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Structural Interpretation of Rocks in Igarra, Southwestern Nigeria, using Very Low Frequency (VLF) Electromagnetic Method

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ABSTRACT

Structural interpretation of rocks in Igarra area, southwestern Nigeria, to delineate geologic discontinuities such as fractures, joints, faults and basement depressions are carried out in this study. Geophysical studies carried out using Very Low Frequency (VLF) electromagnetic method showed that the basement was highly affected by various structural deformations. These structures originated during the pan African Orogeny. In the reconnaissance mode, VLF profiles can be run quickly to identify anomalous conductivity of rocks. It may be used whenever an electrical conductivity contrast is present between geological units. This may include fault mapping, groundwater investigations, overburden mapping, contaminant mapping and mineral exploration. The electromagnetic anomaly amplitudes are more influenced by the conductivity of the overburden or weathered layer, than the overall thickness. Three profiles were covered and interpreted using Microsoft excel and RAMAG. Exe software to delineate the structural features, which played prominent roles in hydrogeological applications, especially in Basement Complex environments because, they usually act as good groundwater accumulation zones in such environments but catastrophic to engineering geology and constructions.

Keywords: Basement Complex, Faults, Lineaments, Shear Zones, Very Low Frequency

Introduction

The Basement complex which constitutes of igneous and metamorphic rocks and their weathered materials covers 50 percent of the total land area of Nigeria. Hydrogeologically, the weathered parts of the basement rocksconstitutes saturated zones which are capable of yielding significant amount of water when tapped for both human use and for industrial purposes. (Ajayi and Adegoke-Anthony, 1988). However, low porosity and permeability of basement rocks impedes the hydrogeological activities around the area, with the exception of only a situation where the basement is faulted and fractured through tectonism, which constitutes large reservoirs for underground water accumulation and also forms zones of mineral accumulation. Hence, to extract groundwater within the basement,detailed hydro-geophysical knowledge of the area is required (Omosuyi et al., 2003). Ajayi and Adegoke-Anthony, (1988) outlined that The extreme lithology and structure variation make geological, hydrogeological and hydrogeophysical exploration for groundwater difficult and water exploration within the basement is favored by some factors such as high rates of annual rainfall within the area, which increases the recharge rates; deep weathered profiles development which provides the petrophysical properties which includes porosity, permeability and the extent of saturation of the lithology; presence of structural and tectonic framework such as faults, fracture and shear zones within the basement rocks, which results in contact zones with associated contrasts in permeability, which favours the occurrence of groundwater and springs (Whitmire, 1980). Exploration within the basement terrain have been retarded as a result of lack of detailed geophysical investigation in which this paper is aimed to resolve.

Geophysical method of very Low Frequency Electromagnetic method makes use of very low frequency radio communication signals to determine the conductivity and resistivity of the subsurface and near-surface stratigraphic sections. This technique maps steeply dipping structures like faults, fracture zones, dykes and areas of mineralization, (Whitmire, 1980). The Very Low Frequency electromagnetic method can be run quickly to identify anomalous areas, this may serve as a reconnaissance tool prior to exploration. Fault mapping, groundwater investigations, overburden mapping, leachates migration (contaminant mapping) and mineral exploration are all achieved through this method. Olorunfemi and Fasuyi, (1993), suggested that weathered layer or the overburden are more conductive than the basement thickness and as a result gives a sharp anomaly from the electromagnetic signal, this is why confined fractures or features are hidden from the signal and makes it unsuitable for its mapping.

Electromagnetic surveying methods utilizes the response of the subsurface to the propagation of electromagnetic fields, which are composed of alternating electric intensity and magnetizing force, (Kearey et al., 2002). Primary electromagnetic fields can be generated by passing an alternating current through a small coil or a single large loop of wire. The subsurface responds to this primary field by generating secondary electromagnetic fields. These may be detected by the alternating currents that they induce to flow in a receiver coil by the process of electromagnetic induction (Kearey et al., 2002).

Kearey et al., (2002), stated that the primary electromagnetic field travels from the transmitter coil to the receiver coil via paths both above and below the ground. When the subsurface is homogeneous there is no difference between the fields propagated above and below the ground surface, other than a slight attenuation of the latter with respect to the former. However, if there is a conducting body in the subsurface, the magnetic component of the electromagnetic field penetrating the subsurface induces eddy currents to flow within the conductor body. These eddy currents generate their own secondary electromagnetic field which travels to the receiver. The receiver then reacts to the resultant of the arriving primary and secondary fields, so that the response differs both in phase and amplitude to the response of the primary field alone. These differences between transmitted and received electromagnetic fields can be used to detect the presence of a subsurface conductor and may also provide evidence on its geometry and electrical properties.

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, surface electromagnetic surveys are faster than electrical surveys (Okwueze, 2008).

The induction of current flow results from the magnetic component of the electromagnetic field. Consequently, there is no need for physical contact of either transmitter or receiver with the ground Surface electromagnetic surveys can thus proceed much more rapidly than electrical surveys, where ground contact is required. More importantly, both transmitter and receiver can be mounted in aircraft or towed behind them. Airborne electromagnetic methods are widely used in prospecting for conductive ore bodies.

All anomalous bodies with high electrical conductivity produce strong secondary electromagnetic fields. Some ore bodies containing minerals that are themselves insulators may produce secondary fields if sufficient quantities of an accessory mineral with a high conductivity are present. For example, electromagnetic anomalies observed over certain sulphide ores are due to the presence of the conducting mineral pyrrhotite distributed throughout the ore body.

Geology of Basement Complex of Nigeria: Regional Geology of Nigeria

Nigeria is located within the Pan African mobile belt between 4° N and 15° N of latitudes and 3° E and 14° E of Longitudes and which however lies between the West African and Congo craton. Woakes et al (1987), stated that Precambrian basement and sedimentary rocks whichoccurs at approximately in equal proportions dominates the Geology of Nigeria.

The Nigerian Basement complex lies within the Pan African mobile belt to the east of West Africa craton and Northwest of the Congo craton. However, thenorthern and eastern margins of West Africa craton shows that the Pan African belt are of tectonic origin which took place about 600Mya. This tectonismresulted from continent- continent convergence (collision) between the passive margin of the West Africancraton and the active margin of Pharusian belt of the Tuareg shield (Burke and Dewey, 1972). These collisions havereactivated the internal region of the belt, of which the Nigerian Basement complex lies. The Nigerian Basement complex can be divided into two provinces:

- The western province approximately west of latitude 8°E is characterized by narrow, sediment dominated N-S trending low grade Schist belts in a predominantly Migmatite-gneiss "Older" Basement and the whole was by Pan African Granitic Plutons.
- The eastern province comprises mainly Migmatite-gneiss complex intruded by larger volumes of Pan African Granites and the Mesozoic ring complexes of central Nigeria.

