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# Integrated geophysical methods for gold exploration in artisanal mining site of Iperindo, Southwestern Nigeria

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## ABSTRACT

Combined Geophysical surveys involving ground magnetic, Very Low Frequency Electromagnetic (VLF-EM), Vertical Electrical Sounding (VES) and Horizontal Profiling (HP) (VES&HP), and Induced Polarization (IP) were carried out at the gold mining site of Iperindo, Southwestern Nigeria. This is aimed at delineating geologic structure and its relation to mode of mineral occurrence and depth to mineralised body. This demonstrates the reliability and effectiveness of combined geophysical surveys in mineral exploration. Interpreted profiles of ground magnetic data revealed fractures, veins, and lithological contact in the study area. Depth estimation of delineated geological structure using Peter's half slope method shows the depth vary between 50 m and 500 m. VLF-EM results revealed shallow linear geological features occurring at depth range of 40 - 200 m. The linear features approximately trend NE-SW, W-E, and NW-SE directions. Interpretation of VES/HP and IP results showed variations in resistivity and chargeability values, respectively. Delineated geologic structures from VES/HP interpreted 2-D section correspond to zone of high chargeability from IP interpreted 2-D section. This indicates the presence of disseminated mineral deposits within the geological features. This study revealed that the occurrence of gold within the mining pits is structurally controlled and disseminated. The study has provided the effectiveness of geophysical application in mineral exploration and the methodology can be applied in any similar geological terrain to unravel mineralization potential.

**Keywords:** Chargeability, disseminated mineral, geologic structure, quartz vein

## 1. INTRODUCTION

Geophysical methods are commonly used primarily as vital tools for unraveling the geologic formation and structure in the subsurface for ore prospecting and other geophysical investigations of economic value. The application of geophysical methods in locating minerals in the subsurface is based on measuring the disparity in the physical properties of the mineral deposit and its surrounding rocks. However, several investigators such as Airen and Babaiwa, (2021), Kayode et al., (2022), Ezeh

and Ikegbunam, (2023), Casulla and Mizunaga, (2023) and Zaid et al., (2023) have shown that distinctiveness and confirmed the usefulness of geophysical methods in targeting disseminated ore deposits and mineralized veins within lithologic. Mineral exploration and development involve investigative activities before to mining.

The gains of successful mineral exploration can be massive if a mineral deposit is revealed, evaluated, and developed into a mine using reliable and effective methods (Olomo et al., 2022a; Olomo et al., 2022b). Integrated geophysical investigations are well known in a wide range of geological, and exploration studies. They play very significant roles in demarcating the lithological contacts and local and regional geological structures, which are keys to mineral exploration (Osinowo et al., 2021). Iperindo is well-known to be a gold mining site as well as other minerals such as rare earth metals in Southwestern Nigeria, where mining activities are ongoing by individuals on a small and large scale (Akande et al., 1988; Garba, 2000; Garba, 2002; Olomo et al., 2018).

However, artisanal miners are indiscriminately engaging in mining activities as shown in plate 1 and 2 without the knowledge of host lithologies, depth and extent of gold mineralisation, and its mode of occurrence. This mining activity has resulted into land degradation in the study region as the abandoned mining pit littered within the area. This study is aims to apply geophysical methods to provide detailed information on mode of occurrence, the extent, the trend and depth to structures (e.g. fracture zones) that might be controlling emplacement of gold mineralisation in the area. Because of these, traverse was established across one of the mineralised mining pits within the study area. This research has shown the efficacy and importance of geophysical investigation in mineral exploration.



**Plate 1** Abandoned Mining Pits in the Study Area

### **Geologic setting**

The study area is part of Precambrian Basement Complex rocks of SW, Nigeria with the presence of Gneiss-Migmatite-Quartzite and Quartz-Schist as main rock types (Figure 1). The study area lies within latitude  $7^{\circ} 30' 20.82''$  N to  $7^{\circ} 33' 2.89''$  N and longitude  $4^{\circ} 48' 44.83''$  E to  $4^{\circ} 51' 28.58''$  E. The gneiss-migmatite-quartzite complex is the basement into which other crystalline rocks are formed (Elueze, 1986; Odeyemi, 1993; Kayode et al., 2011). The quartzite is roughly weathered and exposed. It is also foliated, fissile and demonstrates increasingly alternation amid massive and schistose mixture. The occurrence of quartzite is located on small hills and predominantly on small ridges in the area. Owing to quartzite rock subjected to milling and shattering, it has been hacked into slighter ovoid units (Oyinloye, 2011). The tiny ovoid units are made up of weak deformed quartz bounded by robustly deformed equi-granular grains of similar composition (Oyinloye, 2011). The gneisses and migmatite are interconnected in the area making it difficult to separate them on the field.



