Integrated Geophysical Approach to Solid Mineral Exploration: A Case Study of Kusa Mountain, IjeroEkiti, Southwestern Nigeria.

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ABSTRACT

An integrated electromagnetic and geo-electric study was carried out in some part of Kusa Mountain Ijero-Ekiti, Ekiti-State, southwest Nigeria. Very Low Frequency Electromagnetic (VLF-EM) profiling was measured along eight traverses, and conductive (fractured) zones were established. This enabled the location of 10 vertical electric sounding (VES) points at prominent fractured zone, which was further analyzed to reveal the mineralized zones. A constraining model which was developed with reference to VLF-EM and electrical resistivity results support a W-E trending mineralized zone around the central and northern region. Future exploration and exploitation should be concentrated around these regions.

(**Keywords:** fracture, electromagnetic, geo-electric resistivity, exploration, mineral)

INTRODUCTION

Minerals are the constituents of rocks, ores and meteorites and with a few exceptions are the most stable chemical elements known to Man (Odeyemi, 2001). Minerals are the foundation for economic and industrial development of any nation. According to Runge, (1996) and Vogley, (1985) materials used by humans are derived from two major sources, namely; agriculture and mining; but mining alone accounts for about 70 percent of the total.

A purposeful or detailed exploration of mineral deposits should provide information on the actual mode of occurrence of any identified mineral ore, its peculiar chemical and mineralogical composition, and the reserve. With this information in a country database, investment planning for national economic development becomes easier (Onyemaobi, 2001; Runge, 1996). Systematic field mapping by (Okunlola et al; 2005) reveals that the Precambrian pegmatites of Ijero area are hosted by biotite-gneiss and biotite Schist. Petrographic analysis also shows that they contain mainly quartz, plagioclase feldspar, microcline and muscovite with accessory biotite, hornblende and tourmaline. In this study, a comprehensive reconnaissance study was first carried out using VLF-EM which provides the necessary background information for the geo-electric survey using Vertical Electrical Sounding (VES) technique.

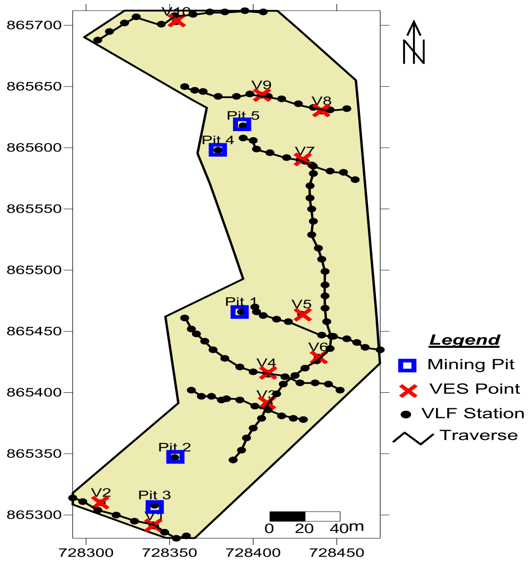

Figure 1: Location Map of the Study Area.

GEOLOGIC SETTING OF THE STUDY AREA

The study area falls within the basement complex of southwestern Nigeria. It is characterized by the abundance of pegmatites which harbors minerals such as gem-stones and rare earth metals as well as metallic-ores such as lepidolite among other minerals.

The study area falls within Latitudes $7^{\circ}49^{\prime}50^{\prime\prime}$N to$7^{\circ}45^{\prime}50^{\prime\prime}$ N and Longitudes $5^{\circ}03^{\prime}$E to $5^{\circ}07^{\prime}$E (Figure 3) of the Greenwich meridian. The Basement Complex rocks of Nigeria forms a part of the African crystalline shield which occurs within the Pan African mobile belt that lies between the West African and Congo Cratons and south of the Tuareg Shield (Oyawoye, 1972) (Figure 2). It is a polycyclic terrain which suffered its most pronounced deformation and mobilization during the Pan-African age (600 Ma).

Grant (1971) established an orogenic belt of similar age in the Ghana-Togo-Dahomey area in the eastern margin of the Craton. Different ages have been ascribed to the Nigerian Basement Complex using different radiometric dating methods such as Rb/Sr, K/Ar and Th/Pb. Grant, (1971) observed that majority of the radiometric ages obtained; fall in the range of 600 Ma, which corresponds to the Pan-African thermo-tectonic event. It is a Precambrian rock occupying about half the landmass of the country and consisting predominantly of folded gneisses, schist and quartzite into which have been emplaced granitic and to a lesser extent, more basic material.