Evidence from radiometric dating shows that the Nigerian Basement complex has a polycyclic setting which are made up of rocks of Liberian age of 2700 ± 200 ma, the Eburnian age of 2000 ± 200 ma, Pan Africa of 600 ± 150 ma and the Kibaran age of 1100 ± 200 ma, which is however questionable. The most obvious effects of the Pan African orogeny in Nigeria is the emplacement of large volumes of Granitoids and the resetting of mineral ages in virtually all rock types in the basement. However, little is known about the nature of the Pan African event in Nigeria or indeed about any of the earlier events. Intensive work has been done within the south-western Nigeria basement complex, the first of such works were carried out when the mineral survey of southern Nigeria was initiated between 1905 and 1906. Notable works were done on the following viz:

- An early phase comprises Granodiorites and quartz diorites;
- A main phase that comprises coarse porphyritic hornblende Granites, Syenites and coarse porphyritic
- A late phase that consist of homogenous Granites, dykes, Pegmatites and Aplites.

Classification of Basment Complex of Nigeria

Many academiers and practicing geologists have given several classifications regarding thebasement complex of Nigeria. Some of the considered classifications are those given by Oyawoye (1970), Rahaman (1973) and Odeyemi (1976).

Oyawoye (1970) in his work classified the rocks of Nigeria basement complex into four major groups. His classification was based on petrological evidences viz;

- The Migmatite complex
- The Metasedimentary series
- The Older granites
- The miscellaneous rock types which include Bauchites, Diorite e.t.c

Rahaman (1973) classified the rock types in the Nigeria basement complex into five major groups namely;

- unmetamorphosed Diorite dykes (youngest)
- Older granites
- Slightly Migmatised to Unmigmatisedparaschists and Metaconglomerate rocks
- Charnockitic rocks, Metagabbros, Pyroxene Diorite
- Migmatite-gneiss complex

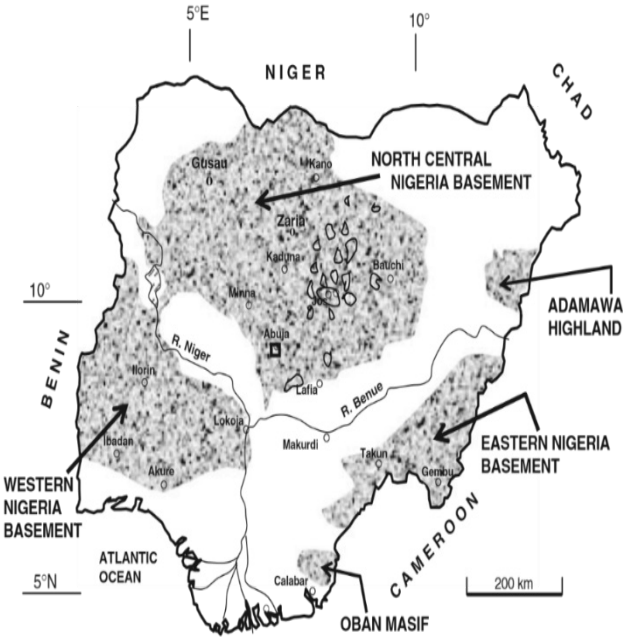

Figure 1.Basement Complex of Nigeria (Burke and Dewey, 1972; Dada, 2006)

Odeyemi (1976) in his work titled preliminary report on the field relationship of the basement complex around Igarra ,Midwest state classified the rock types into four mayor groups viz ;

- Migmatite-gneiss complex
- The metasediments comprising Schists, Calc-gneiss, Metaconglomerate and Quartzites.
- The porphyritic older granites
- The late discordant unmetamorphosed Syenite dykes believed to be the youngest of these Odeyemi (1976) four fold classification.

The Precambrian basement rocks in Nigeria consist of the migmatite gneissic-quartzite complex dated Archean to Early Proterozoic (2700-2000 Ma). Other units include the NE-SW trending schist belts mostly developed in the western half of the country and the granitoid plutons of the older granite suite dated Late Proterozoic to Early Phanerozoic (750-450Ma).

Provenance and Evolution of the Southwestern Nigeria Basement Rocks

A controversial aspect of the geology of the Nigeria basement complex is its geotectonic origin. Only very few workers had applied geotectonics to interprete the origin of the basement rocks in southwestern Nigeria. In my research studies, Sophisticated equipment like scanning electron microscope Cambridge 250 model in the United Kingdom were used to determine the spot chemical composition and empirical formulae of nearly all rock forming minerals in the rocks of the basement complex of southwestern Nigeria as represented by the amphibolite and granite gneisses in Ilesha area. A mineral known as monazite was discovered in this process. This mineral is present as a notable accessory mineral in all the crystalline rocks of the basement complex here in Ilesha area even in the amphibolite which is supposed to be purely igneous. Hither to except in the Younger Granites in the north central Nigeria and in sedimentary rocks in Lokoja and Auchi areas, monazite has not been described by any worker in the rocks of the basement rock of southwestern Nigeria in general and in Ilesha area in particular. Monazite is a phosphate of the rare earth elements, especially the light ones e.g. (La, Ce, Nd) PO_4. Reviewing all the known tectonic environments especially island arcs and back arcs (which had been suggested as the geotectonic setting in which the rocks of the southwestern Nigeria basement complex originated), the petrology, geochemistry and plumbotectonics studies of the rocks understudy implicate a back arc tectonic setting in which an ocean slab was subducted into the mantle. This subduction was due to a collision between an ocean slab and a continental shelf. In such an environment, the ocean slab would be subducted into the mantle with sedimentary materials and water which makes a wet mixed magma formation possible.

Geology of Igarra in Southwestern Nigeria Basement Complex

The area covered by the southwestern Nigeria basement complex lies between latitudes 7^{o}12\`N and 7$^o$20\`N and longitudes 5^{o}55\`E and 6$^o$10\`E right in the equatorial rainforest region of Africa (Fig.1). The main lithologies include the amphibolites, migmatite gneisses, granites and pegmatites. Other important rock units are the schists, made up of biotite schist, quartzite schist, talk-tremolite schist and the muscovite schists. The crystalline rocks intruded into these schistose rocks. For the purpose of this chapter, discussion is limited to the crystalline basement rocks of southwestern Nigeria.

Geotectonic Evolution of Basement Complex

This geotectonic complex which constitutes over 75% of the surface area of the southwestern Nigerian basement complex is said to have evolved through 3 major geotectonic events:

- Initiation of crust forming process during the Early Proterozoic (2000Ma) typified by the Ibadan (Southwestern Nigeria) grey gneisses considered by Woakes et al; (1987) as to have been derived directly from the mantle.
- Emplacement of granites in Early Proterozoic (2000Ma)
- The Pan African events (450Ma-750Ma). Rahaman and Ocan (1978) on the basis of geological field mapping reported over ten evolutionary events within the basement complex with the emplacement of dolerite dykes as the youngest. On the basis of wide geochemical analyses and interpretation, geotectonic studies, field mapping and plumbotectonics, Oyinloye (1998 and 2011) had suggested a modified Burke et al; (1976) sequence of evolutionary events in the Southwestern Nigeria basement complex as detailed in Table 1.

