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Application of Vlf-Em Geophysical Method in Delineating Pb-Zn Mineralization in Ishiagu Area, Ebonyi State, Nigeria

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Abstract: *VLF-EM data over Ishiagu northern outskirt of the Lower Benue Trough, Nigeria was evaluated to detect the extension of Pb-Zn mineralization. The study area is characterized by predominant conductive lineaments trending NW-SE direction and subordinate NE-SW direction. The conductivity contrast assessed indirectly from the evaluated current density and Fraser filtered data were used to delineate the potential zones of Pb-Zn mineralization. Strong electromagnetic induction due to high conductivity contrast was detected in the study area, though the northern extensions of these anomalies are of moderate response, signifying them deeper in the northern district. These zones are interpreted as the potential or inferred structurally controlled mineralized fracture zones with possible Pb-Zn mineralization worthy of further detailed test drilling to authenticate the extended mineralization. The results show the efficiency and reliability of VLF-EM technique for high resolution investigation at shallow depths and its potential for fast acquisition over large surfaces at mineralized zone scale without ground contact.*
Key Words: *VLF-EM SURVEY, Pb-Zn mineralization and In-Phase Planar VLF Measurements*

I. Introduction

The area is bounded by latitudes 5°54' – 5°59' N and longitudes 7°30' – 7°35' E and covers an area of about 25sq.km. Ishiagu is about 80km SSE of Enugu metropolis, and is bordered to the north by Awgu and Aninri areas (Enugu State), to the south by Ugwueke, Isiukwuato (Abia State), to the west by Lokpa and Lekwensi (Abia State) and to the east by Akaeze (Ebonyi State).

The occurrence of Pb-Zn mineralization in Ishiagu has instigated repeated studies and evaluations of the district using different geological and geophysical techniques, though less has been done with electromagnetic technique. Application of better techniques for prospecting and evaluation of solid minerals is so important, but cannot be overemphasized. Fracture is the key geological model for Pb-Zn mineralization, and thus the major source of Pb-Zn ore in Ishiagu, Ebonyi state, Nigeria. There is therefore the need for a suitable geophysical method of exploration for easy extension of the known zones of mineralized fractures in Ishiagu, so as to create a well lucrative and efficient mine development in the area.

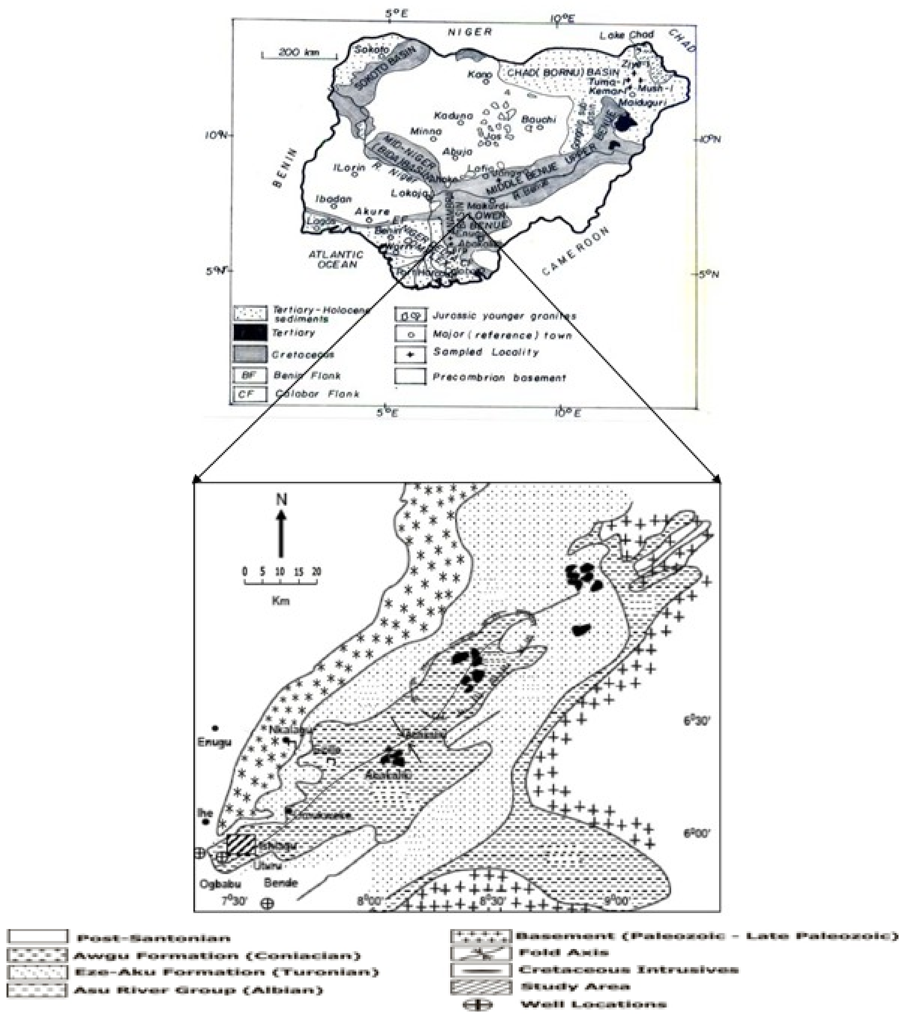
This study aims at ascertaining the extension of mineralogical features and rare metals distribution in the Ishiagu outskirt using VLF-EM method, with a view to elucidating their possible economic potentials and serve as an exploration guide for rare metal mineralization in the fractured zones and the objectives of the studies includes; To obtain the in-phase and quadrature data of the survey area, To analyse and delineate the EM data and indirectly obtain the conductivity anomalies, To delineate the potential fractures of Pb-Zn mineralization from the current density anomalies and To detect mineralized fractures extension in the concealed region. It is hoped that this study will not only improve the known geological setting of the area, but will also generate further geological and geophysical models for lucrative mine developments of the area.