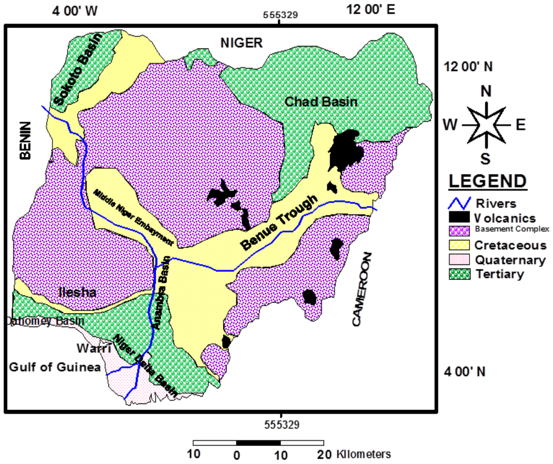

Figure 2: Geological Map of Nigeria showing Basement Complex and Sedimentary Terrain.

It is intruded by the Mesozoic calc-alkaline ring complexes (Younger Granites) of the Jos Plateau and is unconformably overlain by Cretaceous and younger sediments. Several workers have proposed different lithologic classifications for the basement complex terrain. These include Oyawoye (1972) who proposed four major classifications and Rahaman (1976) who proposed six. Three principal subdivisions are recognizable within the basement complex. Odeyemi (1982) gave these subdivisions as: the ancient migmatite-gneiss complex, the Schist belts, and the Pan African plutonic series.

The Migmatite-gneiss-complex is the oldest, most widespread and abundant rock type in the Basement (Ogezi, 1988). It is of Archean-Proterozoic and possibly undergone polycyclic evolutionary histories. The Nigerian Schist belts comprise of low-grade meta-sediments and metamorphosed pelitic and psammitic assemblages that outcrop in a series of N-S trending synformal troughs infolded into the crystalline complex of migmatite gneiss. The Pan-African Granites referred to as Older Granite include rocks of wide range of composition varying from tonalite, granodiorite, granite and syenite (Rahaman et al., 1988). The pegmatite from Ijero area form an intrusion into the older rock of biotite gneiss that occupies the central part of the area, covering about three quarter of the total land mass (Figure 3).

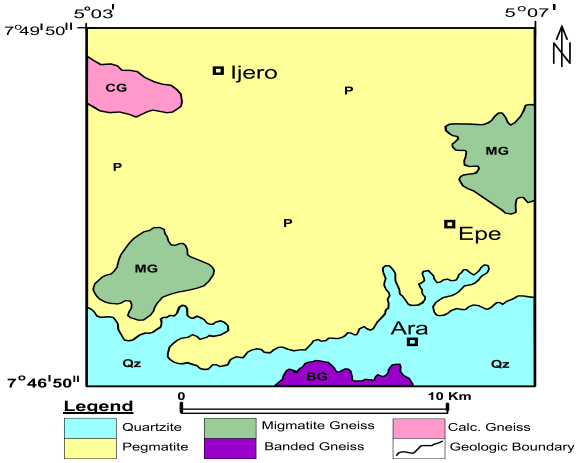

Figure 3: Geological Map of Ijero, Ara, and Epe town.

Mineral composition includes quartz, biotite and hornblende, while accessory minerals include apatite and Opaques. Biotite-gneiss occupies the north-central area and extends towards the northwestern direction. Outcrops of the rock are low-lying, highly foliated with characteristics black tints imposed by the preponderance of biotite. The pegmatites comprise quartz (30 %), albite (27%), muscovite (14%) and microcline (14%) while biotite (1.0%), hornblende (2.8%) and tourmaline (3.2%) minerals occur in subordinate amount.

Quartz occurs as irregular masses of euhedral crystals. Microcline occurs as phenocrysts with characteristic strong cross-hatched twinning and variable microperthiticintergrowth while carlsbardtwinning and albite twinning characterizes the albite. Muscovite occurs as large platy grains. Accessory minerals include tourmaline and biotite. The tourmaline crystals exhibit long needle-like prismatic shapes with their long axis aligned parallel to each other.

MATERIALS AND METHODS

Electromagnetic measurements use alternating magnetic fields to induce measurable current in the Earth. The traditional application of electromagnetic methods in mineral exploration has been in the search for low-resistivity (high-conductivity) massive sulphide deposits. The EM response was measured using the ABEM WADI VLF-EM instrument which measures the in-phase (Real) and quadrature (Imaginary) components of the induced vertical magnetic field as a percentage of the horizontal primary field along the eight profiles.

