Geological Behavior (GBR)

DOI: http://doi.org/10.26480/gbr.01.2025.01.10

ISSN: 2521-0890 (Print)
ISSN: 2521-0491 (Online)
CODEN: GBEEB6

RESEARCH ARTICLE

APPLICATION OF GEOPHYSICAL TECHNIQUES FOR GOLD EXPLORATION IN NORTHCENTRAL NIGERIA.

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ARTICLE DETAILS

Article History:

Received 23 November 2024
Revised 1 December 2024
Accepted 20 January 2025
Available online 5 February 2025

ABSTRACT

Interpretation of airborne magnetic and radiometric data in Birin Gwari area of Northcentral Nigeria reveal some anomalous areas which were further explored using ground Geophysics information of magnetic, induced polarization and resistivity survey. Combined results of the geophysical methods, reveal a wide range of linear structures likely veins, which are believed to host ore mineralization. Careful interpretation and technical assessment of the results, attributes some of these structures as probably mineralized veins with varying degrees of characterization. Their responses to physical parameters also revealed some as conductive and the others as non-conductive. Some are conductors within a resistive host while others are within a conductive host. Several of such bodies trending mostly N-S, NE-SW and NW-SE were identified. And it is instructive to note the high degree of correlation between the airborne and ground geophysical data. About seven of the anomalous zones characterized by high chargeability and high resistivity were identified from nine IP profiles within the study area. The geophysical characteristics of the identified vein lengths range from less than 50m to maximally 600m while the width ranges from few cm to maximally 20m. The identified veins were plotted on their mineral prospective maps. Test drilling should be carried out on the priority targets to authenticate the above submission. The mineral prospective priority target maps should be used as guides for the drilling. Other exploration methods such as geochemical sampling of soil and rock samples should be integrated with this geophysical report to see if high concentration of gold coincides with geophysical anomaly and priority targets; this will assist in more precise drilling of target location.

KEYWORDS

Anomalous, technical assessment, physical parameters, ground geophysical

1. INTRODUCTION

The application of geophysical methods, both ground and airborne, to gold exploration, is increasingly becoming popular globally. Geophysical tools encompassing various techniques such as magnetic, self-potential (SP), induced polarization (IP) and resistivity, are important techniques in mineral exploration for ores located in basement rocks (Sultan et al.,2009). The direct use of geophysical surveys in mineral exploration is to locate and identify potential targets having anomalous physical properties (Airo.,2015). Further uses encompass delineation of larger-scale structures in the deposit they may be related to, or investigation of smaller scale details within the deposit. A key element for exploration is to understand and detect different types of mineral systems, their favorable geological settings and controls at regional to local scales (Oldenburg and Pratt., 2007). Orogenic gold deposits in greenstone belts are commonly located adjacent to crustal-scale shear zones, and on district scales affiliated to smaller shear zones, which are geometrically related to crustal-scale shear zone. The host rock can likely be any rock type and detectable geophysical anomalies can be caused by alteration haloes, from common alteration processes such as carbonatization, sericitisation and silicification (Groves and Foster, 1991; Paterson and Hallof, 1991; Airo, 2002; Allibone et al., 2002; Salmirinne and Turunen.,2007). Crustal-scale structures, faults and shear zones commonly produce observable geophysical anomalies; however, aeromagnetic and gravity surveys are the most useful methods. Detailed ground geophysical surveys are used to detect smaller-scale faults and shear zones, alteration zones and minerals associated with gold, to guide drilling. In general, for shear and fault-zone (Au-quartz veins) deposits, aeromagnetic data can provide valuable mapping information by delineating lithologies, regional faults and shear zones. At deposit scale, magnetic lows can delineate areas of magnetite destruction associated with carbonate alteration (Shuaibu, 2024). EM methods have also been used to map faults, veins, contacts and alterations.

A variety of geophysical techniques are applicable to gold exploration. Specific methods will depend on lithological, mineralogical and alteration characteristics of each deposit type (Ford et al., 2006). The physical properties of gold (Au), such as its density of 19300kg/m^3 and electrical conductivity of 5×10^7S/m, distinguish it as one of the most anomalous elements (Salmirinne and Turunen., 2007). In spite of this, it is almost impossible to get direct geophysical response from gold, because of its low grade in deposits (Doyle., 1990). Nevertheless, geological structures such as faults and shear zones, lithologic units, alteration zones and minerals (e.g. pyrite), that are associated with gold, can often be mapped by geophysical methods (Paterson and Hallof., 1991). IP methods and gamma ray spectrometry may have local applications to map massive quartz veins (resistivity highs) and associated alteration (potassium highs). For epithermal styles of mineralization, several geophysical techniques can delineate favorable structures and alterations. These include regional gravity lows over thick volcanic sequences and local gravity highs

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Cite The Article: Adejuwon, B. B. Okiyi, I. M. and Shuaibu A.M (2025). Application of Geophysical Techniques for Gold Exploration in Northcentral Nigeria. *Geological Behaviour 9(1): 01-10.*

associated with felsic intrusions, magnetic lows associated with alteration, regional potassium highs associated with felsic volcanism and local potassium highs with corresponding low Th/K associated with potassic alteration (Ford et al., 2006). Some past studies have been able to elucidate the applicability of diverse geophysical methods in delineating mineralization. The study used geophysics (VLF, Magnetics, IP and SP) as a basis for making interpretation about the local geology and the nature of mineralization in the Levijarvi-Loukinen gold occurrence of Northern Finland (Holma and Keinänen., 2007). A reaches used high-quality airborne geophysical data to direct exploration from regional to prospect scale and select promising areas for detailed investigations in Finland (Airo., 2007). He characterized geophysical provinces and their boundaries, based on magnetic and electromagnetic (AEM) signatures, via estimation of electrically conductive units and separation of magnetite-bearing units from relatively sulphide-rich graphite-bearing conductors, using AEM data. The general distribution of radioelements within different lithologies was inferred from airborne radiometric (AR) data. (Salmirinne and Turunen., 2007). Used apparent resistivity, chargeability, and gamma radiation to show that depending on the contrast of physical properties of gold mineralized and unaltered country rocks, ground geophysical methods can in many cases be used to locate and study gold mineralization indirectly. They concluded that magnetic, electric or electromagnetic methods are an obvious choice in exploring for gold if sulphides are included. IP detect disseminated sulphides and SP is used to map and classify conductive sulphide and graphite occurrences. IP surveys have commonly been applied in gold exploration to locate sulphides in situations where sulphide concentration is low or moderate. Time-domain measurements with a dipole-dipole array are commonly used, because this array is very sensitive to horizontal changes, and the effects of small local sources are larger than with other configurations (Salmirinne and Turunen., 2007). Since gold mineralization is commonly associated with potassic alterations, radiometric methods prove to be useful (Dickson, 1997; Ford et al., 2007; Airo, 2007 ; 2015 Salmirinne and Turunen., 2007).