II. Geologic Setting

The study area composed of a dominant low-lying sedimentary Formations and some intrusives of different episodes is located in the southwestern part of the Abakaliki Basin in the Lower Benue Trough, southeastern Nigeria (Figure 1). Evolution of this generally low-lying to gently undulating shaly terrain is correlated to basement fragmentation, block faulting, subsidence and rifting of the Lower Benue Trough during the early Cretaceous separation of Africa and America (Grant, 1971).

The Cretaceous successions in the Abakaliki Basin consist of sediments ranging from Aptian/Albian to Santonian. The sedimentation history in the Basin is composed of two sedimentary cycles ranging from Albian − Cenomanian and Turonian − Coniacian sedimentary cycles bounded by the Cenomanian and Santonian unconformities respectively.

The undulating low relief topography of the area, about 85-100m above sea level (Ezepue, 1984) is punctuated by few isolated hills and valleys. Majority of the hills and valleys align in the NW-SE direction, and conform to orientation of the folds from the Santonian orogenic deformation. The study area composed of a dominant low-lying sedimentary Formations and some intrusives of different episodes is located in the southwestern part of the Abakaliki Basin in the Lower Benue Trough, southeastern Nigeria (figure 1). Evolution of this generally low-lying to gently undulating shaly terrain is correlated to basement fragmentation, block faulting, subsidence and rifting of the Lower Benue Trough during the early Cretaceous separation of Africa and America (Grant, 1971). The records commenced with the oldest Albian - Cenomanian successions of the Asu River Group that consists of arkosic sandstones, volcaniclastics, marine shales, siltstones and limestone which overlay the Pre-Cambrian to Lower Paleozoic crystalline basements unconformably. This first Albian – Cenomanian successions are overlain by the Eze-Aku and Awgu Formations (Turonian – Coniacian) consisting predominantly of marine shales, calcareous siltstones, limestones and marls.



Geological map of the study Area. ***(Modified from Akande and Abimbola, 1987*****).**

III. Methodology

To achieve the purpose of this Project work, field measurements using the ground Very Low Frequency Electromagnetic (VLF-EM) method is been deployed. This is a quick and powerful geophysical technique for the study of shallow geological structures most especially in respect of mineral exploration (**Fisher., 1983**). VLF is an excellent and inexpensive reconnaissance tool for high-grading and area of vertically/steeply dipping structures in preparation for more detail geophysical investigations or test drilling, and can make an important contribution to an integrated investigation effort.

3.1 Basic VLF Operating Principles

VLF surveying involves measurement of the earth's response to EM waves generated by transmitters at remote distance from the survey site through current induction. Ground VLF survey provides a quick and powerful tool for the study of geological structures to a maximum skin depth of about 100m (Fischer et al., 1983) though variation in the skin depth is based on changes in subsurface conductivity. Since induction flow results from the magnetic component of the electromagnetic field, physical contact of the transmitter and receiver with the ground is unnecessary, as a result, ground VLF survey requires only one operator for measuring the EM response and is faster than electrical surveys. Furthermore, airborne VLF surveys are possible.

The VLF-EM prospecting is fundamentally based on EM wave impedance (the ratio of the electric field to the magnetic field, E/H) over 2-D geologic structures using the boundary conditions forced on the electric and magnetic fields when an EM wave propagating through air interacts with the earth's surface. The behavior of EM fields at any frequency is concisely depicted by the Maxwell's equations as formulated utilizing the geometry of Figure 2, with the x-axis as the strike direction, and the z-axis positive downwards, describing the interaction between the vector functions of an EM field.