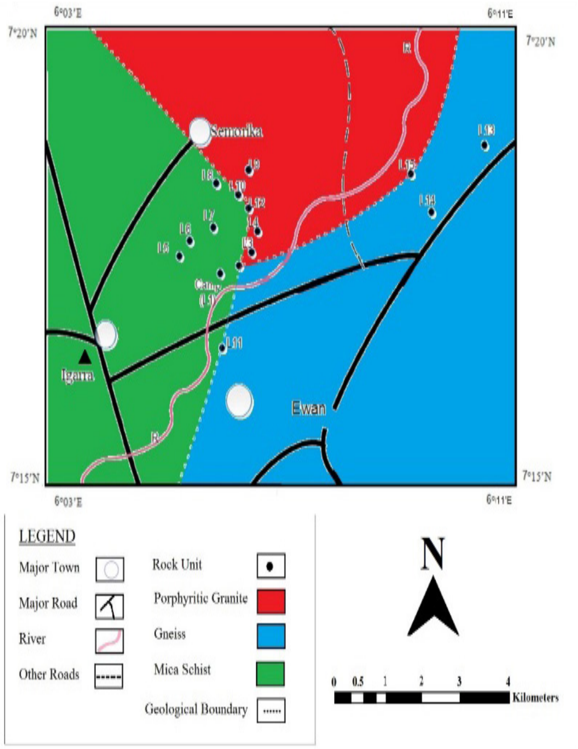

Figure 2.Geology map of the study area

Location of the Study Area

Igarra is the Headquarter of Akoko-Edo local government area of Edo state.

The study area covers the parts of Igarra town and its environs. The plot lies approximately between longitude 5°55\` and 6°10\` east of the Greenwich Meridian and equally lies approximately between latitudes 7°12\` and 7°20\` north of the equator. The same tectonic forces that affected the basement complex of Nigeria resulted from the pan African Orogeny which divided the basement complex into: Oban massif, Obudu plateau, Adamawa upland North central basement and southwest basement complex.

Accessibility

Both the old and new road was used as access path for the exercise. There are also major footpaths which are indicated in the accessibility map extract.

Human Activities

The major occupation of the inhabitants of Igarra and its environs is mainly subsistence farming and the major crops produced are yams, cassava and pineapples; others are maize and cocoa. Most of these farming activities are carried out in the valleys which in most cases have loamy soils and also within a region that has a high water table. The process of bush burning is followed by hunting of bush animals by the indigenes. Some of the farmers produce palm oil in small quantities from the palm trees. There is local quarrying of rocks such as granites and Quartzites for construction work by the inhabitants.

Geochronology of the Basement Rocks of Southwestern Nigeria

It has been established that the Precambrian basement complex of Nigeria including Southwestern Nigeria is polycyclic in nature, (Ajibade and Fitches 1988). The southwestern Nigeria basement complex had undergone 4 major orogenesis in:-

- Liberian (Archaean) 2500Ma-2750± 25Ma
- The Eburnean orogeny (Early Proterozoic), 2000Ma-2500Ma
- The Kibaran orogeny (Mid Proterozoic), 1100Ma - 2000Ma
- The Pan African Orogeny, 450Ma-750Ma.

Geomorphology and Geography

Climate

The climatic condition of Igarra and its environs fall within the warm-horrid tropical climate region where the wet and dry seasons are noticed prominently in the area. The dry season is between November and February while the rainy seasons are mostly between April and October. Average rainfall is between 1000mm and 1500mm with temperature as high as 36.7°.

Drainage

The study area is well drained by dried up stream channels which run across the area from north to the southern part of the study area.

Vegetation

The study area, Igarra and its environs fall into the Guinea savannah vegetation belt. The vegetation here is prominently made up of sparsely distributed trees, herbs, shrubs and grasses. Trees in this area are mostly concentrated along fracture zones within the plutonic bodies and on the Quartzite ridges were adequate soil cover has resulted and there is adequate groundwater retention. The vegetation in this area is mostly secondary i.e. the natural vegetation is being altered and such agricultural crops such as Maize, Yam, Cocoa, Cassava, Pineapple, Cashew, Mango and Sugar cane are grown.

Topography

Within the north-eastern portion is a prominent relief which is an elongated Granite ridge that stretches from Igarra to Aiyetoro. The peak of this ridge is about 1550m above sea level (the elongate ridge that stretches from Igarra to Aiyetoro is the Igarra Pluton).

On the western side of the area are the Quartzite ridges which are of lower elevation of about 1100m maximum.

The Schist and Metaconglomerate occupy the lowlands and has an elevation of about 650m above sea level.

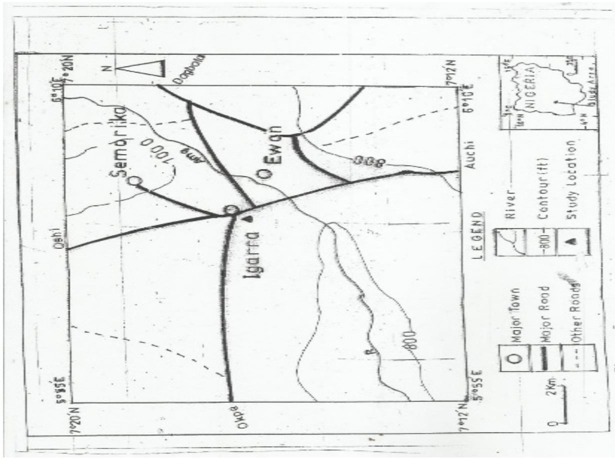

Figure 3.Topographic map of the study area

Hydrogeology of the Area

The hydrogeology of an area is controlled by some factors such as geology, structures and climate of the area (Ademilua and Olorunfemi, 2000; Raghynath, 2002). This is because the geologic formations underlying the area and the structures determine the types of aquifer to be encountered and the means of recharging them while the climate determines the amount and rate of recharge of the aquifer (Shemang, 1990).

Groundwater in general originate as surface water, but their occurrence and distribution are controlled by geologic factors such as lithology, texture of the rock and climatic factors such as rainfall. Sources of surface water supply to the study area are River Odowara and its major tributaries and it is the only perennial river around the area.

In the study area, the high rate of annual rainfall is primarily responsible for the recharge of the groundwater.

The aquifer units in the area and other similar basement complex environment are believed to be derived essentially from the weathered rocks (Bala and Onugba, 2001; Olayinka and Olayiwola, 2001). The weathered profile developed above the crystalline basement rocks in low latitude regions where the study area lies has been documented to comprise, from top to bottom, the soil layer, the saprolite (i.e., the product of the in situ chemical weathering of the bedrock), fractured bedrock and fresh bedrock (Olayinka and Olayiwola, 2001). The highest groundwater yield in basement terrains is found in areas where thick overburden overlies fractured zones (Olorunniwo and Olorunfemi, 1987).

Scope and Limitation of the Study

Scope

The scope of the study is to compare the petrological properties of rocks in Igarra area and its environs and their structural characteristics and the factors responsible for their deformations, metamorphism and restructuring. This is achieved through the use of petrological analysis to identify the various rocks types and their mineral content and the use of Very Low Frequency (VLF) Electromagnetic method to study the structural features and to infer the possible occurrence of minerals, ground water potential and geotechnical characteristics of the area.