Exploration geophysics was instrumental to the discovery of several mineral deposits with gold inclusive in the past centuries but in Nigeria, most gold exploration in the 19th century have been mainly petrological, geochemical, with few drilling practices. In Nigeria, the application of geophysics in mineral exploration has been on the increase. Recent works by (Adejuwon et al., 2018; Labbo et al.,2013). Have demonstrated the efficacy of application of geophysical methods in mineral exploration but specifically for gold exploration, it has been very few, compared to the global trend. (Nigerian Geological Survey Agency in 2011 to;2012).Has successfully used Ground VLF-EM, airborne radiometric, aeromagnetic, ground gravity and geochemical data to delineate primary gold deposits in Ifewara area of Southwestern Nigeria. used Electrical resistivity technique (VES) to study alluvial gold deposits in Minna, Northcentral Nigeria, but suggested that other geophysical techniques be used as a comparative technique(Bello .,2012). His study revealed that there are injections (haloes) of deposits, distributed over the site.

1.1 Location and Physiography

The study area is situated between Longitudes 6° 10' 45"E to 6° 15' 30"E and Latitudes 10° 33' 00" to 10° 36' 45"N, within the Northcentral part of Nigeria (Figure 1). The actual study area with an approximation of 53.4km^2 is located about 4km northeast of Randeggi community and 30km southwest of Birnin Gwari (Figure 1). It is accessible through both tarred and untarred secondary roads especially Kakangi-Randeggi road and other footpaths. The terrain is mainly undulating with gentle hills separated by lowlands with flat soil cover. Elevation varies from 350m to 480m above mean sea level and it rises gently from Southeast to Northwest. The drainage pattern in the area is dendritic and seasonal rivers and rivulets (mostly flowing Southwesterly) run down the hills to the lowland.

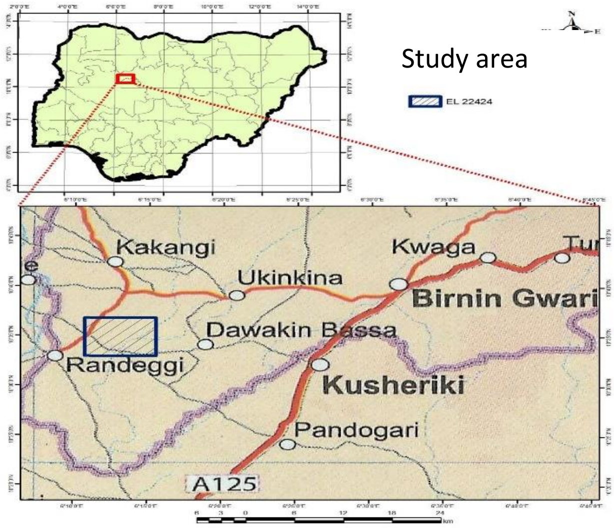


Figure 1: Location Map of area of interest within Kaduna state

The vegetation is Guinea Savanna with transitional Sudan Savannah elements in place and the climate of the area captures wet and dry seasons(NASA.,2019). The wet season is oppressive and overcast, with the dry season being partly cloudy. The hotness is all year round with temperature varying between 57°F - 97°F and rarely below 52°F or above 103°F. The hot season lasts between February to April with an average temperature above 94°F, with the hottest season occurring in March. The rainy periods of the year occur between March to November and the most rain falls in August, with an average total accumulation of 11 inches. The rainless period of the year occurs between November to March, with the least rainfall in December (NASA, 2019).

2. GEOLOGY OF THE AREA

The Regional geological map of 1:250,000 Sheet 31 (Kusheriki), is made up of silicified and sheared rocks, banded migmatites of variable hosts (M), Zungeru Granulites Member (ma), Kubo Quartzite Member (q) and fine to medium grained biotite and biotite muscovite granites. This area of interest falls mainly within the Migmatite (M), Kubo Quartzite Member (q) and Fine to medium grained biotite and biotite muscovite granite (OGm). The Kubo Quartzite Member (q) consists of Quartzite with sillimanite (Figure 2).

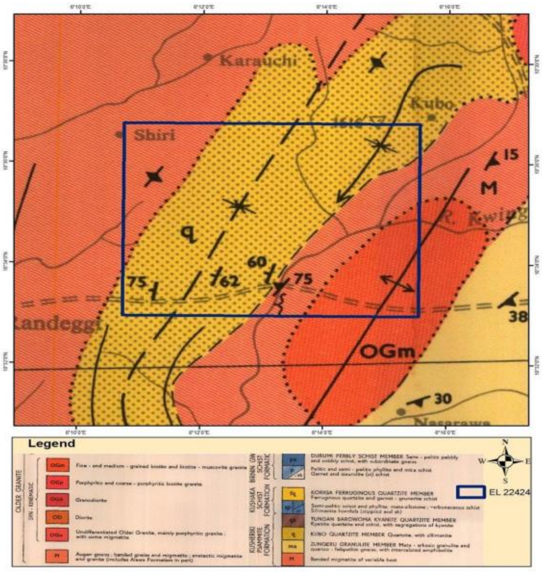
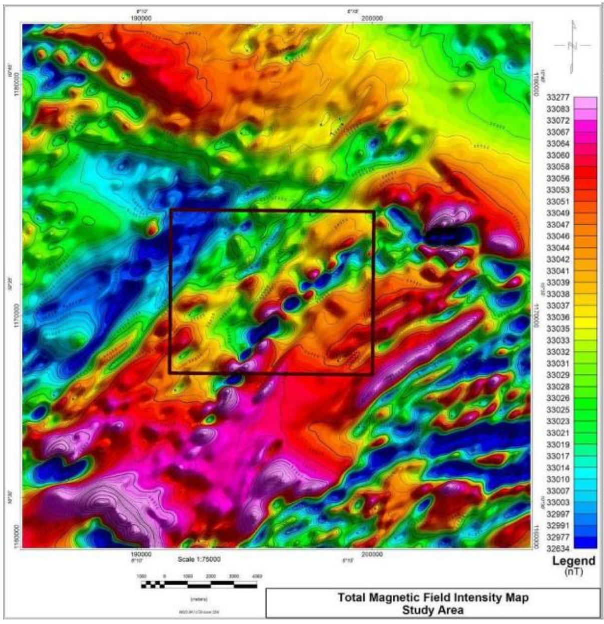


Figure 2: Geological Map Showing Sheet 121 (Kusheriki Area)

3. METHODOLOGY

3.1 Airborne Geophysical Data Acquisition

A high resolution airborne magnetic (Figure 3) and radiometric data of parts of 1:100,000 Sheet 121 (Kusheriki) was used for Reconnaissance Survey (Figures 4, 5 and 6) with other data set such as SRTM data, ternary images, satellite images and regional geological map of the study area. The survey parameters of the aeromagnetic data are: Flight line spacing (500m), Tie line spacing (2km), Terrain clearance (80m), Flight direction is NW-SE while the Tie line direction NE-SW.