Taking into account the constitutive relations between magnetic induction and magnetic field intensity, and between electric current density and electric field for 2-D earth structures, we have

- $\nabla \times E = -\frac{\partial B}{\partial t}$ (1a)
- $\nabla \times H = \sigma E$ (1b)

Where

E = Electrical field intensity (in volts per meter, V/m)

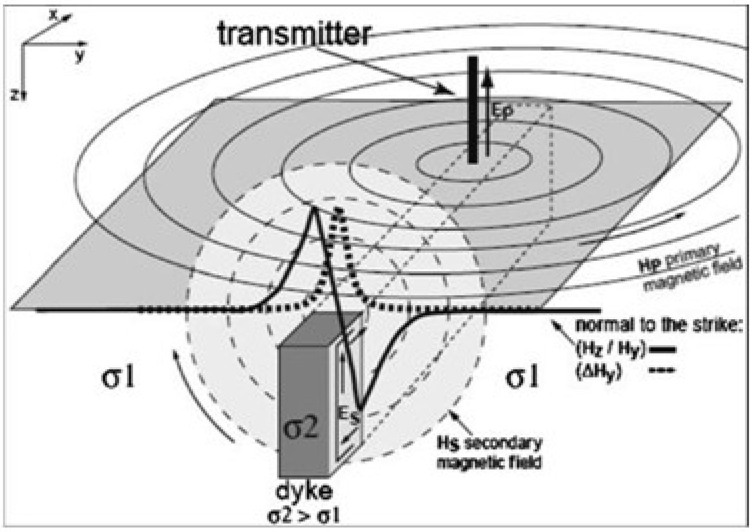
H = Magnetic field intensity (in ampere-turns per meter, A/m)

B = μH is the magnetic induction (in Tesla, T),

σ = Electrical conductivity (in Siemens per meter, S/m)

- $\nabla \times H = J = \sigma E$ **2**

The optimal configuration of the survey is to have the orientation of the geologic strike parallel to the direction of the transmitter so that a vertical magnetic component is generated for any electrical conductivity variation by the propagating horizontal and concentric magnetic field and the orthogonal electrical field (figure 2). This response is a powerful tool for study of variety of different geologic targets. The method also requires detection and incessant use of a precise transmitter with stable and sufficiently strong VLF signal for the entire survey.



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σ = Conductivity

H_P = Primary Magnetic Field **H_Z = Secondary Magnetic Field**

E_P = Primary Electrical Field **E_Z = Secondary Electrical Field**

Figure 2: Field Components of VLF Field from Transmitter at Remote Distance (Ezepue, 1984)

IV. Data Acquisition

In the present study, a sub-meter-accurate Global Positioning System (GPS), compass and pace techniques with photographs were used to create the well pegged study sub-zone (**Fig**.3), providing excellent control for exact spatial positioning of collected field data and plotting station locations. The field data was acquired using an ABEM Wadi VLF system, Model-9133001869, operating on the VLF principle of using radio waves in the VLF band from remote distance transmitters. This is a two-component magnetic receiver (**H_y** and **H_z**), both detected by the antenna unit one of which senses the field's horizontal component while the other senses its vertical component. A northern oriented transmitter of frequency 26.9kHz was chosen for these measurements in consideration to the two prevailing fracture sets in the Abakaliki Basin trending northwest and northeast respectively, with some trending north directly (Ezepue, 1984). The survey area (about 25sqkm) entirely covering Amata Village is in the vicinity of already existing mines in Ihietutu.

In conforming to the model of geophysical investigation of massive sulphides (Lead-Zinc) and as topographic effects in this area are known to be minimal, the area was gridded in order to ensure adequate conductor coupling. The well pegged geophysical grid as illustrated on figure 3 was established from an east-west trending baseline 300m long at a bearing of 90^o. The profile lines as shown on figures 3 were approximately perpendicular to the transmitter. The 10 profiles parallel to each other and to the baseline run at a 100m spacing, whereas stations spacing for the instrument readings along the profiles were at a 10m apart. Prospecting for these conductive zones was then carried out by systematically traversing the ground with the receiver unit alone, having the transmitter source signal at remote distance from the field. On an east-west profile, the operator always orients himself so that he is facing west (or as nearly as possible) when taking a measurement, thereby picking magnetic signals propagating horizontally from transmitter on the northern azimuth. It must be stressed that this method can be successfully applied in areas that are covered with overburden containing relatively thin horizons of anomalously high conductivity.

