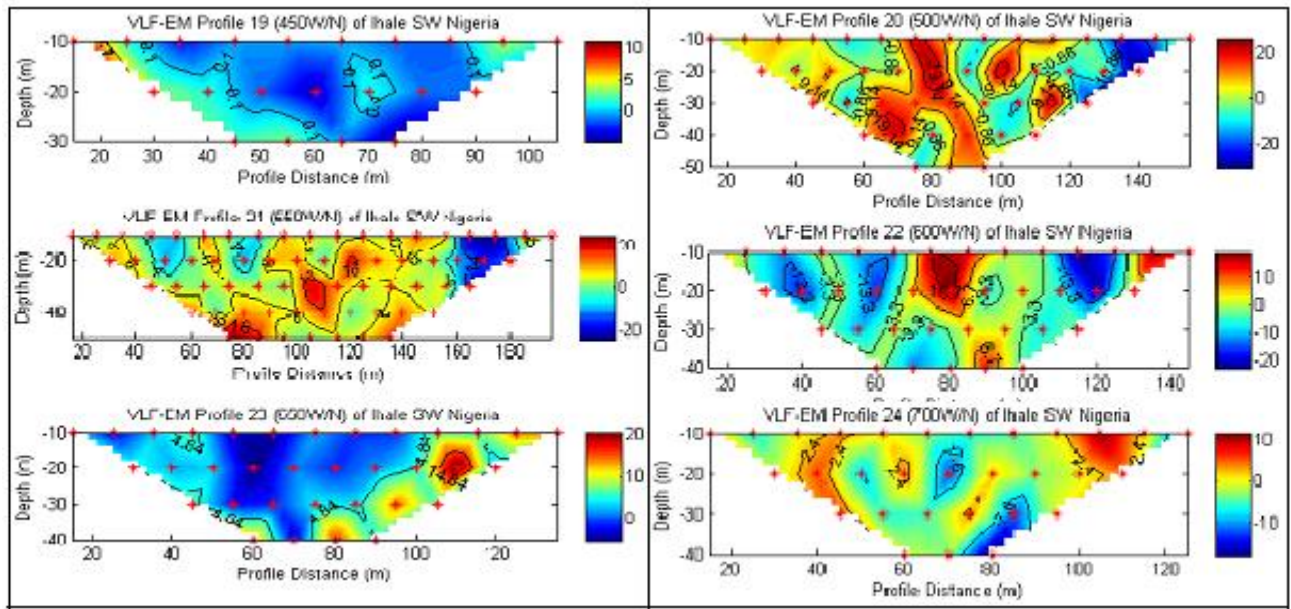


Figure 5 (c). VLF-EM current density sections of profile 19 - 24

Three dimensional (3D) display of VLF-EM current density obtained by combining all the VLF-EM results from all profiles across the study area is presented in figure 6. It presents the current density distribution along the three orthogonal (x, y, z) directions indicating the variation of the subsurface current density along N-S, E-W as well as variation with depth, up to 52.2 m depth. Prominent regions of high and low VLF-EM derived current density are visible on the 3D subsurface model. The 3D model indicates current density varies from -16 to 20 across the study area with some regions of higher subsurface conductivity when compared to the background which presented resistive signatures based on the presented low current density values.

A section through the 3D model in the E-W direction is presented in Figure 7 and it indicates the vertical extent of regions of high current density. The figure revealed that some of the regions of relatively high conductivity maintain their

conductivity at depth which likely suggests the continuity of the pegmatite veins up to 52 m.

Zones of high current density were isolated using isosurface data clip at 18.5 current density cut-off value for the purpose of identifying zones of characteristically high conductivity that can be related to mineralized pegmatite veins (Figure 8). Six (P1 – P6) candidate zones of high current density (≥ 18.5) were identified apart from the one that coincide with the mineralized pegmatite vein (RP) upon which the reference profile was established.

A careful examination of the generated isosurface current data clips (Figure 9), especially when compared with the one generated around the reference profile which was purposively established on pegmatite vein having evidence of gold mineralization in addition to other associated metallic deposits, identified six (P1 - P6) other targets having similar current density signature as candidate zones for further confirmatory investigations.