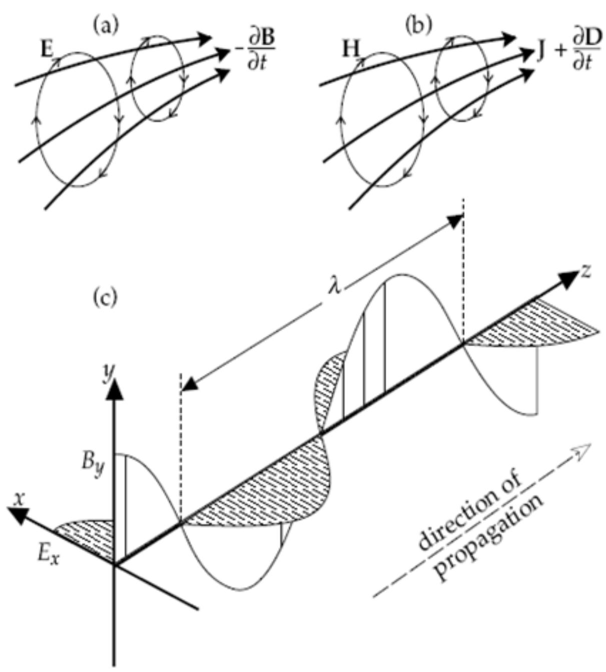

Figure 4.(a) An electric field E is generated by a changing magnetic field (B/ t), while (b) a magnetic field B is produced by the current density J and the changing displacementcurrent density (D/ t); (c) in an electromagnetic wave an electric field Ex and a magnetic field By fluctuate normal to each other in the plane normal to the propagation direction (z-axis) (Lorrie 2004)

Very Low Frequency (VLF) Electromagnetic Method

The VLF-EM is a well-known method for quick mapping of near surface geologic structures most especially in respect of hydrogeological studies, mineral exploration and related geological structures (Saydam, 1981; Ligas & palmoba, 2006; Babu et al., 2007). In addition, it has been used to high level of success to map weathered basement layer and detection of water-filled fractures or shallow faults.

The VLF-EM uses radio signals from worldwide network transmitter stations and operates in frequency ranges between 5 kHz and 30 kHz.

Very Low Frequency Electromagnetic method of geophysics utilize very low frequency radio communication signals to determine electrical properties of near-surface soils and shallow bedrock. The technique is especially useful for mapping steeply dipping structures such as faults, fracture zones and areas of mineralization.

In the reconnaissance mode, Very Low Frequency profiles can be run quickly to identify anomalous areas which may require further investigation with more detailed geophysical measurements. It may be used wherever an electrical conductivity contrast is present between geological units. This may include fault mapping, groundwater investigations, overburden mapping, contaminant mapping and mineral exploration.

Folliation planes, fractures, joints, lineaments, faults and folds are some of the structural features that can be delineated with the use of VLF while petrographic analysis can be used to delineate the various rock types, mineralogical composition and their mode of occurrence.

Raina (1980) classified lineaments into three: curvilinear representing fold, closure and/ or erosional drained pattern. Lineaments represent fracture zones, fault axis and formational boundaries. The third group may consist of linear features which do not fall into the above mentioned categories. They could represent local faults or some other basement features.

Tectonic Framework of the Nigeria Basement Complex

The Nigeria basement complex was affected by major tectonism especially the pan African Orogeny (Ajibadae et al, 1989 and McCurry, 1989). McCurry (1971a) identified two phases of tight isoclinal folding and subsequent polyphase metamorphism during the pan African Orogeny for the basement complex of Nigeria and its supercrustal cover. The first phase of folding, which may have originated during the Precambrian was observed to be striking east-northeast, west-southwest (McCurry 1971a) and East West and North South McCurry (1971a).

The late phase is regional and common over most West Africa. Subsequently, system of faults striking North-Northwest direction, South-Southwest and East- Southeast, West-Northeast and others in varying directions from Northwest- Southeast, East West and Northeast, Southwest were observed in the Northwestern Nigeria.

Figure 5.Quartz vein showing alignment of quartz mineral due to tectonism

Figure 6.Quartz vein showing alignment of quartz mineral due to tectonism and subsequent in-situ chemical weathering

Therefore structural map of any area can correlated with geologic and mineral maps to produce standard base map for solid mineral exploration (Krishnamurty, 1890) and also produce a structural contour map, which matched with area of primary mineralization in Nigeria.

Three main structural indices for characterizing a fracture zone are usually distinguished These include total length of structure - x, total number of structure - y and total number of structure - z, the spatial distribution of structures is taken into account. These are used in mapping and classifying structures.

Methodology

Basic Principle of VLF

The fundamental principle of very low frequency electromagnetic method is the Maxwell's equation. Electromagnetic fields may be mapped in a number of ways, the simplest of which employs a small search coil consisting of several hundred turns of copper wire wound on a circular or rectangular frame typically between 0.5m and 1m across. The ends of the coil are connected via an amplifier to earphones. The amplitude of the alternating voltage induced in the coil by an electromagnetic field is proportional to the component of the field perpendicular to the plane of the coil. Consequently, the strength of the signal in the earphones is at a maximum when the plane of the coil is at right angles to the direction of the arriving field. Since the ear is more sensitive to sound minima than maxima, the coil is usually turned until a null position is reached. The plane of the coil then lies in the direction of the arriving field (Philips Kearey, Michael Brooks, lan Hill (2002)).

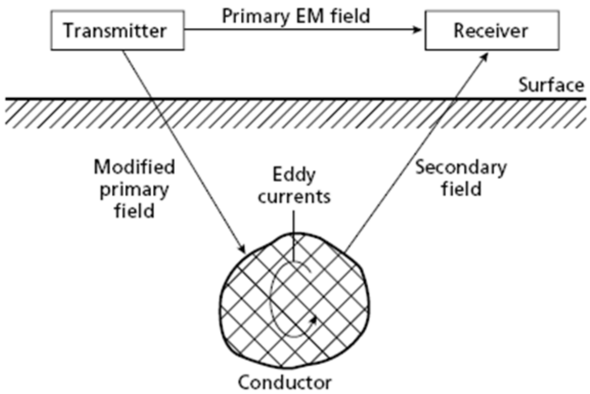

Figure 7.General principle of method (Philip Kearey, Michael Brooks and Ian Hill; (2002)

These principles can be related to the following:

- The source and signal received by the transmitter
- The mechanism of interaction of the signal with the subsurface structures
- Responds of the subsurface features with the signals as detected by the receiver.

Maxwell`s Equation

The fundamental principle of electromagnetic field equations is from Maxwell's equations which is the integration of four equations, viz:

Coulomb's law shows that an electric charge is surrounded by an electric field, which exerts forces on other charges, causing them to move, if they are free to do so. Ampère's law shows that an electric charge (or current) moving in a conductor produces a magnetic field proportional to the speed of the charge. If the electric field increases, so that the charge is accelerated, its changing velocity produces a changing magnetic field, which in turn induces another electric field in the conductor (Faraday's law) and thereby influences the movement of the accelerated charges. This consists of a magnetic field B and an electric field E which vary with the frequency of the oscillator and are oriented at right angles to each other in the plane perpendicular to the direction of propagation. In a vacuum all electromagnetic waves travel at the speed of light ($c=2.99792458\times10^{8}$ ms^{-1}, about 300,000kms^{-1}), which is one of the fundamental constants of nature (William Lowrie 2004)

$\nabla \times E = -\partial B/\partial t$ (Faraday's law) (1)

$\nabla \times H = J + \partial D/\partial t$ (Ampere's law) (2)

$\nabla D = \rho v$ (Gauss' law) (3)

$\nabla \cdot B = 0$ (Gauss' law of magnetism) (4)

They describe the propagation of the B and E field vectors, respectively and are written as:

$\nabla^2 B = \mu\sigma \partial B/\partial t + \mu\varepsilon \partial^2 B/\partial t^2$ (5)

$\nabla^2 E = \mu\sigma \partial E/\partial t + \mu\varepsilon \partial^2 E/\partial t^2$ (6)

$\nabla^2 = \partial^2/\partial x^2 + \partial^2/\partial y^2 + \partial^2/\partial z^2$ (7)

Where E (V/m) and H (A/m) are the electric and magnetic fields, B is the magnetic induction. D (C/m^2) is the displacement current and *p* (C/m^3) is the electric charge density owing to free charges. J and $\partial D/\partial t$ (A/m^2) are the current density and the varying displacement current respectively.