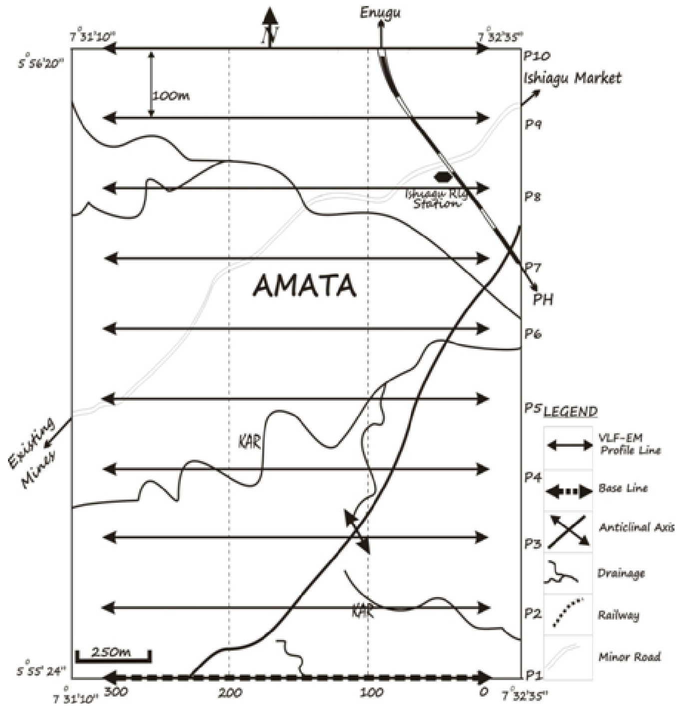


Figure 3: Geophysical Field Map of the Survey area showing the VLF Measurements Layout.

Table 1. The strength of EM responses in relation to the conductance estimates. (Olade and Morton 1980)

Strength	Conductance(S)	In-phase response	Quadrature response	Possible causes
poor	< 1	weak	moderate	- overburden response
moderate	1 - 10	moderate	strong	- siderite
good	10 - 1000	strong	Strong to moderate	- clay-rich overburden - graphite - salt-water sediment - Galena-sulphide
excellent	> 1000	very strong	weak	- Galena-sulphide - graphite - salt-water

V. Results and Interpretation

VLF Data Filtering and Qualitative Interpretation

Anomalies of the raw in-phase data on a profile are usually not isolated, hence, tapering of the data prior to transformation is recommended. The VLF-EM technique is usually associated with large geologic noise component, which results from the relatively high transmitted frequency, long spatial wavelengths and direct current bias, thus, the data requires filtering to transform the noisy non-contourable data into less noisy contourable data, eliminate the dynamic range problem and to reduce the noise problem in order to improve the resolution of local anomalies, thereby making them easier to be recognized.

To make this VLF-EM field data easier to interpret and to smooth noisy data, both the in-phase and quadrature components of all the profiles were processed by two prominent techniques outlined by Fraser (1969); and Karous and Hjelt (1983) to aid in locating the position of concealed targets.

The Fraser filter is an alias filtering technique analogous to passing the in-phase and quadrature data through a band-pass filter which completely eradicates direct current bias and greatly eliminates long wave lengths, completely confiscates Nyquist frequency noise, phase shifts all frequencies by 90° and has the band-pass centered at a wave length of five times the station spacing. This filtering process is a low-pass smoothing operator that reduces noise and transforms zero crossovers into peaks and troughs, thereby making them easier to be recognized.

The filter is expressed as;

$$\mathbf{I_a(\Delta x/2) = \frac{2\pi(0.102H_{-3} - 0.059H_{-2} + 0.561H_{-1} - 0.561H_1 + 0.059H_2 - 0.102H_3)}{Z}}$$

Where

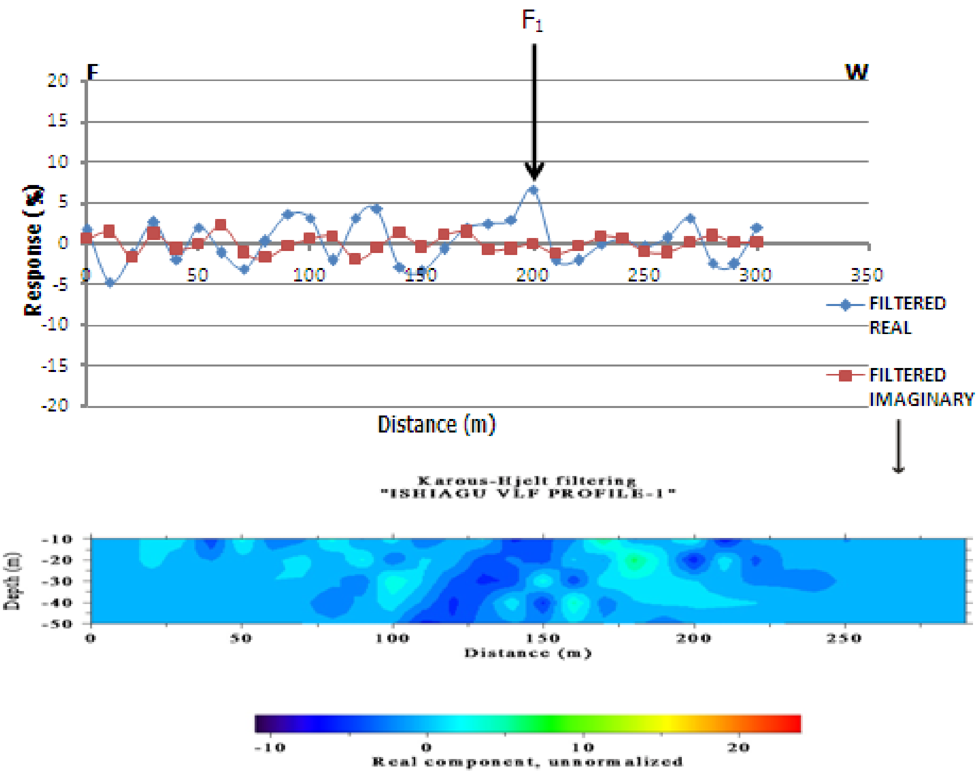
$\mathbf{I_a}$ is the anomalous current density at a specified horizontal position