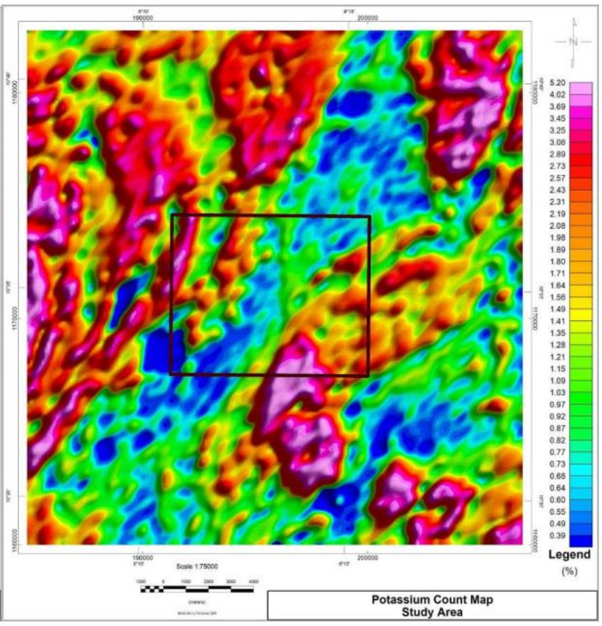
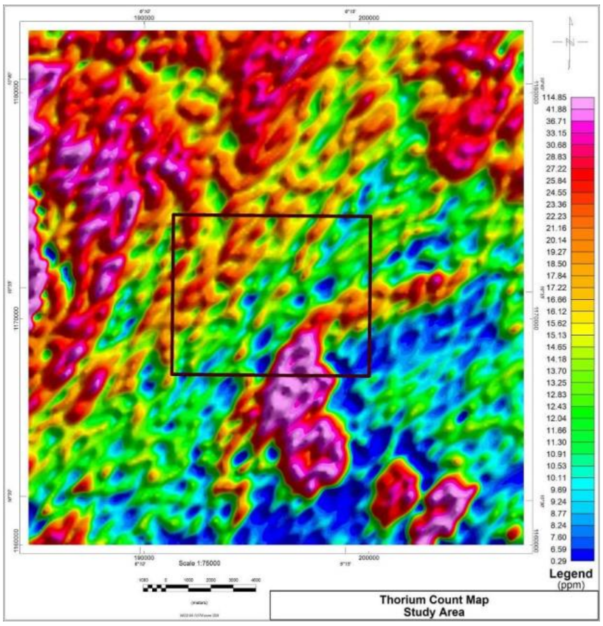


Figure 3: Airborne Total Magnetic Field Intensity and **Map Figure 4:** Airborne Potassium Count Map



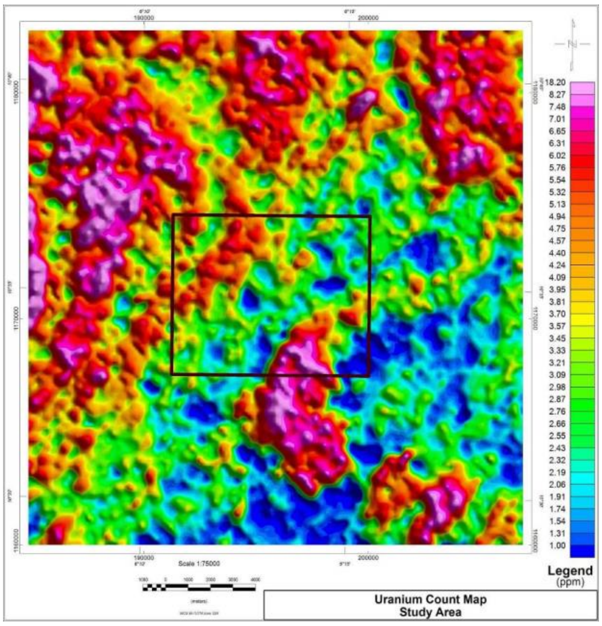


Figure 5: Airborne Thorium Count Map and **Figure 6:** Airborne Uranium Count Map

3.1.1. Processing and Analysis of Airborne Geophysical Data

The acquired airborne geophysical data of parts of sheet 121 (Kusheriki) were processed and interpreted for likely structural and lithological signatures indicative of mineralization (Figures 3 to 12) while the Elevation map (Figures 13) helps in determining topographically induced anomaly from the real one. In order to delineate lateral boundaries due to the main sources of magnetic responses, edge enhancement techniques based on magnetic signal derivatives (vertical gradients), horizontal gradients and analytical signal were used (Figures 7 to 10).

The computed regional anomaly (Figure 16) was subtracted from the total magnetic field intensity (Figure 15) to obtain the field due to local geological events i.e. residual magnetic map (Figure 17). The computed residual field components of the magnetic data were calculated along profiles and were plotted against station locations for profile analysis. These plots of residual fields were stacked to allow qualitative interpretation (Figure 18). Several derivatives of the residual total magnetic field provide value-added products that may contribute to the geological interpretation of magnetic data such as analytical signal, horizontal gradient etc. Since analytic signal (Figure 19) is useful in locating the edges of magnetic source bodies, particularly where remanence and/or low magnetic latitude complicates interpretation. Horizontal gradient (Figure 20) aids in observing the near-surface magnetic anomaly and likely vein structures in the study area. The horizontal gradient method is considered as the simplest approach to estimate the contact locations (e.g. faults) and in contrast, the method is the least susceptible to noise in the data, because it only requires the two first-order horizontal derivatives of the magnetic field (Philip 1998 and Aboud et al 2005).