Where: $\mu = \mu_r \mu_0$, μ_0 is permeability of free space and μ_r is the permeability of material. $\varepsilon = \varepsilon_r \varepsilon_0$, ε_r is the permittivity of free space and ε_0 is the permittivity of material (William Lowrie 2004).

Field Procedure for EM Method

The standard field procedure is profiling along straight lines. It is done along geologic strike with line and station spacing dictated by the amount of detail required, the exception of this being some specialized reconnaissance.

Electromagnetic Method (EM) may be used for vertical drilling in a manner similar to Vertical Electrical Sounding (VES). This can be accomplished by increasing the transmitter - receiver separation while maintaining a constant frequency with fixed spacing. Several of the ground EM methods could be used for depth sounding, but the log-wire transmitter system has a greater depth potential than other method.

Nevertheless, an EM set using variable frequency say with range of 100-5000HZ, suitable for depth probing to perhaps 1500ft, would be much more elaborate and expensive than a Schlumberger resistivity layout. After the data has been acquired, it is now left to the ingenuity of the geologist to interpret.

VLF Stations and Frequency of Primary Field

VLF stations are complex structures with multiple 200-300m, which support metal canopies. Often these canopies are strung from adjacent hills. One or more of these towers can carry the antenna current. In addition, large ground planes or mats of intermeshed wiring cover the ground beneath the antenna. These elaborate procedures are all designed to increase the reading efficiency of the antenna.

Table 1.Some VLF communication stations used for the survey (James L. Wright, 1988)

Call Sign	Frequency (KHZ)	Power (KW)	Location
GBZ	19.6	550	UK
NSS	21.4	1000	Annapolis, MD
NWC	22.3	1000	Exmouth, Australia
NPM	23.4	512	Lualualie, Oahu, HI
NAA	24.0	1000	Cutler MA
NOTE: power unspecified as to either power to antenna or effective radiated power			

These stations radiate electromagnetic waves in the VLF band (i.e. 20.3-24KHZ) at the particular frequency to which the station is assigned (i.e. 24.0 kHz for Cutler, MA). The waves are generated by currents travelling up and down the vertical tower. The current on the antenna (i.e. tower) begins to flow upwards, reaches a maximum, then dies away to zero. Then it begins to flow down the antenna, reaches a maximum and as before, dies away to zero. The process is continued at the frequency of the station, that is, the current oscillates. Magnetic field form concentric circles about this vertical line of current. The circle are centered on the antenna and parallel to the ground. An electric field oriented vertically at right magnetic angle to the field. As current oscillate, so do this associated magnetic and electric fields. The field build, move outward and are pinched off as the current returns to zero. Identical fields the form, both of opposite sign, as the current build to its negative peak. Donut shaped surfaces of magnetic and electric fields are successively pinched off as current on the antenna. The surfaces travel radially outward from the antenna and are detectable for thousands of kilometers. The curvature along the edge of the wave surface (i.e. donut) is so small that the as a wall of magnetic and electric fields. The magnetic field is horizontal, parallel to the ground and the electric field is oriented vertically. These appear to oscillate back and forth as the various wave pass the observer. Another important element is the ionosphere, which is a series of electrically charged layer in the atmosphere at altitudes from 60-400km, the electromagnetic waves emitted by the antenna can be reflected by the ionosphere and/or ground and arrives at the observer by various routs.

Of the various paths, the direct and ground reflected waves usually cancel and the trapped waves which travels through layers in the earth diminishes quickly and are not usually significant.

VLF Anomaly

Anomaly or disturbance in the VLF field are caused by conductivity variation with in the earth. This exclude variations outside the earth such as the ionospheric changes, meteorological conditions or simply operational changes in the transmitter.

The most fundamental anomaly is the responds of uniformly conductive (Homogenous) earth to the primary VLF field. Indeed, the effect to be discussed are always present in varying degree and as such could be considered as part of primary field. However, they are grouped as an anomalous response.

The VLF waves travel over the earth`s surface and is bent or refracted vertically downward. Four important observations results from this process:

- The electromagnetic wave travels directly downward regardless of the angle of incidence, with both fields parallel to the earth`s surface. The magnetic field is perpendicular to the line connecting the observation point to the transmitter and the electric field is parallel to the line.
- Both magnetic and electric fields diminishes as they travel into the earth.
- The electric field leads or get ahead of the magnetic field by radian or 45 degrees.
- Both the magnetic field and the electric field are continually phase shifted by the same amount as they travel into the earth. In the case of electric field, this is in addition to the 45^0 phase shift.

Skin Depth

This is the depth at which the amplitude of the wave drops to 0.368 or approximately 1/3 of its initial value. Likewise, one can observe that for each metre in depth, both magnetic and electric field are phase shifted by radian relative to their initial timing at the earth`s surface. This process of attenuation or fading away of the wave and phase shifting or shortening of the wavelength.

It is important to note that the wave has actually lost all its energy at the point it reaches one skin depth.

This study has set a framework for the interpretation of layered earth model which will be reviewed later. Since these effects are always present to a varying degree, they also present a framework to which all model must be considered.

Data Acquisition

The steps applied in this study, during the acquisition of data, based on the geophysical methods (VLF-EM methods) used, will be explained in detail in this section.

Data Acquisition from Electromagnetic Method

- A survey plan was done, as the point distances were located. The size of the field determines the point distance that should be measured. This point distances served as the stations in the profile in which the ENVI was ran. The stations were spaced at regular interval of.
- A decision was made on how the survey lines were ran. Where terrain features such as; valleys, hillocks, creeks etc. are ran in a given direction. If the terrain is sloppy, it is better to move up and down the slope, rather than transverse it.
- Standing at the beginning of the first profile and facing the direction in which we intended to walk, the ENVI instrument was powered on with the power key.
- Pressing the stations key, the frequency was set at 0.00Hz and re-pressing the stations key, ENVI scanned the VLF band and logged on to the most powerful transmitter presently on the air (which was located roughly at right angles to the profile), thereby displaying the Very Low Frequency (VLF) on the display screen.
- Consequently, the keyboard was used to set profile direction, distance between profile and between station intervals.
- Pressing the start key, the ENVI instrument was got in ready mode. With the instrument held steadily, measurements were taken for in-phase, quadrature and tilt values which were displaced on the display screen. These procedures were repeated at subsequent stations. For calculation of EM data, the station should be spaced at regular intervals.