$\mathbf{\Delta z}$ is the assumed thickness of the current sheet,

$\mathbf{\Delta x}$ is the distance between the data points and also the depth to the current sheet,

$\mathbf{H_n}$ values are the normalized vertical magnetic field anomaly at each of six data points. Location of the calculated current density is beneath the center point of the six data points.

By taking data points with increasing horizontal distance, current density can be computed at successively greater depths. The obtained equivalent apparent current densities would cause the measured magnetic field.



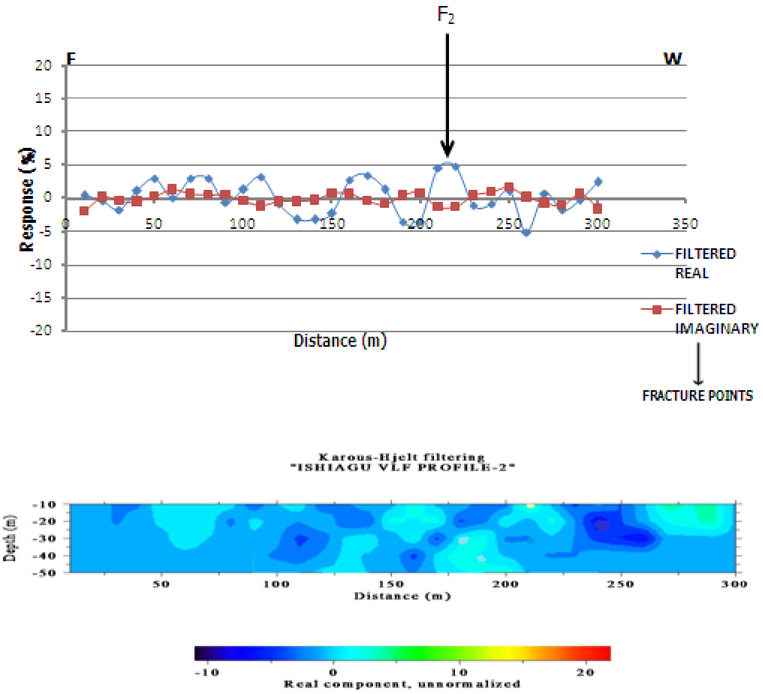


Figure 4b: Profile-2 VLF Anomaly Curves and Corresponding Current Density Pseudo-Section. (Trend: E-W)

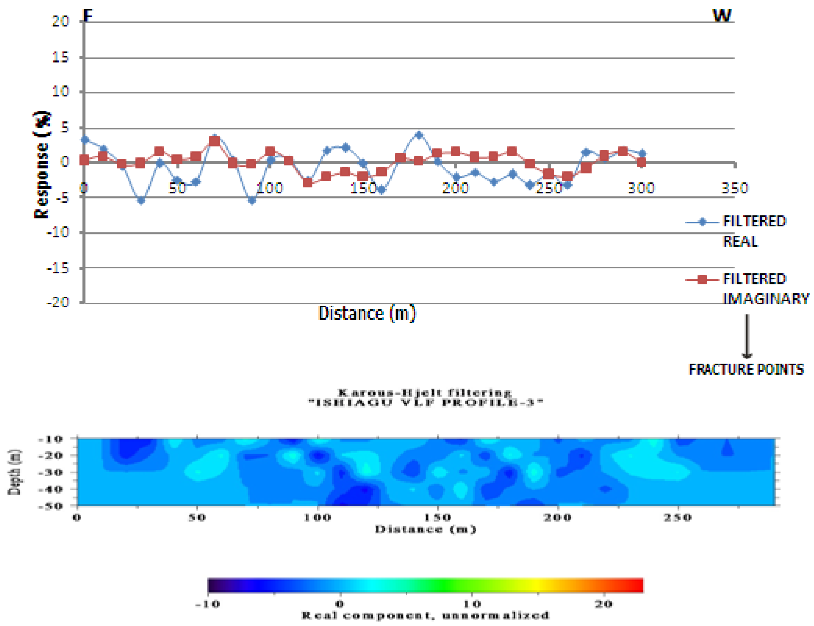


Figure 4c: Profile-3 VLF Anomaly Curves and Corresponding Current Density Pseudo Section. (Trend: E-W)

Positive in-phase anomalies, which ideally have a positive peak flanked by slightly asymmetric negative shoulders, generally indicate the presence of anomalous conductivity. Negative in-phase anomalies on the other hand, ideally have a pronounced trough with nearly symmetrical positive shoulders. Negative in-phase anomalies may be caused by a resistive body located in a field of more conductive material, such as a resistive dike outcropping in a fissure of conductive sulphide (Grant and West, 1965). Normally, only the positive values are contoured and analyzed, because the negative quantities generally represent anomaly flanks, and they do not aid interpretation but may confuse the conductor patterns.