**Plate 2** Artisanal Miners Engaging in Mining Operation

## 2. MATERIALS AND METHODS

A traverse line in approximately W-E direction with station separation of 30 meters at regular interval was established adjacent to mineralized mining pit for geophysical investigation within the area.

### Magnetic Prospecting Method

Firstly, magnetic data was acquired using the Proton Precession Magnetometer, which is equipped with nuclear magnetic resonance (Telford et al., 1990). At the start of the survey, a based station outside the traverse lines was established where magnetic readings were taken before and after the survey. The magnetic readings were taken twice at each station concurrently with the times. The total magnetic field ( $\Delta T$ ) was calculated and also smoothed using equations 1 and 2.

$$3 \text{ points running average reading} = \frac{\text{Drift corrected magnetic values for 3 consecutive stations}}{3} \quad (1)$$

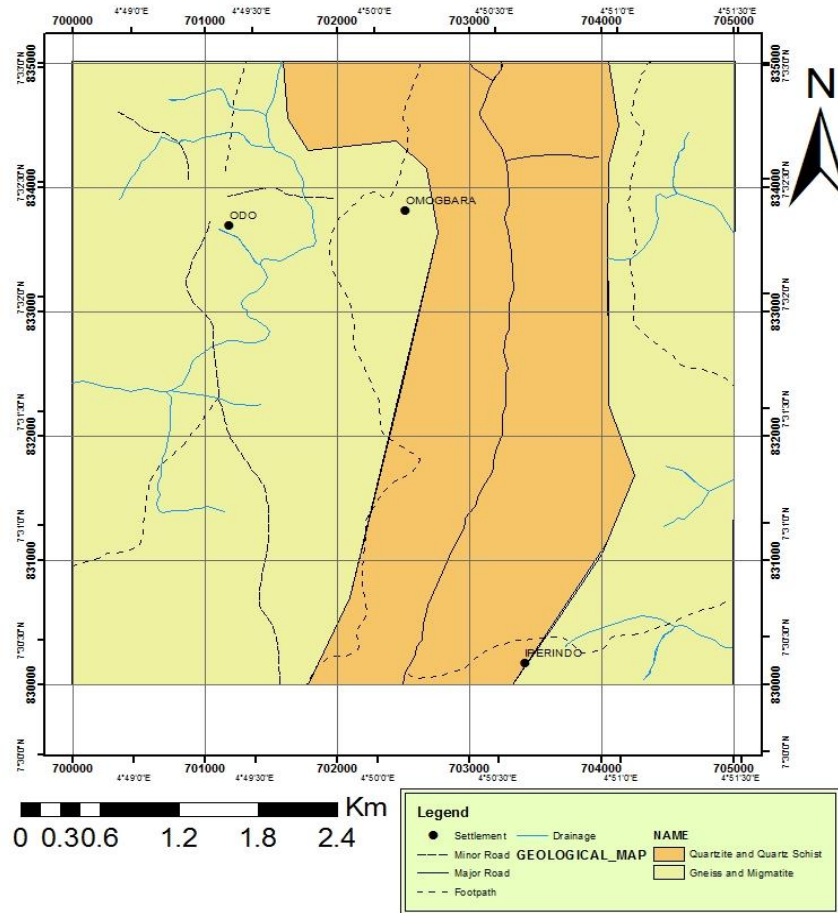
$$\text{Smoothing } \Delta T = (3 \text{ points running average reading} - IABSR) \quad (2)$$

where *IABSR* = Initial average base station reading

The method of removing regional gradient over a moderately smaller survey area by Kearey et al., (2002) was adopted to remove the regional anomaly from the drift-corrected total relative magnetic values. A trend line was fitted to the observations using the least squares criterion and subsequently subtracted from the observed data to leave the local anomalies as positive and negative residuals.

### Very Low Frequency Electromagnetic (VLF-EM)

Abem Wadi VLF measuring instrument used in calculating the EM response of the subsurface was employed to delineate the conductive zones in the area. The equipment measures the real component, the imaginary quadrature, current density and the filtered imaginary. At first, the equipment was allowed a few minutes to explore for the appropriate transmitter by scanning the entire transmitter in the world. At frequency ranging between 18.6 - 26.4 KHz, readings were taken along the established traverse at regular interval of 30 metres station separation. The equipment measured the raw real component on the field and the raw imaginary while the filtered real was downloaded from the equipment after completion of the survey. Real component were plotted against filtered real to produce VLF profile. The KHFFILT software (Karous-Hjelt and Fraser filtering of VLF measurements) was also used to process and interpret the data.