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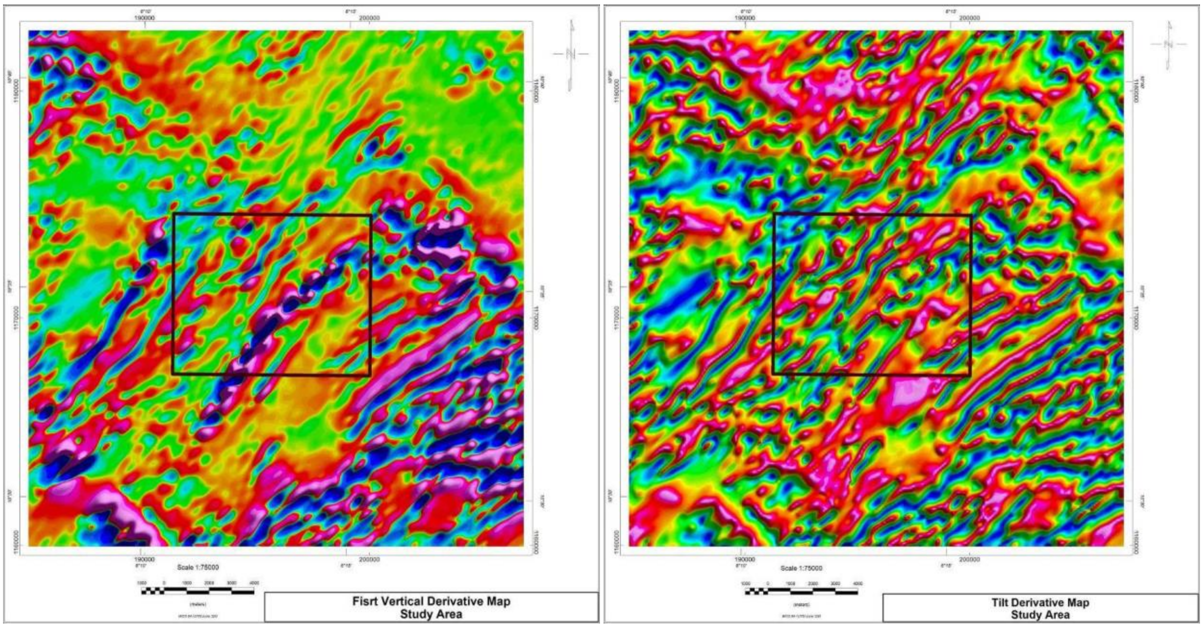