The preliminary survey of the area entails studying of rock outcrops and their distribution on the study area, road networks and major features so as to come up with a location map of the study area in order to establish geophysical traverses. Measurements were taken at 10 m intervals along each of the profiles lines in the West-East direction with lengths ranging from 250 to 350m (Figure 1).

The EM data was interpreted and inverted into a 2-D section using the Karous-Hjelt filtering (Karous and Hjelt, 1983). The EM profiles were interpreted quantitatively by matching with geophysical models (McNeil, 1980a and Palacky et al., 1981).

The quantitative analysis enabled the identification of profiles where positive amplitude of filtered real crossover the inflection points of the raw real as points of anomaly for vertical electrical sounding (Sundarajan et al., 2007). The VLF-EM data were presented as maps by plotting filtered real and filtered imaginary values as contour maps using Surfer 10 software.

The equipment employed for the resistivity field data measurements is the resistivity Meter – Model-SSR-MP1. Ten (10) vertical electrical soundings were conducted, using the conventional Schlumberger technique, with half electrode spacing (AB/2) varying from 1 to 65m. The VES were conducted at selected locations based on the results obtained from the VLF surveys.

The apparent resistivity values obtained from the VES were plotted against electrode spacing on a bi-log paper. Visual inspection of these curves gave qualitative interpretation of the subsurface resistivity variations. Quantitatively, the sounding curves were interpreted by partial curve matching technique (Keller and Frischknecht, 1966) using a 2-layer master curves and the corresponding auxiliary curves. Layers parameters from this manual interpretation were inverted with the aid of computer aided iteration curve matching techniques using Resist Version 1.0 (Vander Velpen, 1988). The results of the quantitative interpretation of the VES data are summarized in Table 1.

RESULTS AND DISCUSSION

VLF-EM Results

Filtered real component readings were plotted as a contour map of the study area (Figure 4). VLF-EM anomalies were delineated as fairly-conductive, conductive, highly-conductive, fairly-resistive and resistive responses at different locations across the study area. The map is characterized with zone of positive and negative anomalies, the readings range between –9.9 to + 7.0 %.

Positive anomaly is indicative of steeply-dipping linear features such as fractures which are prominent around the central and the northern flank. These features serve as channels for migrating fluids and minerals. Mineralized zones are indicated by positive anomaly on the map.

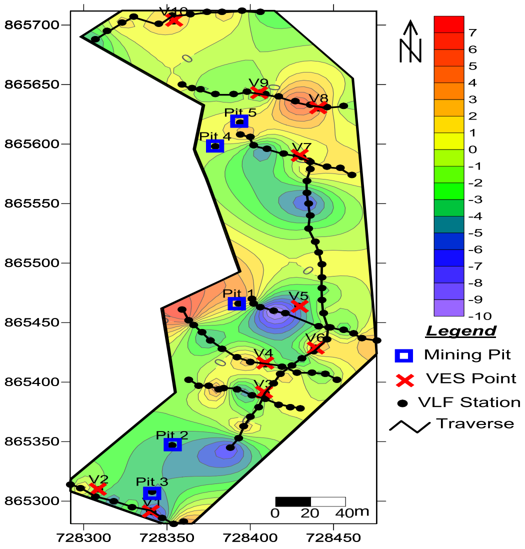

Figure 4: Filtered Real Component Map of the Study Area.

The filtered imaginary map is a plot of the filtered imaginary response across the study area (Figure 5). These values range from –8.5 to + 6.8 %. Very good conductors, e.g. mineralization or fracture zones (with conductive fluid), will in general show very large anomalies in as well the real as the imaginary part (WADI Instruction Manual).

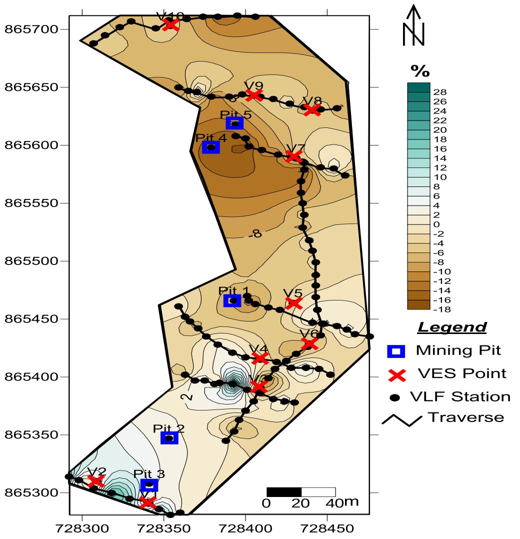

Figure 5: Filtered Imaginary Component Map of the Study Area.