**Figure 1** Geological map of Iperindo and its Environs (Modified After Geological Survey of Ilesha Iwo Sheet 60, 1980)

### Combined Horizontal Profiling and Vertical Electrical Sounding

SAS 4000 resistivity meter, with the power source (direct current of 5-500mA) and the potential measuring device (voltmeter of 10mV-20V), was employed. A dipole-dipole electrode arrangement with 30 metres electrode and array expansion factors 5 was utilized. The traverse follows the W-E direction. The apparent resistivity of dipole-dipole data was inverted using DIPPRO software from which the field data in appearance of pseudosection, theoretical data pseudosection and the 2-D resistivity structure images of the subsurface were produced. The electrode arrays used in resistivity surveys were engaged for IP surveys. The IP data were inverted using DIPPRO software to convert the field data into pseudosection, theoretical data pseudosection, and the 2-D chargeability structure images of the subsurface.

## 3. RESULTS AND DISCUSSION

Figure 2 shows the integrated results of the ground magnetic, and its modeled geomagnetic section, VLF-EM profile and its current density section, 2-D resistivity structure pseudosection and 2-D induced polarization pseudosection along the established traverse within the study area. A total of 1020 m traverse running W-E direction was covered in the ground magnetic having maximum amplitude peak at 100 nT and minimum amplitude peak of -80 nT (Figure 2a). A probable fracture, F1 was delineated along the distance 180 m and depth 75 m. A geologic contact between migmatite and quartz schist represented by F2 was observed at distance 510 m to the east of the traverse, with depth of 80 m.

This geologic contact is within the mineralized large mining pit observed on the field during acquisition, which indicates that the mineral deposit in that area is controlled by the geological structure. Figure 2b shows the profile of raw real and filtered real components of VLF-EM data and corresponding 2-D Karous-Hjelt's in the current density section. From the 2-D current density section

(Figure 2b), conductive zones was observed at depth up to 125 m and 80 m. In addition, a conductive zone was observed at the distance 660 m with a depth of more than 200 m and width up to 120 m.

The Probable delineated fractures F1 and F2 from the geomagnetic section (Figure 2a) coincide with the area delineated as a probable fracture zone on the VLF component profile along the traverse at distances of 150 m and 660 m (Figure 2b). Also, it was detected that both the resistivity and IP sections show similar trends and consistent anomalies over zones of low resistivity and high chargeability at a distance of 210 - 360 m. Based on the 2-D resistive structure in Figure 2c, the resistive parts represented by purple color observed at a depth of 120 with a distance of 0 and 210 m with resistivity values ranging from 680 -13227 ohm-m (Figure 2c). The high resistivity values may be attributed to the quartzite veins serving as a host for gold deposit or fresh bedrock in the subsurface.

On the other hands, typical low resistivity values which are represented by yellow color having resistivity values range from 152-551 ohm-m extended to about 120 m in the subsurface along the distances of 210 m to 360 m suggests subsurface geology structures (fractures) and consequently suspected to be hosting structurally controlled gold deposit within the quartzite schist region. The interpretation of 2-D pseudosection from induced polarization (Figure 2d) shows high chargeability values indicated by purple colour, at shallow depths of approximately 60 m, having chargeability values ranging from 17 to over 70 msec with a well distinct NE-SW trend. These high chargeability anomalies suggest disseminated sulfide and gold mineralization within quartz veins.

The high pervasive IP anomalies at very shallow depths with no specific trend may partly be related to widespread clay minerals resulting from the weathering and alteration of the mica schist and the massive sulfide-bearing quartz veins. The high IP anomalies with well-defined patterns could be as a result of mineralized sulfide gold-bearing quartz veins that are sub-parallel to the regional shear system with a NE-SW orientation. It was discovered that relatively low resistivity anomaly along F2 (Figure 2c) corresponds to high chargeability anomaly (Figure 2d), implying structurally controlled disseminated gold deposit. The almost homogeneous patterns and trends defined by the anomalous zones delineated from deployed geophysical methods suggest that the mineralization is structurally controlled and highly disseminated and follows an NE-SW orientation.

Also, there was a high resistivity value indicated as purple color (Figure 2c) corresponding with high chargeability (Figure 2d). This could be a result of highly disseminated mineral occurring within the quartzite vein. The correlation implies that the underlying bedrock is well fractured; to the depth over 150 m. The results of integrated geophysical methods deployed for this study are consistent over the mineralized mining pit in the area and this is an indication these geophysical methods are complementary and can serve as an essential tool in delineating occurrence of mineral deposit. It is also necessary to state at this point that the integrated geophysical method was conducted in a monolithic study area. The interpreted results can potentially serve as a reference for other abandoned mineralized mining pits near the study location.