Figure 7: First Vertical Derivative Map and **Figure 8:** Tilt Derivative Map

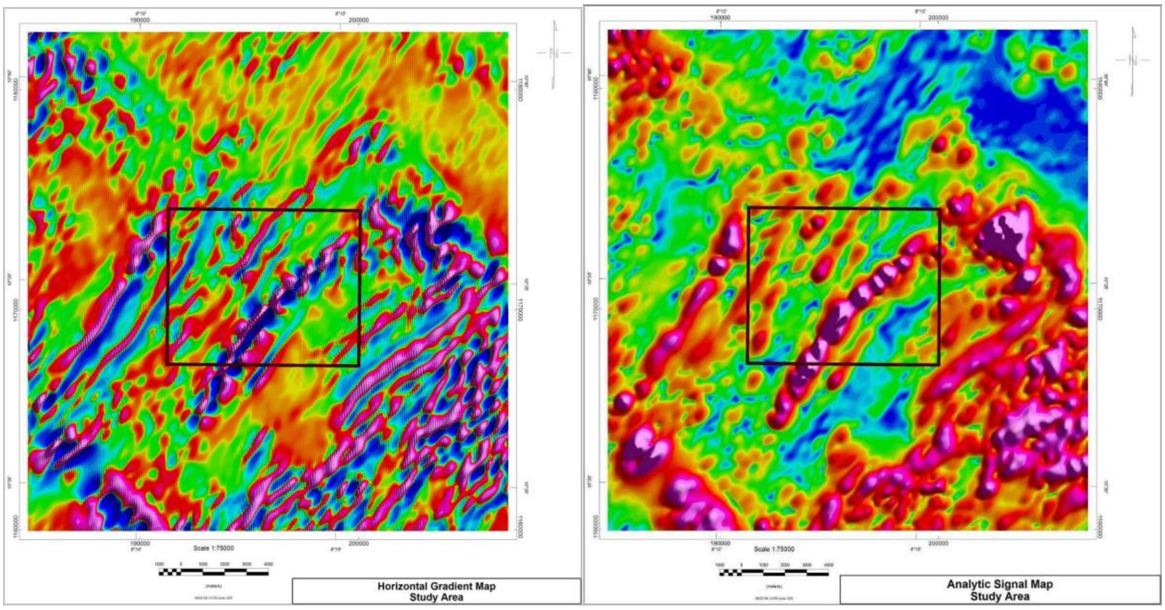

Figure 9: Horizontal Gradient Map and **Figure10:** AnalyticSig

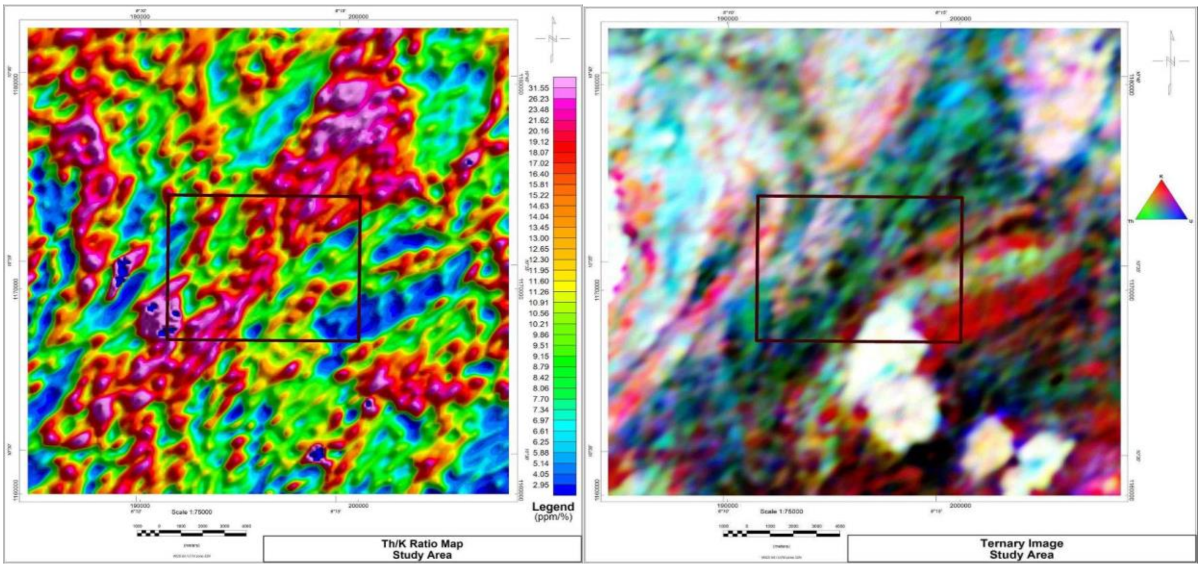

Figure 11: Thorium/Potassium Ratio Map and **Figure 12:** Ternary image

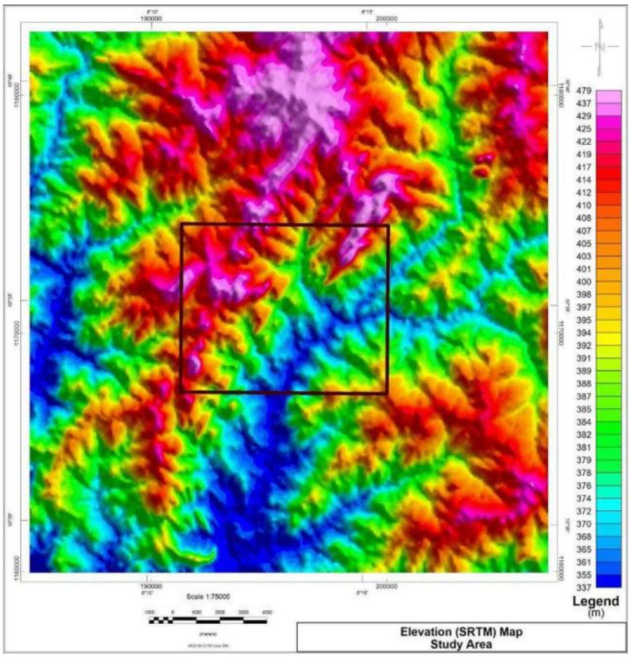

Figure 13: Elevation (SRTM) Map

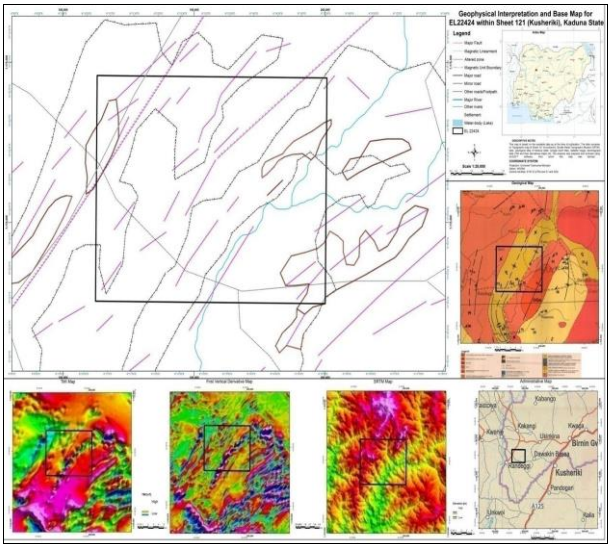

Figure 14: Interpreted map from the airborne data around the study area

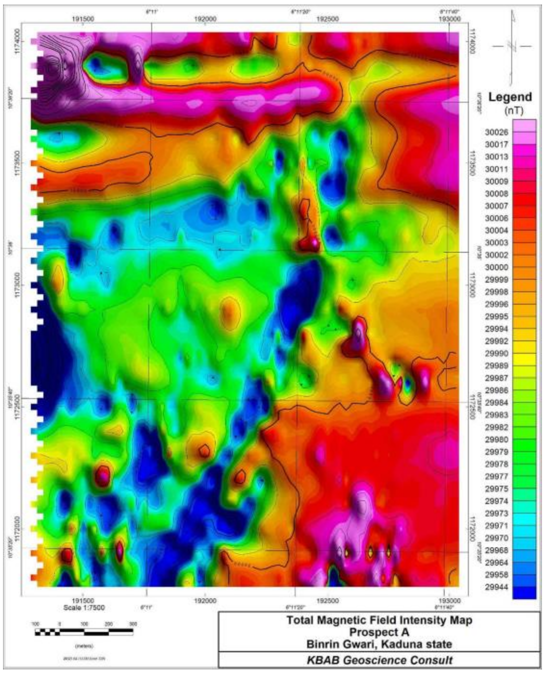

Figure 15: Total Magnetic Field Intensity -map

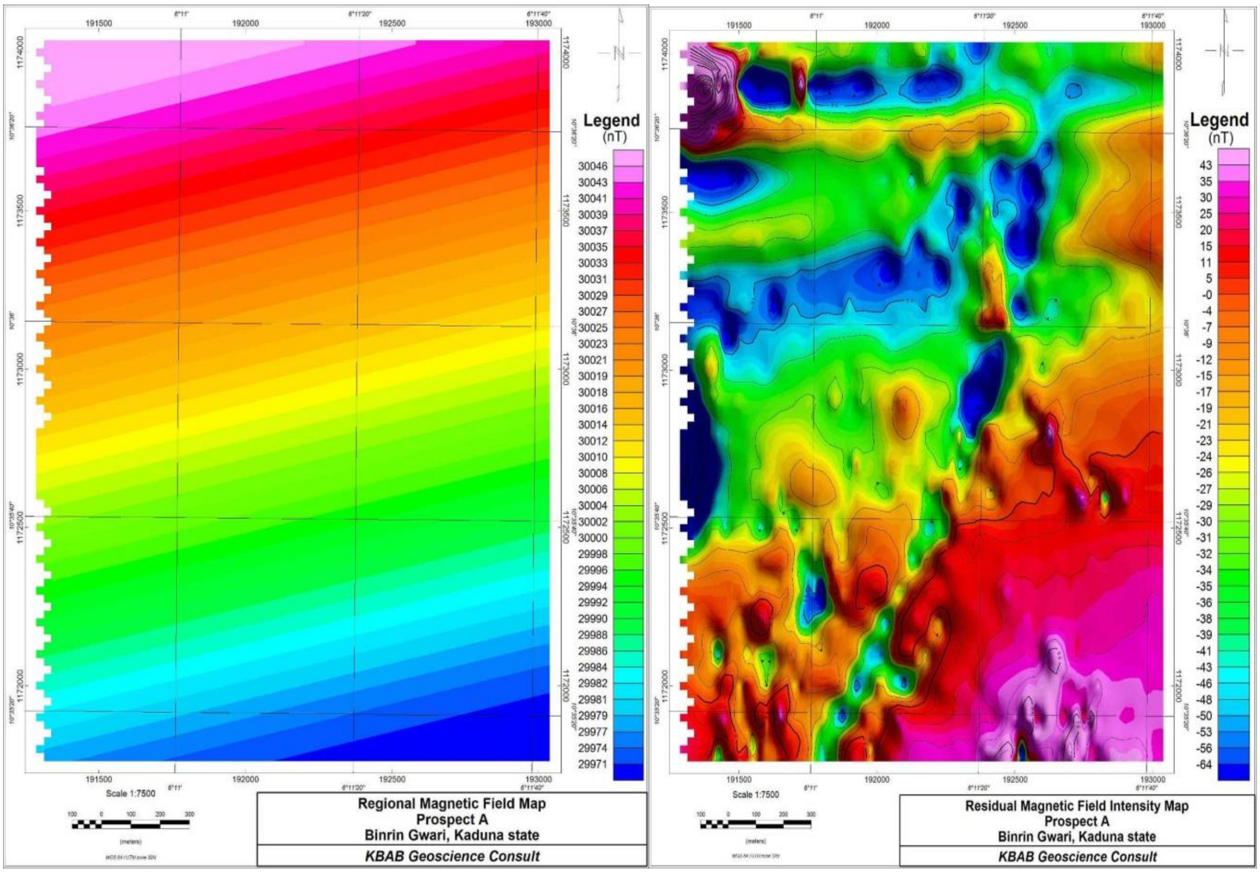

Figure 16: Regional Magnetic Field Intensity and **Figure 17:** Residual Magnetic Intensity