Using the SCINTREX ENVI VLF instrument captures three (3) frequencies at each profiles which eradicates the idea of running an additional parallel profile when using the SCINTREX to see whether a zone is wide enough to provide a good yield.

Parameters Measured

Whatever the source of the secondary magnetic signal, be it by vortex or galvanic currents, it will be oriented in one unique direction and can be represented by a vector. However, this vector can point in any direction. The primary magnetic field is totally horizontal and oriented at right angle to the line connecting the observation point to the transmitter. These two vectors add, the result being a vector which traces out an ellipse with time. That is, as it oscillates at the vlf frequency, its tip traces an ellipse. The orientation of this ellipse is arbitrary, but is greatly extended along the direction of the primary field. This is referred to as polarization eclipse and the total VLF field is said to be elliptically polarized. Two special cases are noted: if the ellipse is a circle, the field is circularly polarized and if the ellipse collapses to a line, then the field is linearly polarized. The total field is measured in the VLF survey simply because there is no convenient means of to separate the primary and secondary fields.

Two parameters measured by earlier VLF receivers are: the tilt angle (α) of the major axis of the polarization eclipse and the ratio of the minor to the major axis (H_2/H_1) referred to as the ellipticity (ε).

At any point in space, the total VLFfield is the sum of the primary field and secondary field caused by the induced current or charges.

It is notable that the primary field is totally horizontal while the secondary field can assume any orientation. Also, the secondary field can be phase shifted by an amount Ø relative to the primary. Of course the primary is assumed as the phase reference.

The tilt angle is approximately equal to the in phase part of the vertical component. The in phase and out of phase part of the horizontal component are also measured. Once the in phase (real) and out of phase (imaginary) part of the three components are known, any parameter can be derived. These are considered the fundamental parameters which completely describe the vlf field.

Plotting VLF Parameters

For field detailed interpretation of single line data, the various parameters are generally plotted in profile form.

Method Data Interpretation

As in other geophysical method where quantitative interpretation is possible, the assessment of data acquired should progress from rough preliminary estimates made in the field towards sophisticated methods of interpretation, eventually based on the complete survey. Such a procedure keeps the fieldwork up to date, control the day-by-day programmer and indicates where more intensive work is warranted, both in the field survey and its interpretation.

This section deals with a detailed explanation of the methods used for interpretation of data acquired from the Electromagnetic and Resistivity survey methods used in this study.

Method of Electromagnetic Data Interpretation

In the Electromagnetic (EM) survey, a notice in the rise of the curve signified that a conductive structure has been encountered as ENVI displayed a peak (anomaly) in a normally straight line. When the complete anomaly was shown in the screen and the cursor moved to the peak value, by pressing the INTERPRETE key, ENVI indicated the depth to the conductive zone and its dip. In other words, the instrument can be reprogrammed (with a few simple key strokes) to display the in-phase and quadrature, magnetic field, tilt angle components used by most geophysicists for interpretation.

Therefore, the interpret key on the ENVI instrument aided interpretation in the stations where an anomaly was discovered.

Hence, unlike most geophysical instrument, ENVI interprets data on site without requiring complicated interpretation.

VLF Data Interpretation Method

The VLF data was interpreted using Microsoft excel spread sheet and RAMAG.EXE geophysics software. The Microsoft excel sheet was used to reduce the raw data into compactible format for further interpretation. The RAMAG. EXE software was used to interpret the data properly.

The Quantitative Interpretation

The quantitative interpretation such as:

- Conductivity determination which aim at determining facts about the body`s conductivity.
- Model collection which present a collection of models to aid interpretation. Each model present a given geometric shape.
- Fraser filter which is a process applied to profile data to provide contour results. That is, one works with a contoured plane map as opposed to individual or stacked profiles. This process simply involves mathematically passing (convolving) the shape of an expected anomaly along the various profiles. When this anomaly outline matches one in the measured data, a large positive number result. Noise in the data and reverse cross over reverse cross over and long rolling responds are all suppressed mathematically. The values plotted on the line as the filter (sample anomaly) passes and the positive values contoured to produce a map.
- Hjelt filter which can be thought of as a generalized Fraser filter, while the Fraser filter is based upon the notion of pattern matching and the basic filter theory, the hjelt filter was developed from the concept of magnetic fields associated with current flow.

Qualitative Interpretation

The layered earth model and sheet like conductor are suitable for attempting a quantitative interpretation. Both model have received extensive coverage in the literature and are relatively well understood.

Result Presentation and Interpretation

Data Presentartion

A comprehensive VLF data reduction and interpretation was carried out to evaluate the structural deformations which are associated with the basement complex especially the study area.

Very Low Frequency (VLF) Electromagnetic Study

The VLF data obtained were filtered, using a Karous-Hjelt filter, processed and presented as profiles by plotting of the filtered real and filtered imaginary components against distance using Microsoft Excel package while the corresponding Karous-Hjelt (K-H) pseudosections of the profiles are shown in Figures respectively. The Karous-Hjelt filter computes the approximate subsurface current density giving rise to a given profile of data and the values are relative across the profile. The output of the Karous-Hjelt filter is relative current density versus surface position at a chosen depth. Lower values of relative current density correspond to higher values of resistivity. Interpretations were done normally by considering the high amplitude signal, which is diagnostic of weathered or fractured zones. The double plots of the filtered real and filtered imaginary enable qualitative identification of linear features i.e. point of coincidence or crossovers and positive peaks of the real and filtered anomaly. From these plots (figures, minor linear features suspected to be faults/fractured zones (plumes).

The VLF data, i.e. (real and imaginary components) of the EM fields measured was subjected to Fraser (1969) filtering to increase the signal to noise ratio of the data set and enhance the anomaly signature. The filtered real transform every genuine crossover or inflection points of the real anomaly to positive peaks while reverse cross over become negative peaks. Interpretation of the data along these traverses indicate a resistivity high (less positive values) over the contaminant plume, which correlates with the electrical resistivity data.

The magnitude of the resistivity of the subsurface materials decreases going away from the fractured or faulted area.