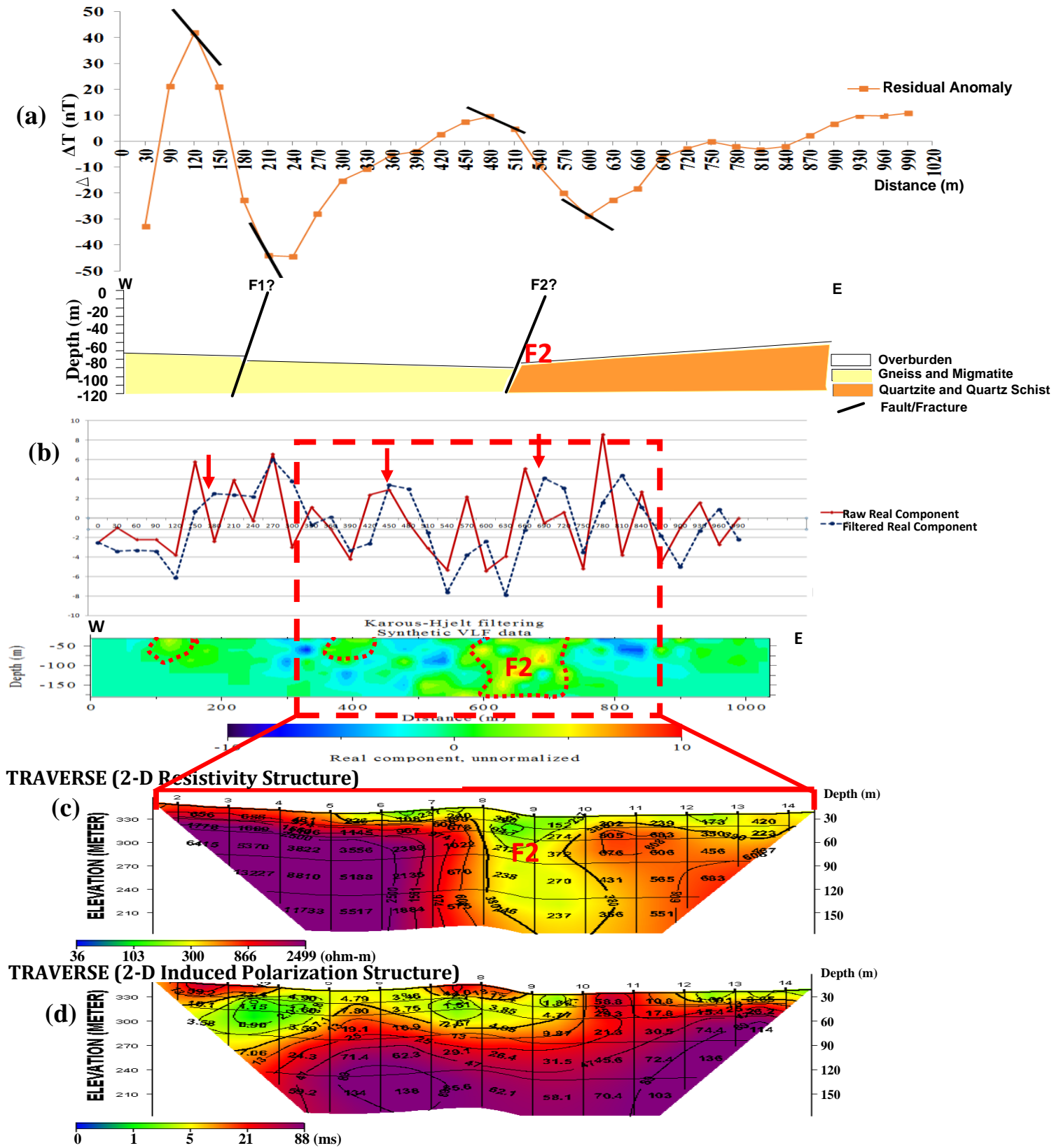


Figure 2 (a) Ground Magnetics and its Geomagnetic Section, (b) VLF-EM Profile and its 2-D Map, (c) 2-D Resistivity Pseudosection, (d) 2-D Induced Polarization Pseudosection.

#### 4. CONCLUSION

The results obtained from the different geophysical methods show anomalies indicating that mineralization in the abandoned pits is structurally controlled and disseminated. All anomalies show consistent trends in northeast-southwest direction, indicating the presence of a single mineralized body with potential for gold exploration. This suggests that further exploration is needed to confirm the feasibility of extracting gold from this area. Analyzed findings show that the depth to gold mineralization in the area is 60 m to over 150 m.

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### Author Contributions

Kazeem O Olomo: Conceptualization, Investigation, Methodology and original draft, supervision and review

Oluwatoyin K Olomo: Supervision and editing, review, analysis and validation

### Informed constant

Not applicable

### Ethical approval

Not applicable.

### Conflicts of interests

The authors declare that there are no conflicts of interests.

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### Data and materials availability

All data associated with this study are present in the paper.

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