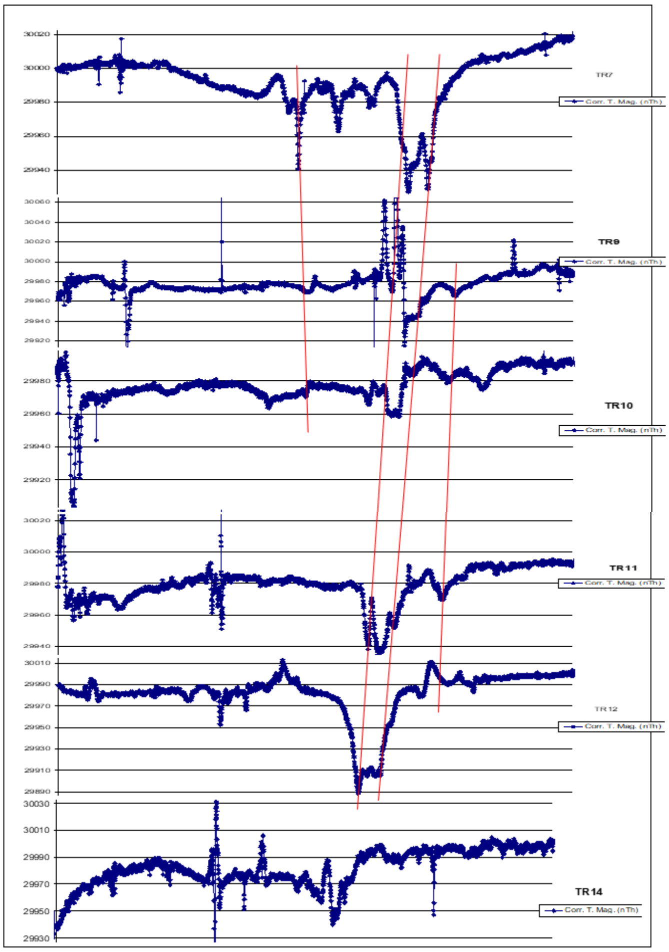

Figure 18: Stacked magnetic profile plot

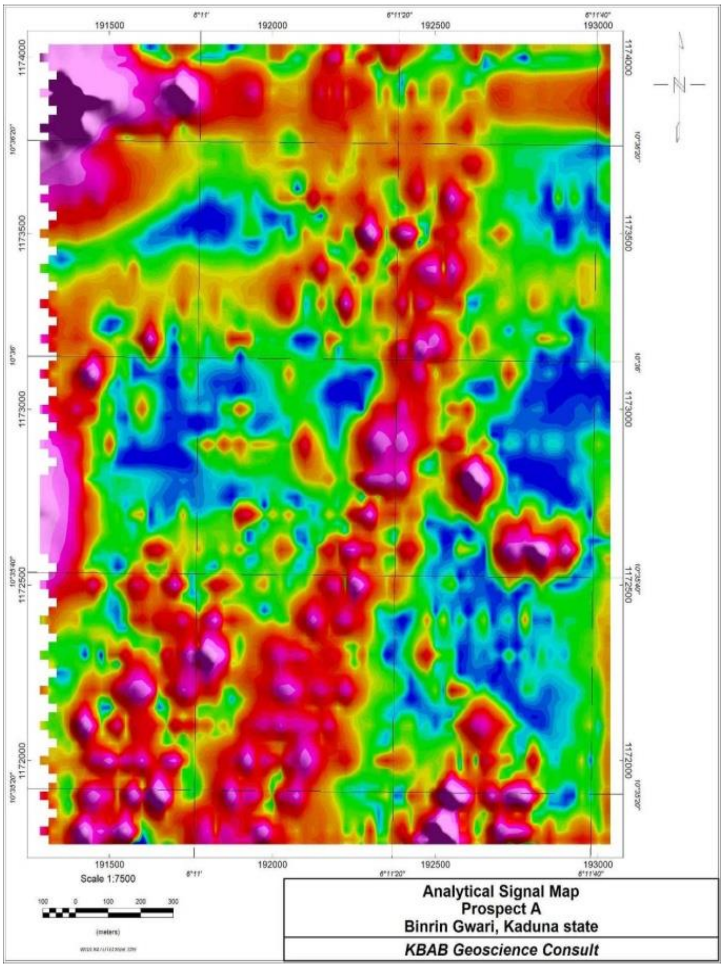

Figure 19: Analytical Signal grid of the TMI

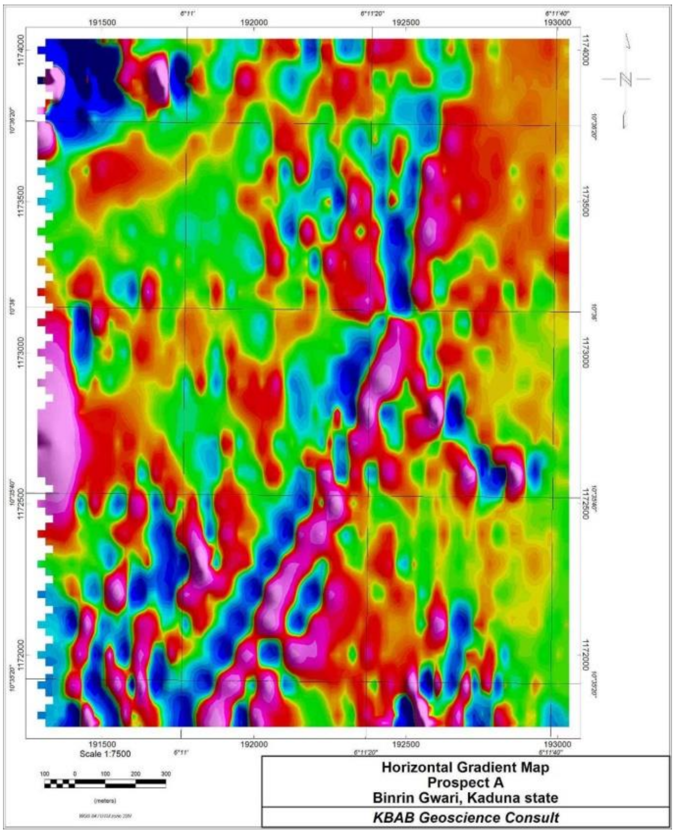

Figure 20: Horizontal Gradient grid of the TMI

3.2 Instrumentation and Ground Field Data Acquisition

One major areas of interests (Block A) delineated from the interpreted map (Figure 14) was explored using ground geophysical methods. Twenty three (23) 1.6km long profiles were covered in Block A with GSM-19 v7.0 Overhauser instrument (Plate 1 and 2) manufactured by GEM SYSTEMS, Canada. It is a total field magnetometer with inbuilt GPS, representing a unique blend of physics, data quality, operational efficiency, system design and options that clearly differentiate it from other quantum magnetometers. Base station method for correction of diurnal variations (plate 1 and 2) was used while the area selected for base station was magnetically quiet, i.e. free from moving automobiles and not close or on top of any major outcrop.