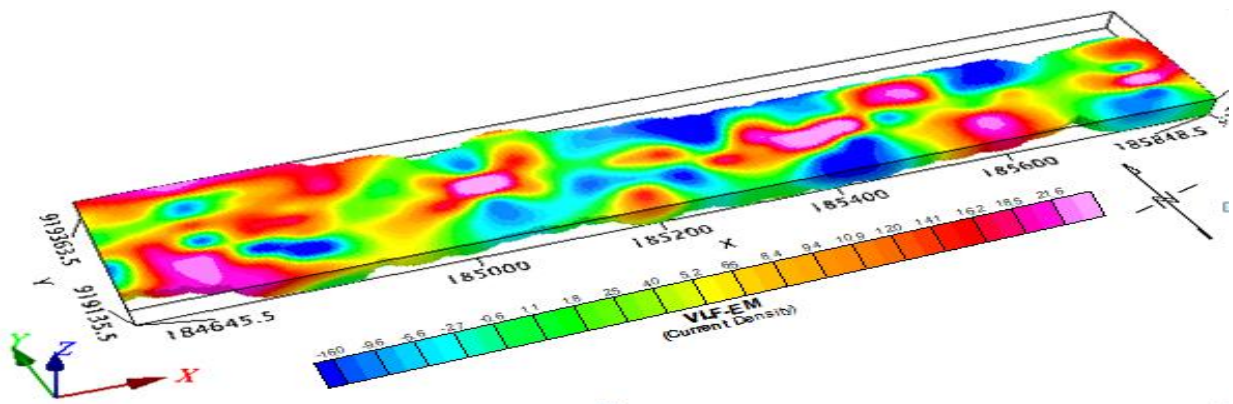


Figure 6.3D VLF-EM current distribution model of the surface area.

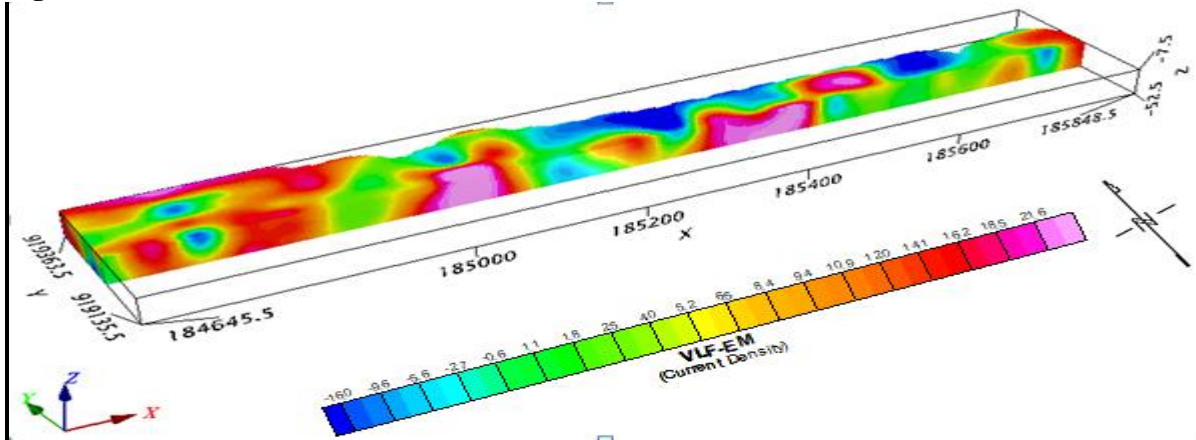


Figure 7.E-W section through VLF-EM 3D model of the study area.

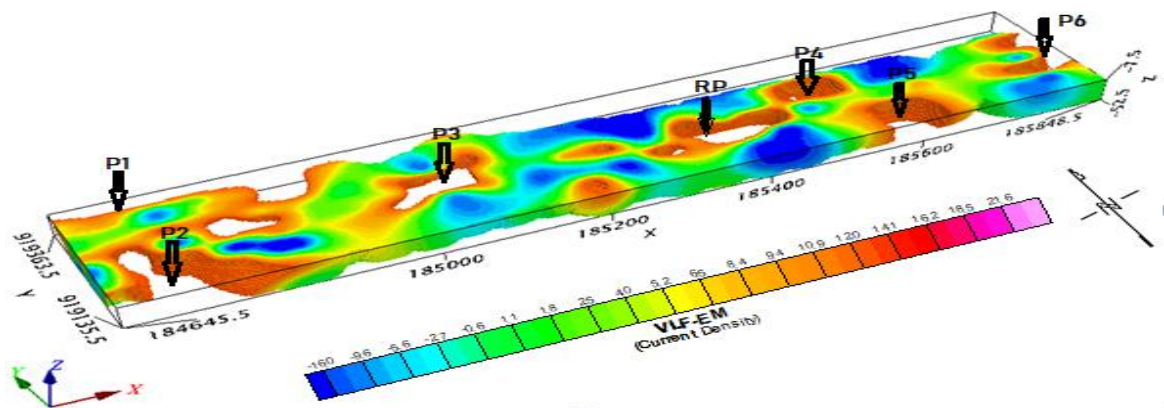


Figure 8.Isosurface data clip at 18.5 current density cut off to delineate zones of high conductivity.