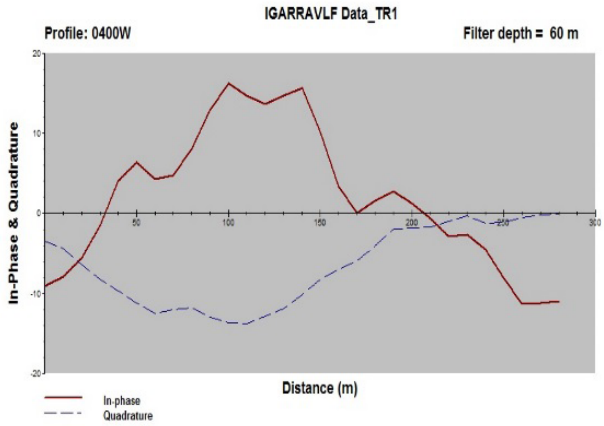

Figure 8(b).Karous & Hjelt filter for traverse I

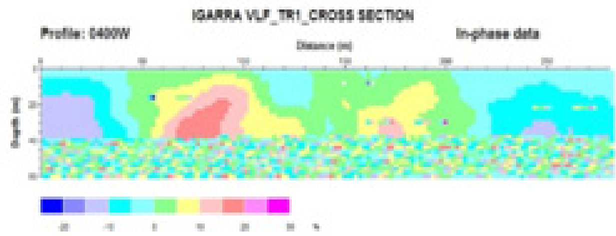

Figure 8(c).Traverse I cross section (RAMAG) software

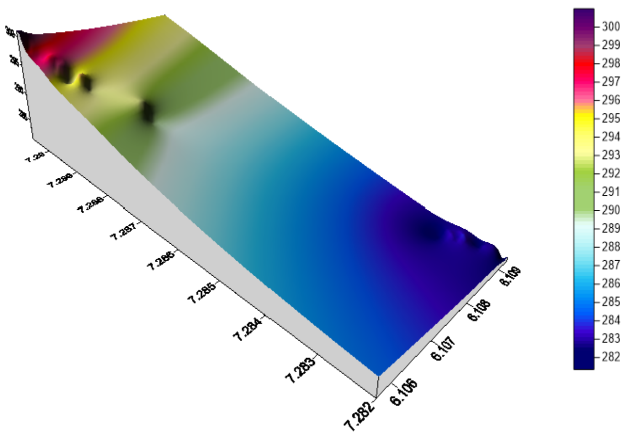

Figure 8(d).Traverse I cross section (RAMAG) software

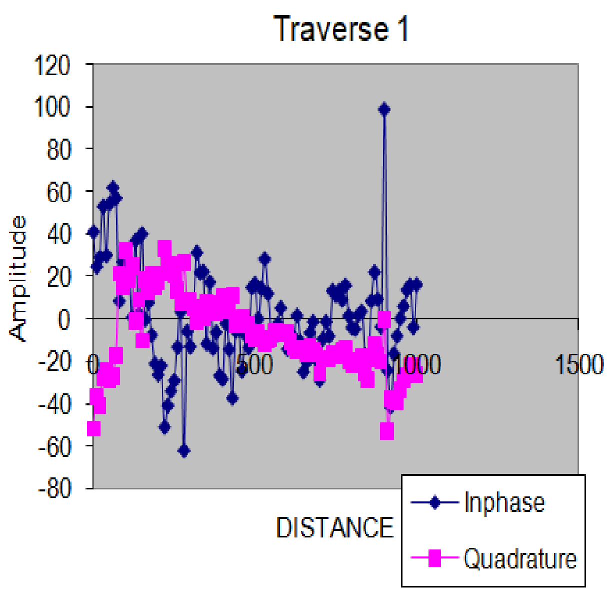

Figure 8(a).Cross plot of traverse I

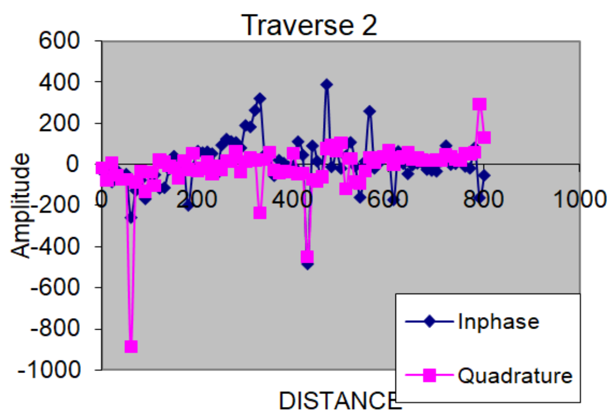

Figure 9(a).Cross plot of Traverse 2

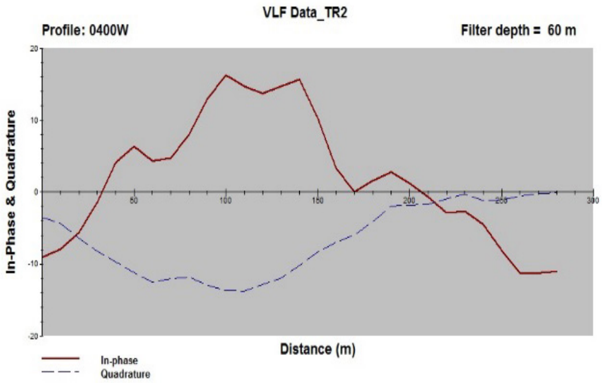

Figure 9(b).Karous & Hjelt filter fir traverse 2

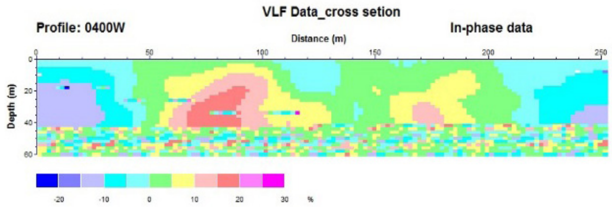

Figure 9(c).Cross section of Traverse 2

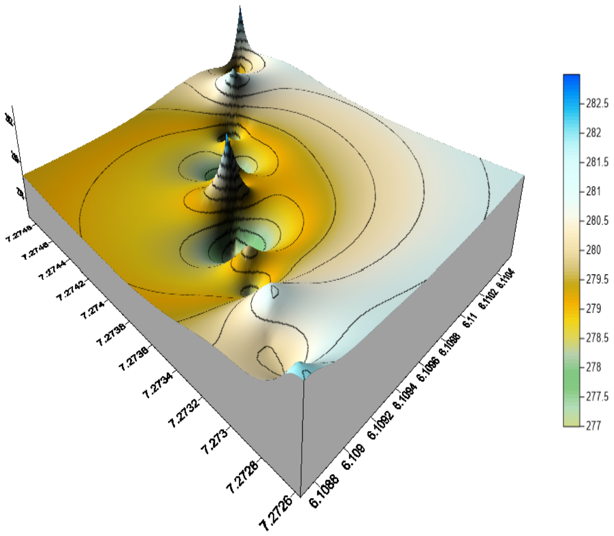

Figure 9(d).Topographic section of traverse 2

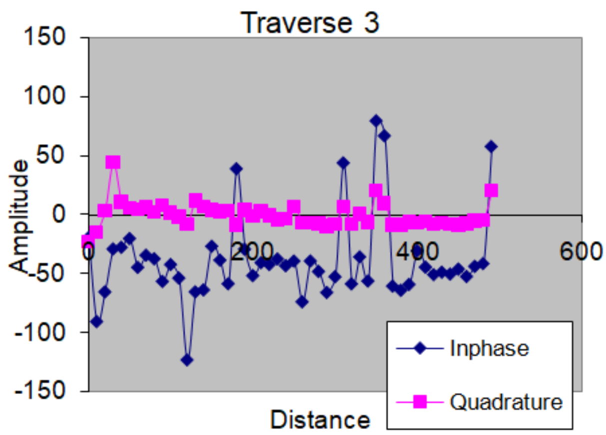

Figure 10(a).Cross plot of Traverse 3

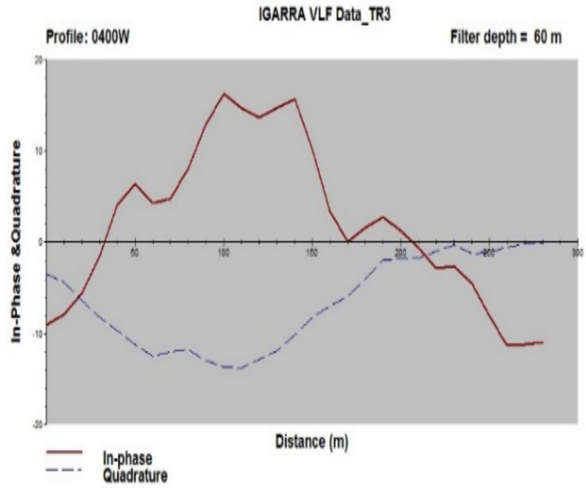

Figure 10(b).karous & Hjelt Filterr for traverse 3

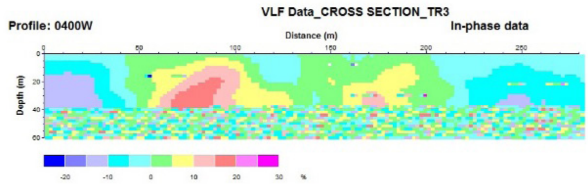

Figure 10(c).karous & Hjelt Filterr for traverse 3

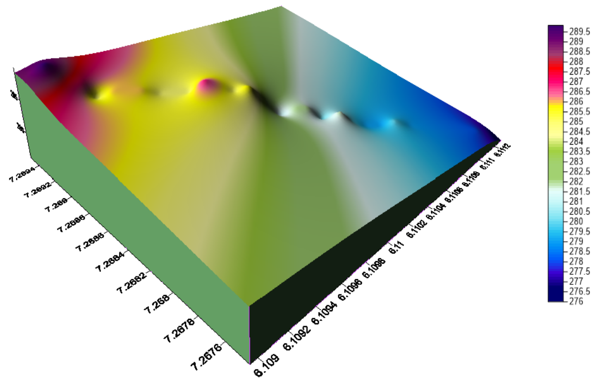

Figure 10(d).Topographic section of traverse 3

Profile Interpretation

VLF-EM Profile along Traverse 1

For the profile along this traverse (Figure 10a),which is located southwest-Northeast, i.e., Asjam Hotels (base station) to market junction, points diagnostic of conductive zones are found at horizontal distance between 80m, 130m, 160 m, 320m, 480m and 900m. The structure of the point at a distance of 900 is very diagnostic with a very high amplitude in phase of 99.1. Thus, this point can be a center of probe if further geophysical investigation is to be carried out at the study area. This means that the area is probably highly fractured and can serve as a conductive zone.

VLF-EM Profile along Traverse 2

High conductivity zones whose response are highly significant and occurs at horizontal distance of 340m, 470m and 560m with their characteristic in phase values of 265.2,390.2 and 260.3 respectively, located along Igarra market road to junction leading to Uromi-Auchi road. This high amplitude and in phase values of these zones shows the occurrence of weathered and highly conductive zone. Due to this conductivity responds, we can infer the presence of geologic structure such as weathered, fractured and faulted rocks.

VLF-EM Profile along Traverse 3

For the profile along this traverse, located along Uromi-Auchi road, points diagnostic of conductive zones are found at horizontal distance between horizontal distance of 170 and 190 with an in phase value of 38.8, at a distance of 310,the in phase value is 43.8. At a distance between 350m and 370, there is an occurrence of structure with an in phase value of 79.5 and also at a distance of 490, a structure occurs with an in phase value of 57.7. These points are highly conductive zones as shown by intrinsic and characteristic highs. It can be suggested that these points serve as a zones of proper attention when working in the study area.

Discussion, Conclusion and Recommendation

Discussion

A plot of the in-phase, quadrature, Fraser-filtered and amplitude analytical signal of the in-phase component of three traverses, located in three different locations as seen in Figure ,10, 11 and 12, was first carried out in order to compare how well the Fraser-filtered and the amplitude analytical signal can be used to locate the exact position of an anomaly. The result for all the traverses shows how the maximum of the bell-shape symmetrical curve of the amplitude analytical signal compares very well with the peak of the Fraser-filtered data over the crossover points between the in-phase and quadrature. A qualitative interpretation of VLF-EM data is based on the cross-over point between the real and imaginary data which appears as positive peaks in the Fraser-filtered real curve, these regions constitute anomalous zones which can be attributed to the presence of vertical conductor or lateral contacts of different resistivities beneath the surface (Srigutomo et al. 2005). This therefore ascertains a simple fact that the amplitude analytical signal of the in-phase component mimics the Fraser-filtered of the in-phase component. The existence of VLF shows the occurrence of relatively more conductive zone. The VLF anomaly is well developed and appear to be possible bedrock sourced.