The map shows both positive and negative anomalies, with positive anomaly indicating conductive structure approximately 90°out of phase with the primary field. The region around VES 1, 2, 3, 4, and 10 shows high positive anomaly suspected to be fractures which favor the accumulation of minerals.

Geo-Electric Method

Electrical resistivity methods primarily reflect variations in ground resistivity (Omosuyi et al., 2008). These variations are due to observable contrast between geo-electric boundaries within the subsurface. The 2-Dimensional view of the geo-electric parameters (resistivity and thickness) obtained from the electrical resistivity sounding data with respect to the VLF-EM results obtained earlier were used to delineate the mineralized layers. The geo-electric sections (Figures 6, 7 and 8) of some VES stations within the study area are shown below.

Figure 6 shows a geo-electric section of VES 3with topsoil (mainly superficial deposit) having resistivity values of 613.1 Ohm-m and thickness of 0.6 m. Under this is a layer of soil with resistivity value of 188.6 Ohm-m and thickness 1.3 m believed to be lateritic in nature. Just after the lateritic soil is the anomalous layer which is characterized by high resistivity value of 1590 Ohm-m and thickness 7 m suspected to be a mineralized zone. The fractured basement is the last geo-electric sequence with resistivity value of 350.8 Ohm-m and depth to bedrock is 8.9 m.

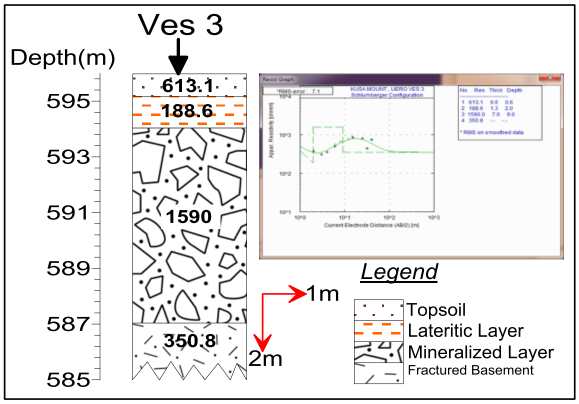

Figure 6: Geo-Section of VES 3.

Figure 7 is a geo-electric section of VES 4 with topsoil (mainly superficial deposit) having resistivity values of 208.4 Ohm-m and thickness of 1.3 m. The next layer is a lateritic soil of resistivity 362.7 Ohm-m and thickness 6.6 m. This is underlain by arbitrarily resistive layer suspected to be a mineralized layer (resistivity value 4392.7 Ohm-m and thickness 7.8 m). The weathered layer is below the resistive rock with resistivity 248.7 Ohm-m and is 5.1 m thick. The fifth and last layer is the infinite bedrock of resistivity 856.8 Ohm-m. The depth to bedrock is approximately 20.8 m.

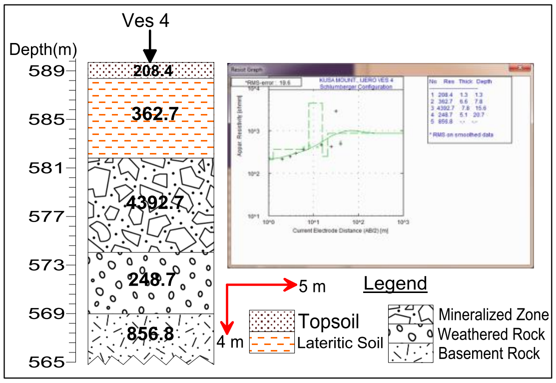

Figure 7: Geo-Section of VES 4.

Figure 8 reveals geo-electric layers under VES 8 with topsoil of resistivity values of 1030.7 Ohm-m and thickness of 0.9 m. The topsoil is underlain by a thin lateritic soil of resistivity 123.3 Ohm-m and thickness 0.2 m. Under the lateritic layer is the anomalous layer with resistivity value 1139.7 Ohm-m and thickness 2.4 m believed to contain solid minerals. The weathered layer is just below the mineralized layer having resistivity 330.8 Ohm-m and thickness 7.9 m. This is underlain by a fresh basement of resistivity 2983.7 Ohm-m and depth to bedrock 11.4 m.