Based on the result from the magnetics survey result, anomalous areas delineated were further explored using Induced polarization and resistivity imaging. Seven (7) lines of about 1300m each were covered with the GDD IP system. GDD IP system manufactured by Instrumentation GDD Inc. Canada is a time-domain induced polarization system. It consists of GDD 5000W-2400V-10A IP Transmitter (model TxII) unit (plate 3), Model GRx8-32 IP Receiver unit (plate 3), two electrodes (transmitter Tx1 and Tx2) and nine porous pots (plate 4) as receivers and connecting cables (plate 4). The dipole-dipole array was used for this survey (Figure 21-24).

3.2.1 Processing and Analysis of Ground Field Data

The IP extension in the Oasis Montaj software was used for the 2D-inversion of the resistivity and IP data from the GDD IP system. The observed apparent resistivity and IP data is presented as pseudo-section and 2-D inverted resistivity-IP mode (Figures 21 to 24) to show a qualitative idea of resistivity and chargeability distribution within the subsurface.

4. RESULTS AND DISCUSSION

4.1 Interpretation and Discussion of Results from Airborne Data

Qualitative interpretation of airborne data shows some prominent linear and broad magnetic anomalies with high and low gradients and closures with varying amplitudes. The Total Magnetic Field Intensity (TMI) map (Figure 3) of the area exhibits zonation and alteration. This is an indication of hydrothermal alteration which is usually associated with mineralization. The area has undergone tectonic activity which resulted in fracturing, faulting and shearing. The major lineaments trend in the NE-SW direction.

Plate 1: Magnetic Data acquisition (Rover**)** and **Plate 2:** Magnetic Data acquisition (Base)

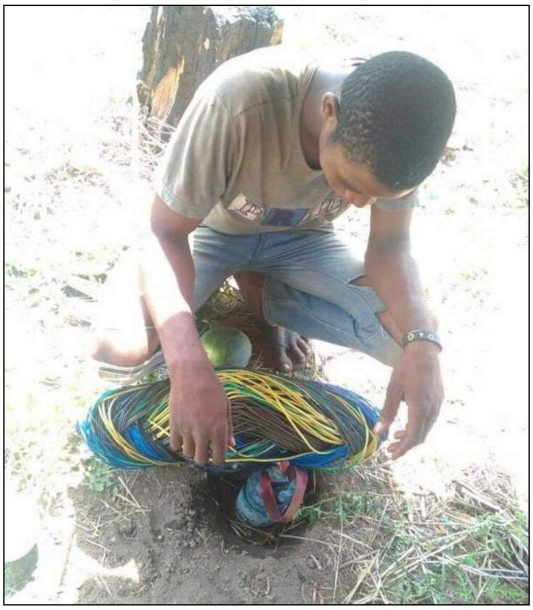

Plate 3: Data Acquisition with GDD IP System and **Plate 4:** Porous pot and connecting cables

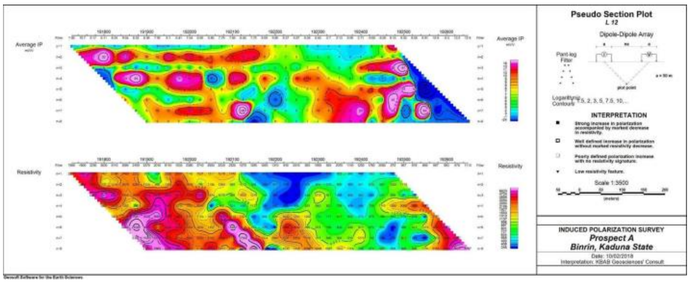

Figure 21: IP and resistivity pseudo Section for Block A Traverse 12

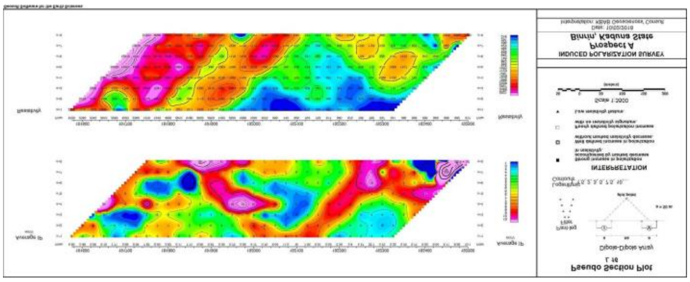

Figure 22: IP and resistivity pseudo Section for Block A Traverse 16

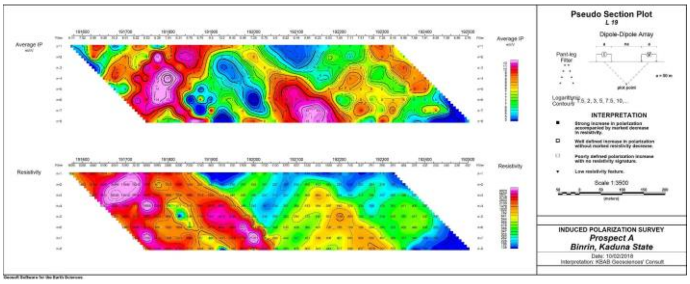

Figure 23: IP and resistivity pseudo Section for Block A Traverse 19

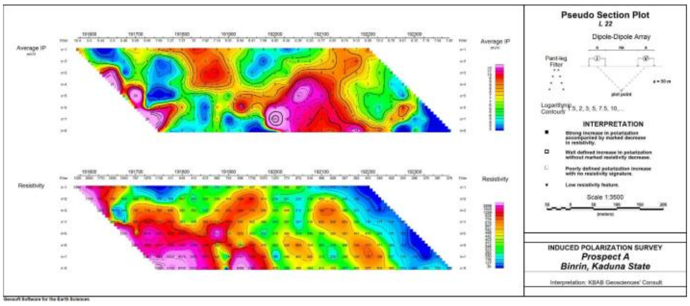

Figure 24: IP and resistivity pseudo Section for Block A Traverse 22

Most of these structures are not too deep-seated since they are mappable on the First Vertical Derivative of the Total Magnetic Field Intensity (TMI) which emphasized near surface structures (Figure 3). Regional and localized aeromagnetic anomalies with associated lineaments are targets for mineralization (Figure 14). The contacts between different geologic units; magnetic units; the intersections between linear features; sheared and fractured zones are potential traps for minerals and therefore give a significant exploration vector. Also, alteration zones which are marked by low Th/K ratio and corresponding high K are delineated (Figures 11 and 4).