Application of VLF

An assortment of international examples follow up which deals with a variety of VLF applications. These demonstrates interpretational procedures and may introduce the user to unfamiliar application.

Mineral Exploration

The VLF data taken over the study area can be used to analyze the occurrence of mineral deposits of possible occurrence in the study area. Both the in phase and out of phase vertical components are given, as well as the horizontal in phase component parallel to the survey line (i.e. x-component). This horizontal component is normalized by the primary field which, in this case, is also oriented directly down the survey line. The analysis of this data can be characteristic and diagnostic of the zones of possible mineralization.

Ground Water Studies

Figures, 10, 11 and 12, shows the plots of data obtained at Igarra, Southwestern Nigeria, which is a basement terrain. Objective of the survey was to locate structures in the bed rock which could serve as catchment for ground water. The profile indicate extreme phase rotation. This is to be expected since the basement is highly fractured. Bed rock depressions beneath conductive structures likely produce VLF responses as a result of galvanic current flow. That is, the large current sheet flowing in the overburden as a result of the primary electric field, is channeled along the basement structures and appear as a line of anomalous current. Therefore assertions can be made based on this observation as regards to groundwater investigation and subsequent analysis.

- Structures found within the basement terrain are capable of being a good source for ground water and can be located with the aid of VLF
- Structures within the basement are usually zone of accumulation of conducting materials and are detectable to depths approaching the theoretical limit set by dampening of the VLF wave.

Engineering Studies

Some of the objectives of these mathematical modelling and interpretation is to determine the depth to basement along the profile. Possible applications include foundation studies, road construction, overburden volume calculation etc. The measured parameters include the apparent resistivity (ℓ_a) and phase angle $\O_a$.

Conclusion

Both petrological and geophysical studies and techniques improve the efficiency of mapping the basement complex terrain. VLF-EM technique which is denoted by different anomalous areas in conductivity. The electrical conductivity varies largely with depth, which may be attributed to differences in the nature and permeability of subsurface materials. The basement has been identified as a conductive feature, the low resistivity zone below the basement is an indicative of possible zone of structural deformation. The

VLF data successfully identified relatively broad areas of conductivity by detecting the edges of broad conductive zones. The obvious conclusions derivable from these results is that the basement complex of southwestern Nigeria is highly affected due to pan African orogeny and the structures formed are now possible zones of groundwater occurrence in the area.

Recommendation

Based on the resent studies and various review, the following are recommended for adequate and more fruitful studies:

- Structural and hydrogeologic map of the area constitute a useful base map for ground water exploration. The technology of VLF should be more diversified for both water and mineral exploration and for engineering construction. water abstracted from the area must be treated appropriately due to the occurrence of iron to mitigate its hazards to the inhabitants.
- Proper data processing and interpretation technique should be made available (including the software) for proper geophysical studies.

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