The quadrature readings are of negative peak for anomalous conductivity though can turn to positive peak depending on the thickness and conductivity of overburden that masked the geologic structure. Thus, quadrature response that is similar to the in-phase response (positive or negative sign) indicates highly conductivity in fracture zone, though quadrature readings close to zero indicate thick overburden.

VI. Results And Discussion

The obvious tipper responses on the profiles are rather used to detect the various points of anomaly as the secondary in-phase component of the magnetic field maximizes at the conductors sites, while the negative peaks of the corresponding quadrature readings in contrast, indicate the thickness and conductivity of the overburden casing the causative material. It is possible, at least theoretically, to use this tipper characterize the subsurface conductivity distribution over 2-D structures on which bases some other parameters like subsurface position of the conductive body, anomaly thickness, dipping direction and depth of structures are detected on further qualitative interpretation.

The outstanding motivations that anticipated debates on the extension of these Ishiagu mineralized fractures as gotten from previous researches and already developed mines are attributed to the facts that:

1) There is a close relationship between the Pb-Zn mineralization and the structural features in Ishiagu;
2) The fractures normally fade out farther away from the Pb-Zn lodes and the quantity of Pb-Zn deposits in mineralized fractures diminishes with depth as fractures become narrower.

Virtually all the profiles exhibit an anomaly where the Ishiagu fractures are expected to occur. These anomalies consist of a positive in-phase peak and a corresponding negative or positive quadrature peak, with the latter being generally broader and flatter than the in-phase (Fig 5).

The main fracture raptures are separated into parallel branches all trending northwestward and some subordinate branches trending northward. Two outstanding anomalies in Amata field are exhibited on lines 400N to 900N. Some lines, (800N and 900N) exhibit a triple outstanding peak rather than a double peak as common in the field profiles.

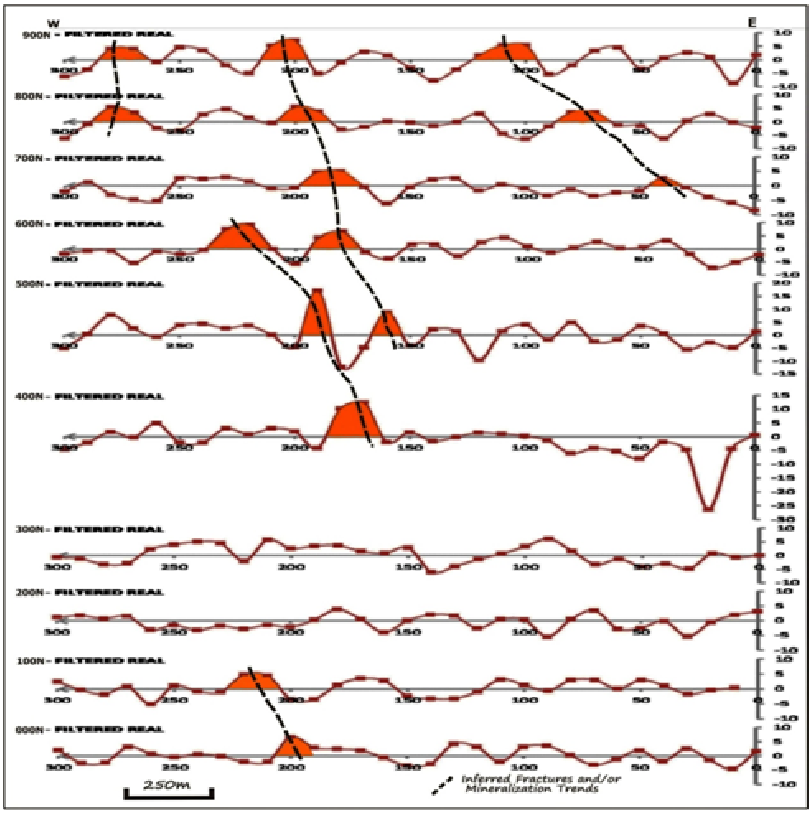


Figure 5: In-Phase Planar from VLF Measurements

The outcomes for the entire grid of study area were contoured using surfer-10 on a 2-units scale and a number of anomalous zones were perceptibly detected. Figures 6 below show the current density distribution and 3-D conversions of the measured in-phase data sets of the survey area. Correlating the results in view of the relationship between the in-phase and quadrature components of tipper responses, we can divulge three core anomalies all trending to NW and a NE core anomaly. A railway track in the swampy farmland on the eastern parts of profiles 700N, 800N and 900N greatly feigns the field anomalies as $\mathbf{P_{Anom\text{-}6}}$, and this should not be considered typical anomaly. We will present and discuss the results from the first zone where current induction effect is relatively stronger.