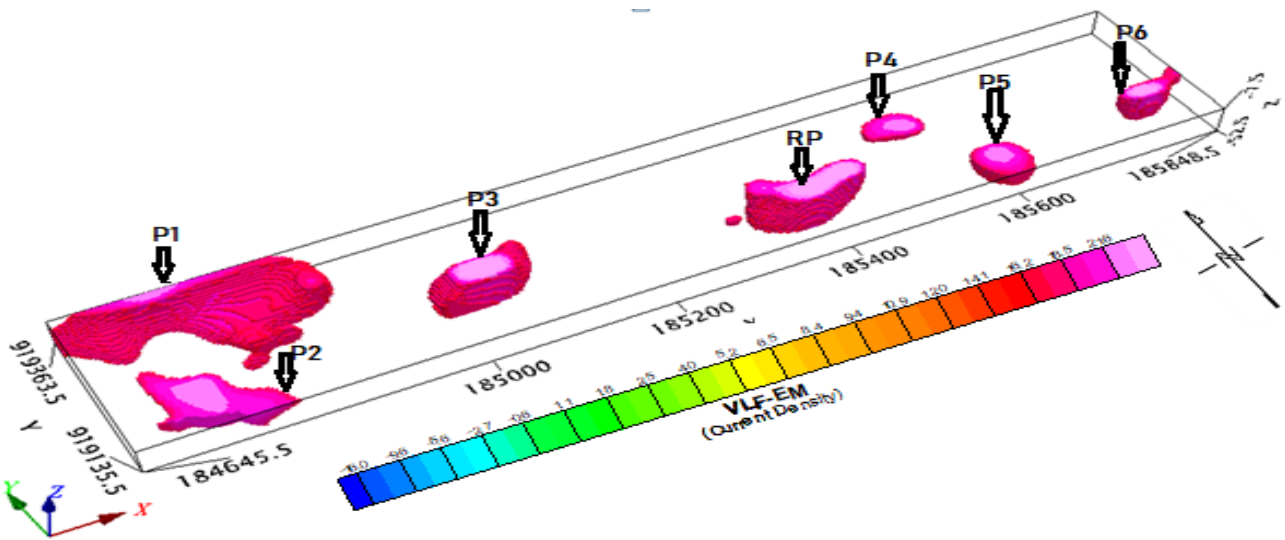


Figure 9. Generated isosurface current density data clips (at 18.5 current density cut off).

Conclusion

This study highlights the importance of carefully planned ground magnetic and VLF - EM surveys for the purpose of identifying other likely mineralized pegmatite veins situated around a mineralized reference pegmatite vein upon which a measurement survey profile was purposively established. The close correlation between the magnetic and VLF-EM current density signatures between the already established mineralized pegmatite vein and other delineated zones isolate them as targets for gold and other metallic deposits' prospect development around Ihale in Bunu - Kabba area of Kogi, north central Nigeria.