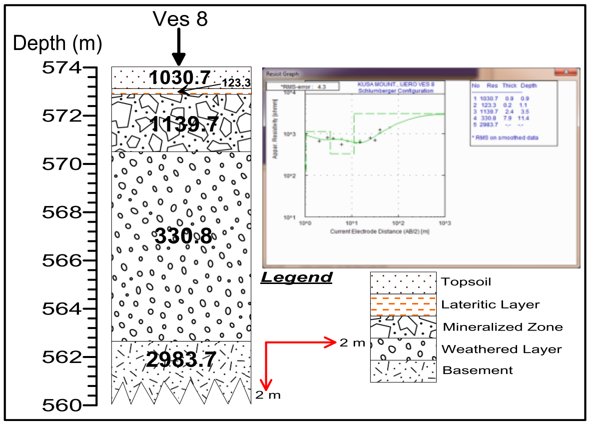

Figure 8: Geo-section of VES 8.

Mineral Potential map of the study area

Evaluation of the occurrence of mineral within the study area is based on the characteristics of the geo-electric parameter (resistivity and thickness) of the suspected anomalous layers within the study area. The mineral potential map (Figure 9) was used to classify the study area into high, medium, and low mineral potential zones. It is believed that the mineral in question is highly resistive.

Table 1: VES Result Summary for within the Study Area.

VES Num.	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	h_1	h_2	h_3	h_4	Northing	Easting
1	668.4	571	128.5	600.9	-	1	2	1.4	-	728341	865291
2	1447.6	415.3	696.4	-	-	0.4	3.1	-	-	728309	865310
3	613.1	188.6	1590*	350.8	-	0.6	1.3	7	-	728408	865390
4	208.4	362.7	4392.7*	248.7	856.8	1.3	6.6	7.8	5.1	728408	865416
5	1140.1	236.3	973	-	-	0.9	6.5	-	-	728429	865464
6	424.9	288.7	661.9*	168.6	9489.4	0.7	0.5	5.9	-	728439	865429
7	756.3	286.5	1957.7	-	-	0.4	9.7	-	-	728431	865589
8	1030.7	123.3	1139.7*	330.8	2983.7	0.9	0.2	2.4	7.9	728441	865630
9	692.2	342.5	1850.7	-	-	0.7	0.9	-	-	728405	865643
10	183.3	3906.5	1085.9	-	-	0.5	1.3	-	-	728354	865703

Note: Asterisk values of layer resistivity are anomalous (they are believed to contain resistive minerals).

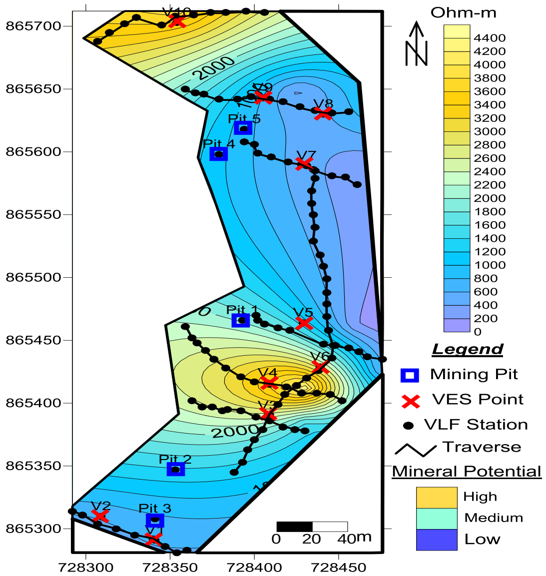

Figure 9: Mineral Potential Map of the Study Area.

The area under VES 3, 4, 6 and 10 are classified as high mineralized potential zone, while the remaining part shows low to medium mineralized potential. A constraining model which was developed with reference to VLF-EM and electrical resistivity results support a W - E trending mineralized zone around the central and northern region.

CONCLUSION

Integrated geophysical technique has proved very successful and cost effective in delineating structures suspected to have favored the accumulation of minerals within the study area. The VLF-EM results revealed fractures (positive anomalies) which are suspected to have served as migration path for the minerals delineated. VLF-EM and geo-electric methods jointly reveal potential and trend of minerals and this enable the classification of the area into low, medium, and high mineral potential zones.

Kusa Mountain, Ijero Ekiti is highly mineralized; as revealed by this study. The trend of mineral occurrence is approximately W-E, structurally controlled and highly localized. Therefore, future exploration and exploitation programs should be restricted to the high mineral potential zone while scrupulous geophysical survey should be carried out prior to drilling.

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SUGGESTED CITATION

Ogungbemi, O.S., O.O. Alu, and O. Ologe, O. 2014. **"**Integrated Geophysical Approach to Solid Mineral Exploration: A Case Study of Kusa Mountain, Ijero Ekiti, Southwestern Nigeria". *Pacific Journal of Science and Technology.* 15(1):426-432.

Pacific Journal of Science and Technology