Detected on the western part of profiles 400N to 600N in a linear fashion was a strong positive anomaly, $\mathbf{P_{Anom-3}}$, trending NW and very close to the NE trending anticlinal axis. The value range of in-phase readings on this anomaly is 7.6% to 17.1%, and this portrays a highly conductive fracture that terminates at line 600N. The long length (about 200m) and proximity of this highly conductive structure to area of existing mines in Ihetutu indicates its mineralization potentials. The broadening of the narrow-curve of this anomaly further north (as in profile 600N) is attributed to fracture depth increase in the northern section. The corresponding quadrature readings over the anomaly are of negative peaks except on line 600N that is of positive peak, and this is also a lucid indication of the northward thickening of overburden. Attached to this anomaly $\mathbf{P_{Anom-3}}$ is a subordinate branch, $\mathbf{P_{Anom-2}}$ trending northward.

Density pseudo-sections (Figures 4a and 4c) elucidate that the anomaly can be caused by a 1m width and 30m thick fissure, with estimated depth of about 8m to the top of the conductive body. This NE dipping incline vein of anomalous conductivity as indicated by the positive VLF-EM in-phase anomaly thus, suggests fracture apparently filled with saturated materials such as massive sulfide mineralization.

Inclusive on lines 500N to 900N is a distinct anomaly, $\mathbf{P_{Anom-4}}$ parallel to the $\mathbf{P_{Anom-3}}$, though somewhat elongated up to 400m. This anomaly is of similar character on various profiles with the in-phase readings on the value range of 4.7% to 8.8%, while the quadrature components appear as negative peaks, very close to zero. This moderately high intensity anomaly emerges very thin in profile 500N but, broadens along profiles 600N, 700N, 800N and 900N as thick overburden in that region reduces the skin depth of VLF signal, thereby lessening the maximum coupling of the conductor with the transmitted field. Once again the peaks are generally asymmetric, with the steeper slope still on the western side indicating NE dip of the vein. This result indicates a second deeper fracture at the eastern part of the shallow fracture, previously explained.

This fracture appears to surpass the area of survey from line 900N readings. Hence, the local improvement of conductivity contrast in the northern outskirt of Ishiagu, irrespective of the thick Turonian overburden encasing the Albian source terrain probably indicates fracture saturated with sulphide. Estimated depth to the top of the conductive body is on the average of about 30m from the current density sections.

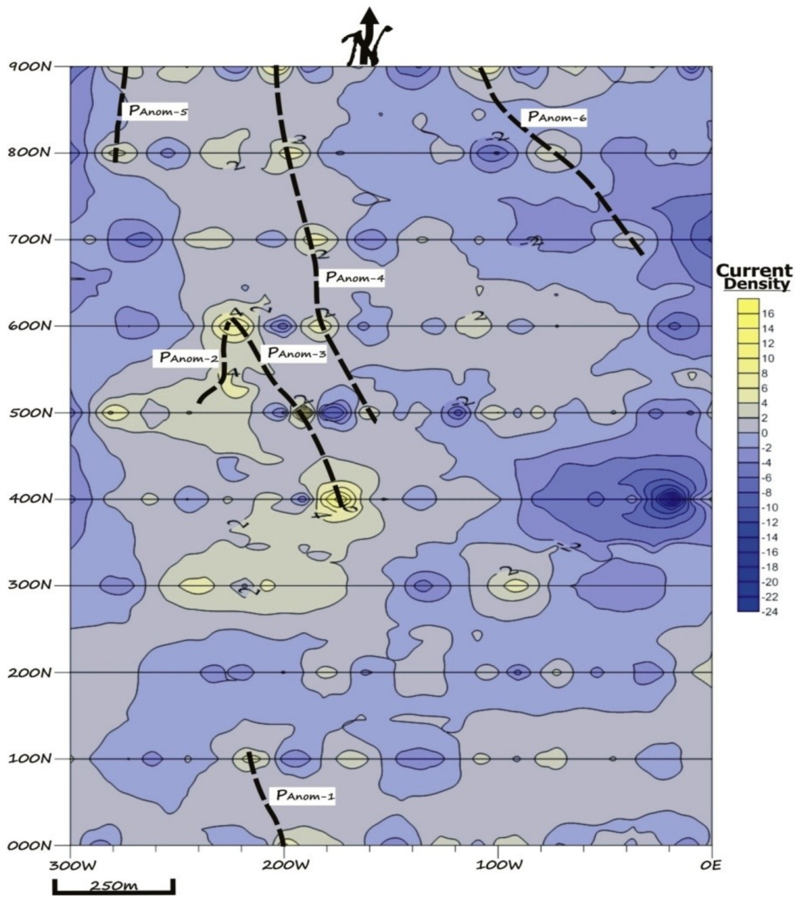


Figure 6: Equivalent Current Density Distribution from the VLF-EM Measurements.