The aeromagnetic anomalies show minima and maxima amplitudes (Figures 15 and 17). Generally, the signature showed positive magnetic amplitude (maxima) of about 100nT above the background while the negative amplitude (minima) of about -120nT. This is quite appreciable for reasonable magnetic anomaly and it suggests that the magnetic susceptibility of the study area is quite contrasting, hence amenable to magnetic method of exploration. High amplitude anomalies from the residual magnetic field intensity map of the area (Figure 17) generally show some N-S and NW-SE trends, which is in conformity with some of the structural trends in the area as identified from the aeromagnetic interpretation. Low amplitude anomalies have noticeable NE-SW and E-W trends. The prominent low amplitude anomaly cross-cuts almost the central part of the area and this is diagnostic of quartz veins when traced to the geologic map (Figure 2). These are most likely going to host massive or disseminated sulphide and accessory minerals in association with gold(Doyle.,1990),.

4.2 Interpretation of the Ground Field Data

A major magnetic anomaly occurs around 450m to 1300m from the western base-line and it traverses from profile 23 to 1 (South to North). The signature showed positive magnetic amplitude (maxima) of about 90nT above the background while the negative amplitude (minima) is about -120nT. This shape of magnetic signature obtained in the ground magnetic survey generally suggests a step or an edge structure at certain depth such as a dyke. Its orientation of NE-SW (Figures 15, 17 and 20) and location compares well with orientation of the anomaly from the interpretation of the aeromagnetic data (Figure 14). It intersects with ENE/WSW trending anomaly traversing from profile 10 to 3.

Disseminated Sulphide mineralizations are characterized by higher-than-average chargeability which can be measured with Induced polarization. Primary gold deposit in this part of the northern schist belt is associated with sulphide mineralization, hence high chargeability become a major factor for prospect delineation. Quartz veins are characterized by high resistivity (low conductivity). Also, from field observation within this site and nearby goldfield as well as previous studies by other geoscientists, most primary gold mineralization in the schist belt commonly occurs in quartz veins within several lithologies, therefore geophysical characteristics of the quartz veins becomes another important factor in prospect delineation. Since the expected primary gold deposit in these areas are within quartz veins associated with sulphide mineralization, such zone will be characterized by higher-than-average chargeability and high resistivity (low conductivity).

From the IP and resistivity models (Figures 21 to 24), several bodies with high resistivity and corresponding high chargeabilities, were identified at a relatively shallow depth (less than 70m). Also, some massive chargeable bodies were delineated at depth, traverse 15 and 17 (Figure 24). IP survey revealed that most of the magnetic anomalies investigated are chargeable and that their chargeability increases with depth.

Combining the results of the airborne and ground geophysical methods presented here, a wide range of linear structures likely veins which are believed to host ore mineralization were identified. Mineral prospective priority target map (Figure 25) which encompasses the various structures delineated from airborne and ground magnetic techniques, have been able to relate the occurrence of minerals to structures. This has also corroborated the findings of some works in times past, that of all geophysical methods, magnetic method being the oldest is widely used in locating structures (crevices, fissures, joints, faults) associated with mineral deposits (Sharma, 1987; Ajakaiye and Ananaba, 1987).

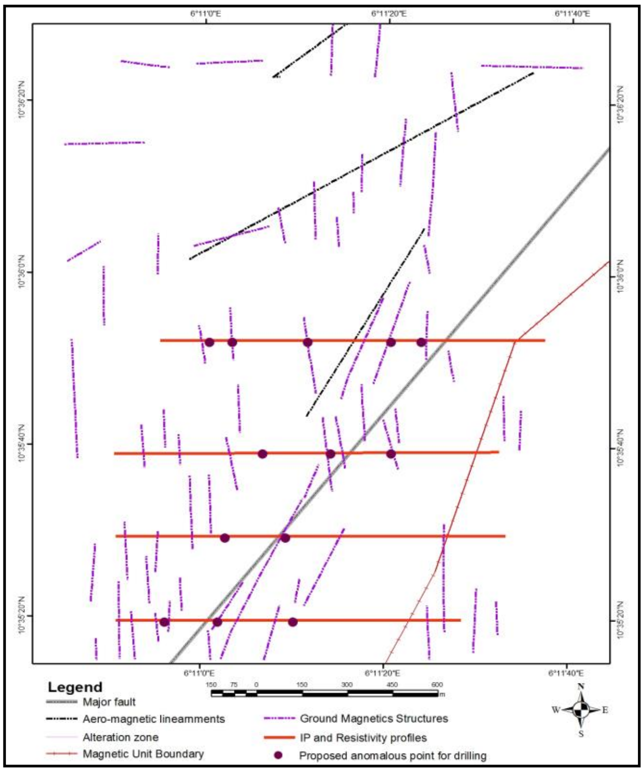

Figure 25: Mineral Prospective Priority Targets Map

The aeromagnetic research conducted in the Birnin Gwari area of Northcentral Nigeria demonstrates the effectiveness of integrating airborne and ground geophysical methods in delineating gold mineralization. Through the interpretation of magnetic and radiometric data, the study successfully identified several anomalous zones characterized by structural and lithological features indicative of mineralization.

The combination of aeromagnetic and radiometric surveys revealed linear and broad anomalies with structural trends primarily oriented N-S, NE-SW, and NW-SE.

These anomalies, associated with hydrothermal alterations and tectonic activities, suggest the presence of quartz veins, faults, and shear zones, which are potential hosts for gold mineralization.

Ground geophysical surveys using magnetic, induced polarization (IP), and resistivity methods validated and enhanced the findings from airborne data.

High-priority targets were identified, marked by high chargeability and resistivity, correlating with quartz veins associated with sulphide mineralization.

The geophysical characterization of identified veins showed lengths ranging from 50m to 600m and widths up to 20m.

These structures were mapped and integrated into mineral prospective maps, providing precise locations for future exploration.

The study confirms that aeromagnetic techniques, complemented by ground geophysics, are highly effective in identifying and mapping structures related to gold mineralization. The high-resolution data and analytical methodologies employed ensured a robust interpretation of subsurface features.

RECOMMENDATIONS

Conduct drilling at the identified priority targets to verify the presence of gold and validate the geophysical findings.

Combine soil and rock sample geochemistry with geophysical data to correlate high gold concentrations with the identified anomalies.

Extend geophysical surveys to adjacent areas with similar geological settings to identify additional potential zones.

Utilize advanced 3D modeling and inversion techniques to refine subsurface interpretations and improve target accuracy.

This research highlights the potential of geophysical methods to enhance gold exploration in under-explored regions, particularly in Nigeria, and sets a benchmark for future studies in similar geological settings.

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Cite The Article: Adejuwon, B. B. Okiyi, I. M. and Shuaibu A.M (2025). Application of Geophysical Techniques for Gold Exploration in Northcentral Nigeria. *Geological Behaviour 9(1): 01-10.*