References

- [1] Nabighian, M. N., 1991, Electromagnetic methods in applied geophysics v. 2: SEG.
- [2] Lymburner, J and Smith. R. S., 2015. A procedure for collecting electromagnetic data using multiple transmitters and receivers capable of deep and focused exploration. *Geophysics***80**:1, E1-E10.
- [3] Smith, R. S., 2014. Electromagnetic Induction Methods in Mining Geophysics from 2008 to 2012. *Surveys in Geophysics***35**:1, 123-156.
- [4] Barnett, C. T., 1976, Theoretical modeling of the magnetic and gravitational fields of an arbitrarily shaped three dimensional body: *Geophysics*, 41, 1353–1364.
- [5] McNeill, J. D., 1990, Use of electromagnetic methods for groundwater studies, in S. H. Ward, ed., *Geotechnical and environmental geophysics v. 1*: SEG, 191–218.
- [6] Oyawoye M.O., 1972. The Basement Complex of Nigeria. In: *African Geology*. Eds. Dessauvage, T. F. J. and Whiteman, A. J., Ibadan Univ. Press, Nigeria, 67-99.
- [7] Palacky, G. V., 1987. Resistivity characteristics of geologic targets. *Electromagnetic Methods Appl Geophys* 1:1351
- [8] Grant, N. K., 1978. Structural distinction between a metasedimentary cover and an underlying basement in the 600m.y. old Pan-African domain of north-western Nigeria. *Bull. geol. Soc. Am.* 89: 50-58.
- [9] Rahaman, M. A. 1988. Recent advances in the study of the basement complex of Nigeria. In: Oluyide, P. O. et al. (eds) *Precambrian Geology of Nigeria*. Geological Survey of Nigeria Publication, Kaduna 11-43.
- [10] Odeyemi, I. B., 1977. On the petrology of the basement rocks around Igarra, Bendel State, Nigeria, Ph. D. Thesis (Unpublished), 223 p. Univ. of Ibadan, Nigeria.
- [11] Ajibade, A. C. 1976. Provisional classification and correlation of the Schist belts of Northwestern Nigeria. In: Kogbe, C. A. (ed.) *Geology of Nigeria*. Elizabethan Pub. Co., Lagos, 85-90.
- [12] NGSA, 2009. Nigerian Geological Survey Agency's published Geological Map of Nigeria.
- [13] Eze, C.L, Mamah, L.I. and Israel-Cookey, C., 2004. Very low frequency electromagnetic (VLF-EM) response from a lead sulphide lode in the Abakaliki lead/zinc field, Nigeria. *International Journal of Applied Earth Observation and Geoinformation* 5: 159-163
- [14] Fraser, D. C., 1969. Contouring of VLF-EM data. *Geophysics* 34: 958-967.
- [15] Dobrin M. B. and Savit C. H., 1988. *Introduction to Geophysical Prospecting*. 4thed. New York: McGraw-Hill 867.
- [16] Pearson, W. C. and Skinner, C. M.: 1982, Reduction-to-the-pole of low latitude magnetic anomalies: 52nd Ann. Internat. Mtg., Sot. Expl. Geophys., Expanded Abstracts, 356-358.
- [17] Keating, P., and L. Zerbo, 1996. An improved technique for reduction to the pole at low latitudes. *Geophysics*. 61: 131-137.
- [18] Heng, L. Z. and Yara R. M., 2013. A new RTP method via nonlinear thresholding at low latitudes. 13th International Congress of the Brazilian Geophysical Society & EXPOGEF, Rio de Janeiro, Brazil, 26–29 August 2013, 337-33
- [19] Palacky, G. J., 1987, Resistivity characteristics of geologic targets, in Nabighian, M. N., ed., *Electromagnetic methods in applied geophysics*, v. 1: SEG, 53–130.
- [20] Ogilvy, R.D., Lee, A.C., 1991. Interpretation of VLF-EM inphase data using current density pseudosections. *Geophysical Prospecting* 39: 567-580.

- [19] Fraser, D. C., 1973, Magnetite ore tonnage estimates from an aerial electromagnetic survey: *Geoexploration*, **11**, 97–105.
- [20] McNeill, J. D., Labson, V., 1991. Geological mapping using VLF radio fields. In: Nabighian, M.N. (Ed.), *Electromagnetic Methods in Applied Geophysics*, vol. 2. Society of Exploration Geophysicists, Tulsa, OK., 521-640.
- [21] Park, C. G., and Helliwell, R.A., 1978, Magnetosphere effects of power line radiation. *Science* 200: 727-730.
- [22] Karous, M. R. and Hjelt, S. E., 1977. Determination of apparent current density from VLF measurements: Report. Department of Geophysics, University of Oulu, Finland, Contribution 89. 19pp.
- [23] Sundararajan, N., Rameshbabu, V., Prasad, N.S. and Srinivas, Y., 2006. VLFPROS- A MATLAB code for processing of VLF-EM data. *Computers & Geosciences* 32: 1806-1813.
- [24] Hunt, C., Moskowitz, B.M. and Banerje, S.K. 1995. Magnetic properties of rocks and minerals. In: *Rock Physics and Phase Relations. A Handbook of Physical Constraints. AGU Reference Shelf* 3, 189-204.

Journal of Science Research, ISSN 1119 7333

Citation: Olawale Olakunle Osinowo and Michael Oluseyi Falufosi

Application of ground magnetic and very low frequency electromagnetic (VLF- EM) surveys for gold and base metal exploration around Ihale in Bunu – kabba area of Kogi, North-central Nigeria. Volume 16, 2017, pp 96-104.