VII. Conclusion and recommendation

The field results on both the EM profiles and equivalent current density sections agree very well with the theoretical results of mineralized fractures and there trend of mineralization. The theoretical profiles show the type of VLF response to be expected over a mineralized fracture, and this type of anomaly is observed over the Ishiagu fractures. In fact, the simultaneous analysis of in-phase and quadrature parts of tipper in the investigated area provides distinct models with excellent lateral resolution and to some extent even depth resolution when the plane electromagnetic waves penetrate the overburden. Distinct contact type responses are observed over nearly all abrupt changes in apparent resistivity, and the vertical secondary field components (in-phase and quadrature) behave as predicted over such changes.

Moreover, drilling assessment is recommended for full reclamation of Pb-Zn deposits in the Ishiagu outskirt so as to avoid dispersion of the mineral lodes by the quarry stone blasting currently going on in some parts of the district. The broad in-phase readings owing to transmuted overburden characters in the northern parts of the inferred fractures indicate the need for very deep drill holes in that outskirt district. If this drilling is encouraging, the VLF-EM survey should be expanded to cover the entire Ishiagu outskirt districts.

References

[1]. Akande, S.O. and Abimbola, A.E. (1987). Aspects of the Genesis of Lead-Zinc-Fluorite-Barite Mineralization in the Nigerian Benue Trough. Current Research in: Journ. African Earth Sci. G.Matheis and H.Schandelmier [editors], pp. 365-369.
[2]. Akande, S.O. and Mucke, A. 1989. Mineralogical, Textural and Paragenetic Studies of the Lead-Zinc-Copper Mineralization, Lower Benue Trough and their Genetic Implications. Journ. African Earth Sci. Vol. 9, pp. 23-29.
[3]. Akande, S.O., Zentili, M. and Reynolds, P.H.1989. Fluid Inclusion and Stable Isotope Studies of the Lead-Zinc-Barite-Fluorite Deposits in the Lower and Middle Benue Trough, Nigeria. Mineralium Deposita, Vol. 24, pp.183-191.
[4]. Akande, S. O., Mucke, A. and Umeji, A. C. (1990). Mineralogical Textural and Paragenetic Studies of the Lead-Zinc-Copper Ores in the Lower Benue Trough and their Genetic Implications. Jour. Min. Geol. Vol. 26, No. 2, pp. 58-64.
[5]. Bougue, R.G. and Reynolds, R.R. (1952). Reports on the Lead–Zinc Deposits of Abakaliki District, Nigeria. Unpub. G.S.N Rpt. No. 1001: 22p.
[6]. Ezepue, M. C. (1984). The Geologic Setting of Lead-Zinc Deposits at Ishiagu, Southeastern Nigeria. Jour. of Afri. Earth Sci. Vol. 2, pp. 97-101.
[7]. Fischer, G., Le Quang, B.V. and Muller, I. (1983). VLF Ground Surveys, a Powerful Tool for the Study of Shallow 2-D Structures. Geophys.Prosp. Vol. 31, pp. 977-991.
[8]. Grant, F.K. (1971). South Atlantic, Benue Trough and Gulf of Guinea Cretaceous Tripple Junction. Geol. Soc. Amer. Bull. Vol. 82, pp. 2295-2298.
[9]. Grant, F.S. and West, G.F. (1965). Interpretation Theory in Applied Geophysics: McGraw-Hill Book Co. 309p.
[10]. Nwachukwu, S.O. (1972). The Tectonic Evolution of the Southern Portion of the Benue Trough, Nigeria. Geol. Mag. Vol. 109, pp. 411-419.
[11]. Odoh, I.B. and Onwuemesi, A.G. (2009). Estimation of Anisotropic Properties of Fractures in Presco Campus of Ebonyi State University Abakaliki, Nigeria using Azimuthal Resistivity Survey Method. Jour. Geol. and Mining Research, Vol. 1(8), pp. 172-179
[12]. Ofoegbu, C.O. (1985). A Review of the Geology of the Benue Trough of Nigeria. Jour. Afri. Earth Sci. Vol. 3, pp. 283–291.
[13]. Ofoegbu, C.O. and Odigi, M.I. (1990). Basement Structures and Ore Mineralization in the Benue Trough. In: The Benue Trough Structures and Evolution. Ofoegbu, C.O. (ed.). pp. 239-247.
[14]. Olade, M. A. and Morton, R. D. (1980). Temperature of Ore Formation and Origin of the Ishiagu Lead-Zinc Deposit, Southern. Benue Trough, Nigeria. Jour. Min. Geol. Vol. 17, pp. 119–127.
[15]. Olade, M.A. and Morton, R.D. (1985). Origin of Lead-Zinc Mineralization in the Southern Benue Trough, Nigeria-Fluid inclusion and Trace Element studies. Jour. Mineral Depos., Vol. 20, pp. 76–80